The realization of L*+H pitch accent in Greek

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We experimentally examined the realization of the L*+H pitch accent in Greek, in several positions and environments. In the literature, L*+H is described as a rise from an L at the consonant onset of the stressed syllable, to an H in the post-stress syllable (Arvaniti et al. 2006, 2000, 1998; Arvaniti & Baltazani 2005). L*+H is described in GRToBI (Arvaniti & Baltazani 2005) as a pre-nuclear accent in statements and polar questions and the nuclear accent in wh-questions and negations. Experiment 1 (production) used 36 statements varying in the number of syllables (0, 1, or 2) between the L*+H accents and replicated the alignment results in the literature for the L and H targets, showing that the inter-accent distance influences this alignment. Experiment 2 (production and perception) compared the pre-nuclear stretch in polar questions and affirmatives. We used 60 sentences to test the hypothesis that these two types of utterance are indistinguishable in the pre-nuclear stretch since both have an L*+H pre-nuclear accent. We found that listeners could not discriminate statements from polar questions until they heard the nuclear part of the utterance. Experiment 3 (production) used 60 wh-questions and negations with 0, 1, or 2 syllables between accents. The results suggest that under pressure the H aligns with the nuclear vowel, but when there is no such pressure it aligns with the first post-nuclear vowel.

1. General Introduction

This paper reports the phonetic realization of the L*+H pitch accent in Greek in a variety of environments. For our analysis we followed the auto-segmental metrical theory and in particular GRToBI, a system based on ToBI and adapted for Greek by Arvaniti & Baltazani (2005). Specifically, the autosegmental theory assumes that intonation contours consist phonologically of specific points realized as tonal targets. There are two types of tonal events, pitch accents and phrasal tones. Pitch accents phonologically associate with stressed syllables and align with them (Arvaniti et al. 1998, 2000). Phrasal tones are divided into phrase accents and boundary tones.

The most frequently occurring pitch accent in Greek is the bitonal accent L*+H, i.e. an accent with a stable low "starred tone" aligned with the onset of the stressed syllable and an High "trailing one" in the post-stressed syllable (Arvaniti 2001; Arvaniti et al. 1998). The realization of the L*+H pitch accent is compressed in tonal crowding contexts, but remains stable once tones are more than two syllables apart (Arvaniti & Ladd 1995; Arvaniti et al. 1998, 2000, 2006a). In the present study, we set out to examine the behavior of L*+H in different types of utterances, namely: statements, polar and wh-questions and negatives, since this pitch accent, according to GRToBI, is found in the pre-nuclear position in all of the above utterance types and moreover, it is the nuclear pitch accent in wh-questions and negatives. Our aim was to determine whether this pitch accent has the same phonetic realization in all the above positions.

In what follows, we present three pilot experiments with L*+H in different positions and environments. For each experiment we recorded three or four native speakers of Greek, different for each experiment (in total 10 speakers). In the first pilot experiment, we used statements with the L*+H pitch accent in the pre-nuclear position. The second one had two parts: a production task where we compared the realization of the pre-nuclear L*+H in polar questions with that in statements and a perception one, where we tested the discriminability

between polar L*+H and statement L*+H. In the third pilot experiment, we examine the L*+H pitch accent as the nuclear accent in wh-questions and negatives.

2. FIRST EXPERIMENT: L*+H IN STATEMENTS

The first pilot production experiment was designed to replicate literature results on the phonetic realization of the L*+H pitch accent in Greek as a pre-nuclear pitch accent in statements. In the literature, the L*+H is described as a rise from an L at the consonant onset of the stressed syllable, to an H in the post-stress syllable (Arvaniti et al. 2006a, 2000, 1998; Arvaniti & Baltazani 2005).

2.1. Aim

The aim of this study was to examine the exact realization of an L*+H pre-nuclear pitch accent in Greek, and also to examine the anchoring of the L and the H target and the factors which affect this realization.

2.2. Method

We recorded four native speakers of Greek, between the ages of 23 and 27 (two males and two females). The phonetic materials were analyzed in Praat (Boesma & Weenink 2009) using the guidelines of GRToBI.

We measured the frequency and alignment of the lowest point at the syllable onset as the L(ow) target of each L*+H pitch accent and the highest point in the post-stress syllable as the H target. We also measured the lowest point after the H(igh) target of the pitch accent. For the alignment, we measured the distance in m/s between the Low and the High targets and the anchoring of the L and the H targets to the segmental material.

2.3. Materials

The 36 statements we used were divided in three groups. In the first group there were two L*+H pre-nuclear pitch accents with two unstressed syllables between them (1). In the literature, two or more unstressed interval syllables represent the canonical conditions of the realization of the pitch accent. The second group contained statements with two L*+H pre-nuclear pitch accents having unstressed interval distance (2). The last one contained two pre-nuclear pitch accents under tonal crowding conditions, that is, with no unstressed syllables between them (3).

(1) /ie'leni mi'la metoma'noli/
“Helen speaks with Manolis.”

(2) /ima'ma ma'loni tope'ði/
“Mother scolds the child.”

(3) /ima'ma 'malose tope'ði/
“Mother scolded the child.”

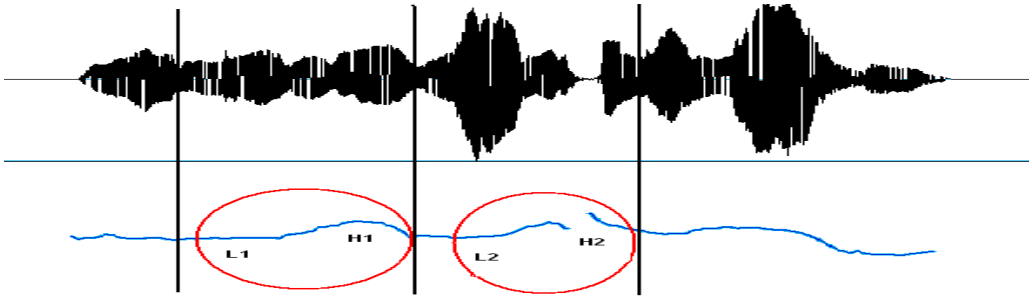
2.4. Results

Under canonical conditions, that is, with two or more unstressed interval syllables between two pitch accents, this pitch accent is realized with the L tone at the onset of the stressed

syllable and the H tone at the consonant or the beginning of the vowel of the following syllables (Arvaniti et al. 1998, 2000).

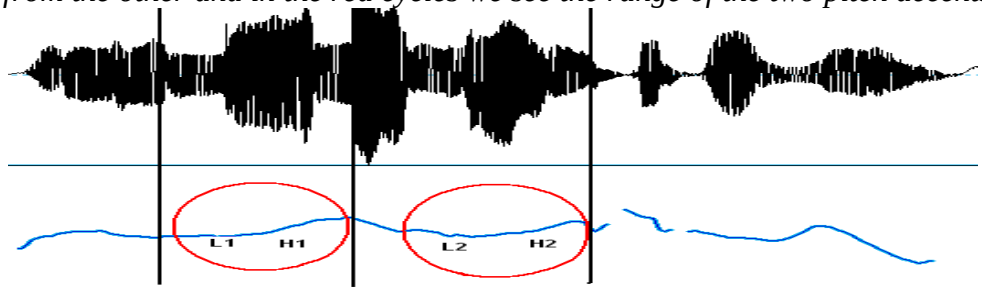
In Figure 1 we can see an example of two unstressed syllables' distance between the two L*+H pitch accents. For both, the L target of the first pitch accent aligns with the consonant of the stressed syllable and the H one with the end of the first post accentual syllable, as is described in the literature (Arvaniti et al. 1998, 2000).

(Figure 1) *Spectrogram and f0 contour of the utterance /ie'leni mi'la metoma'noli/, with two interval syllables between the two pitch accents. Vertical black lines distinct each pre-nuclear pitch accent from the other and in the red cycles we see the range of the two pitch accents*



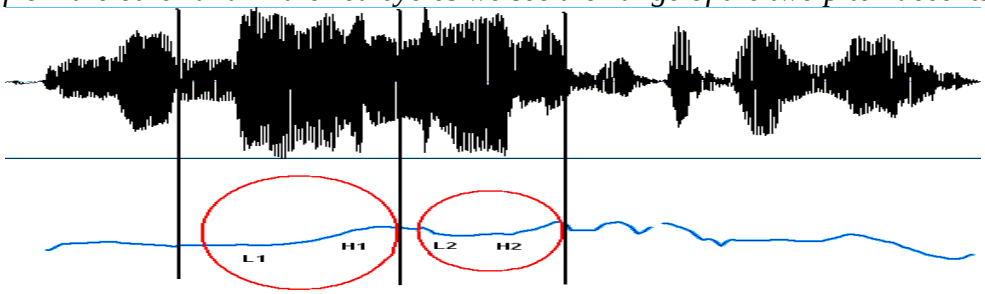
In Figure 2 there is only one unstressed syllable between the pitch accents. As we can see the first pitch accent, due to tonal crowding, is realized earlier. That is, the H target aligns with the consonant of the first post-stressed syllable. Replicating the literature, we found that in a series of two L*+H accents the realization of the first one is affected by the second one under conditions of tonal crowding.

(Figure 2) *Spectrogram and f0 contour of the utterance /ima'ma ma'loni tope'ði/, with one interval syllable between the two pitch accents. Vertical black lines distinct each pre-nuclear pitch accent from the other and in the red cycles we see the range of the two pitch accents*



In Figure 3, we can see the phenomenon of tonal crowding in the most extreme form, since there are no interval syllables between the two pitch accents. We can see the pressure of the first pitch accent to the second one, due to the lack of an unstressed interval syllable. The second pitch accent occurs earlier, compared to what happens in the previous occasions. The H point of the second pitch accent occurs at the end of the stressed syllable. Also, the L target of the second pitch accent is scaled higher, and this is another effect of tonal crowding.

(Figure 3) *Spectrogram and f0 contour of the utterance /ima'ma 'malose tope'ði/, with no interval syllables between the two pitch accents. Vertical black lines distinct each pre-nuclear pitch accent from the other and in the red cycles we see the range of the two pitch accents*



Finally, to sum up, our first experiment replicated the alignment results in the literature for the L and H targets. We found that the inter-accent distance influences this alignment. With two unstressed interval syllables, the L tone appears in its canonical position at the consonant onset of the stressed syllable and the H tone at the post stress vowel. Shorter inter-accent distances compress the alignment of the H target of the first pitch accent and the L target of the second one.

3. SECOND EXPERIMENT: COMPARISON OF L*+H IN STATEMENTS AND POLAR QUESTIONS

The second experiment compares the production and perception of the intonation of polar (yes/no) questions and statements in Modern Greek, in the pre-nuclear pitch accent position (L*+H). Studies of the intonation system of Greek show that the most frequently used pre-nuclear pitch accent is L*+H across all utterance types (Arvaniti et al. 1998; Arvaniti & Baltazani 2005). As Arvaniti et al (2006a) point out, polar questions in Greek, as in some other European languages such as Spanish and Italian, can be string identical to statements. Our study shows that, despite the fact that the two types of sentences differ pragmatically, they present similar contour (rise-fall) at the pre-nuclear pitch accents (L*+H) (see also Arvaniti et al. 2006b). The most characteristic difference that we located in both types of sentences lies in their ends: the statement ends in an Low plateau, while the question shows a characteristic bell-shaped end, something shared by all polar questions in Greek. Furthermore, in the structure of the polar question intonation the interaction between the location of lexical stress and the location of the utterance nucleus play a crucial role in the realization of the tune (for details see Arvaniti et al. 2006b).

3.1. Aim

Our aim has been to see whether there are any differences in the phonetic realization of these rise-fall movements, and if so, whether the differences are perceptually relevant.

3.2. Method (production experiment)

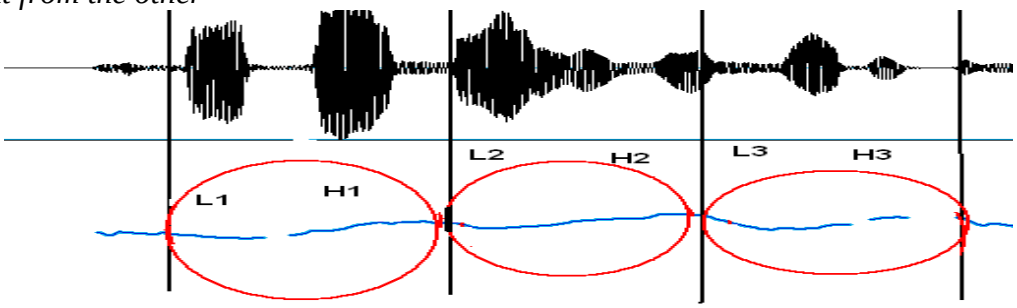
In order to explore the possibility that both types of sentence have the same realization in the pre-nuclear stretch, we designed a pilot production experiment. We built a corpus of twenty sentences (ten polar questions and ten statements), which were string identical. A characteristic example is the sentence “mother only scolds Melina” which in Greek, when it is a statement, is /ima'ma ma'loni timeli'na/, and when it is a polar question, is /ima'ma ma'loni timeli'na/ with the nucleus in both sentences on Melina. The utterances were designed to have three or four pitch accents, two pre-nuclear or three pre-nuclear, followed by one nuclear. Our informants were three female native speakers of Modern Greek in their twenties, who were given explicit instructions about the position where the focus (nuclear word) of each sentence

is. We divided the results of the production experiment in two categories. The first category is when two or three unaccented syllables intercede between two pre-nuclear pitch accents (L*+H), and the second category is when only one unaccented syllable intercedes. We made this distinction in order to see if tonal crowding plays some role in this comparison. The recordings were made and analyzed in Praat (Boesma & Weenink 2009).

In the relevant literature, it is assumed that the type of pre-nuclear pitch accent is the same across polars and statements, and this is L*+H. The phonetic realization of the Greek L*+H has been described as a gradual rise from a Low point (the L tone) to a peak (the H tone) (cf. Arvaniti et al. 1998). However there have also been reports of fine phonetic differences in the realization of L*+H between statements and polar questions (Baltazani 2006b). Therefore, according to our initial hypothesis, which is based in relevant studies for Greek, we do not expect to find any big differences in the part of pre-nuclear accents for both types of sentences.

In this production experiment we took the following measurements. First, scaling of High and Low point of the three pre-nuclear pitch accents was measured in order to detect possible differences between statements and polars. Second, for alignment differences we took two measurements, the point where the Low and the High point of the three pre-nuclear pitch accents align with the segmental material.

(Figure 4) *Here we have three pre-nuclear pitch accents /ima'ma ma'loni mo'no/ in the statement /ima'ma ma'loni mo'no timeli'na/. Vertical black lines distinct each pre-nuclear pitch accent from the other*



3.3. Results (production experiment)

The results of our production experiment show that there is a difference in the realization of the L*+H pitch accent in statements and polar questions. We found differences in scaling of the High point but we also found systematic differences in alignment. More specifically, the results on the alignment showed that on the one hand, there are no consistent differences between polar questions and statements at the Low point. The alignment of Low point is almost identical for both types of sentences at the beginning of the stressed syllable.

However, on the other hand, there are differences in the alignment of the High point between the two types of sentences. The High point aligned on average 25 m/s earlier in statements than in string identical polars at the first unstressed vowel. Our results show that the H is aligned earlier in statements than in polars across stress conditions. In other words, both in normal and in tonal crowding conditions the H is aligned earlier in statements than in polars. It should also be pointed out that the earlier alignment of High point in statements appears across all three pre-nuclear pitch accents.

(Table 1) *The numbers in the table are averages across stress conditions. Firstly we present the distance from the start of the low elbow until the time which aligns the lowest point (L1, L2, L3). After we present the distance from the start of High until the peak of it (H1, H2 ,H3)*

STATEMENTS			**POLARS**		
L1	**L2**	**L3**	**L1**	**L2**	**L3**
3ms	4ms	4ms	4ms	4ms	4ms
H1	**H2**	**H3**	**H1**	**H2**	**H3**
6ms	4ms	8ms	29ms	30ms	31ms

As for the scaling results, we observe that our informants show no difference for the L tones across sentence types, but on the other hand they showed a tendency to realize the High tones higher in polar questions.

(Table 2) *Average scaling results across stress conditions*

L TONES		**H TONES**	
Statement	**Polar**	**Statement**	**Polar**
171.5 Hz	171 Hz	235.5 Hz	260.5 Hz

3.4. Method (perception experiment)

In order to test the hypothesis that pre-nuclear pitch accents are similar in statements and in polar questions we also conducted a perception experiment. Our initial hypothesis was that in utterances with a number of pre-nuclear pitch accents preceding a Late nucleus listeners would have to wait for the nucleus to be uttered before they can determine whether the utterance they are processing is a statement or a question. We used sixty sentences half of which were polar questions and the other half statements. The polar questions were string identical with statements. The material used comes from the sentences uttered in the production experiment. The number of participants was 30 and their ages range from 17 to 35. Each of the 60 sentences was cut into three parts (when there were two pre-nuclear accents) or four (when there were three pre-nuclear accents), and presented to the listeners incrementally. The participants were told that they would hear progressively fragments of a statement or a question and that their task was to decide for each fragment whether it was a statement or a question. The listeners recorded their answer in a printed out questionnaire. In all cases statements and polar questions were presented in random order.

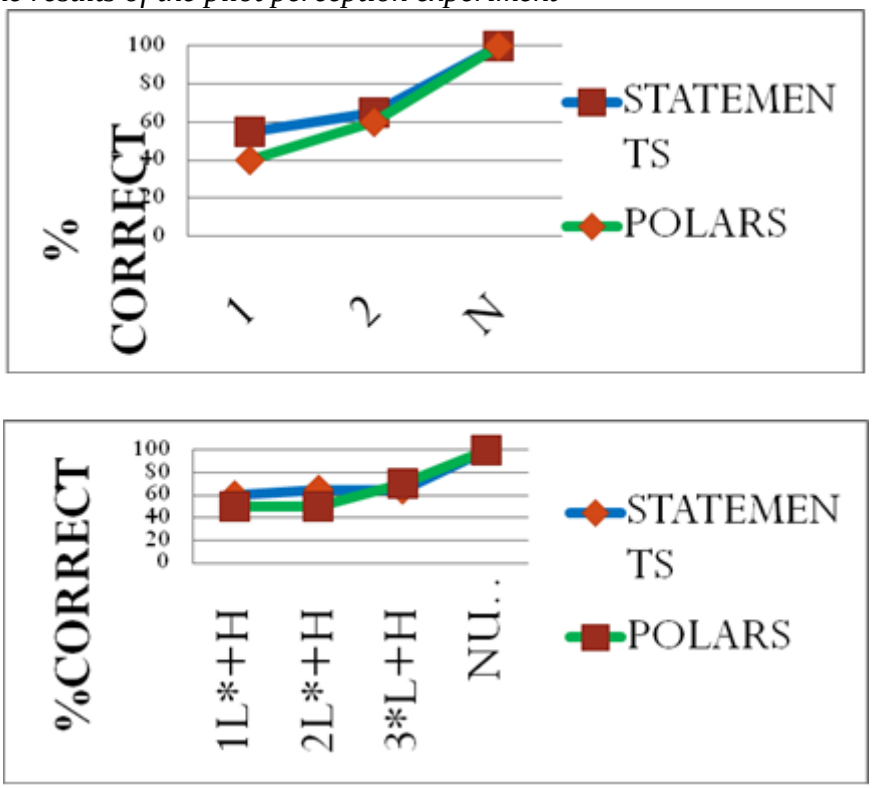
As is known from the literature, each sentence type has an acoustically distinct tonal structure, characterized in Greek by the type and location of tonal prominence (nucleus) and boundary tone (Baltazani 2002; Botinis et al. 2000).

3.5. Results (perception experiment)

The results of this pilot perception experiment show that it is not easy for the listeners to distinguish between the pre-nuclear pitch accents for the statements and for the polar questions (Figure 5). In Figure 5 below, the vertical axis shows percentages of correct

identification of utterance and the horizontal axis shows the points at which the listeners were asked to identify the type of utterance, that is, after they heard the first fragment, the second fragment and the nucleus for the top graph. The bottom graph shows the results for the longer sentences, which contained four fragments. The correct identification rates for the statements are shown in blue, those for polars in green. We see that for the pre-nuclear stretch the listeners' performance was very near the 50% chance level. However, there is a small tendency for easier recognition in statements in both graphs. Furthermore, identification got a little better as listeners heard more of the utterance, especially for the long polar utterances.

(Figure 5) *The results of the pilot perception experiment*



At this point we must say that in the grammar of Greek the nucleus in neutral polar questions is located on the verb. Interrogativity is signaled by means of intonation alone and the verb, as the head of its prosodic phrase, carries the intonational marker (an L* nuclear pitch accent) in polar questions (Baltazani 2006a). Also it is more common in questions for the verb to be located at the beginning of the utterance. Many participants admitted that they did not expect to hear three pre-nuclear pitch accents at the beginning of a polar question. This might have played a role in the problem with correct identification of polar questions in the experiment. For this reason, our next goal is to conduct the same pilot perception experiment using a 'low pass filter' to eliminate the interference of listeners' grammaticality judgments.

Summing up, the results of the production experiment suggest that there are differences in the realization of L*+H between statements and polars. On the other hand, in this perception experiment at least, listeners could not always distinguish between the pre-nuclear pitch accents in statements and those in polar questions. It remains to test this through more perception experiments. If the listeners remain unable to understand the difference between the two types of sentence through more experiments then the different realizations of the L*+H must be merely phonetic 'allotones' of the same tonal category (see also Baltazani 2006a).

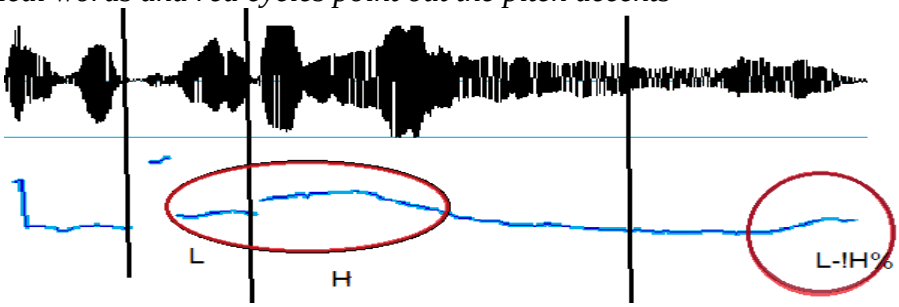
4. THIRD EXPERIMENT: L*+H IN WH-QUESTIONS AND NEGATIONS

The third experiment focused on the realization of L*+H in wh-questions and negations in Greek. We examined the realization of L*+H both in wh-questions and negations in the same experiment because they share the same melody (Baltazani 2002; Arvaniti & Baltazani 2005). According to the literature, wh-questions and negations in Greek consist of a rise-fall contour followed by a Low plateau and a rise in the end of the utterance, that is, an L*+H L-!H% melody. In general, L*+H appears in the utterance initial position and it is the nuclear pitch accent. The nuclear pitch accent – the prominent stressed syllable – aligns with the wh-word in wh-questions and the negative particle [*ðen*] in negations followed by a de-accented low plateau. This low plateau has been attributed to the presence of a Low phrase accent, L-, which spreads from the right edge leftwards over the de-accented material. It is claimed (Grice et al. 2000) that the phrase accent seeks to associate with metrically prominent syllables rather than being manifested phonetically at the edge of the phrase. Our hypothesis is that various factors can affect the scaling and the alignment of the intonational targets such as tonal crowding, the length of the utterance, the introduction of information in the phrase, the number of the syllables of the wh-word or the negative particle and the length of the word following the particles.

(4) and (5) below and Figures 6 and 7 show a wh-question and a negation respectively with the location of the L and the H tones of the L*+H pitch accent marked on them.

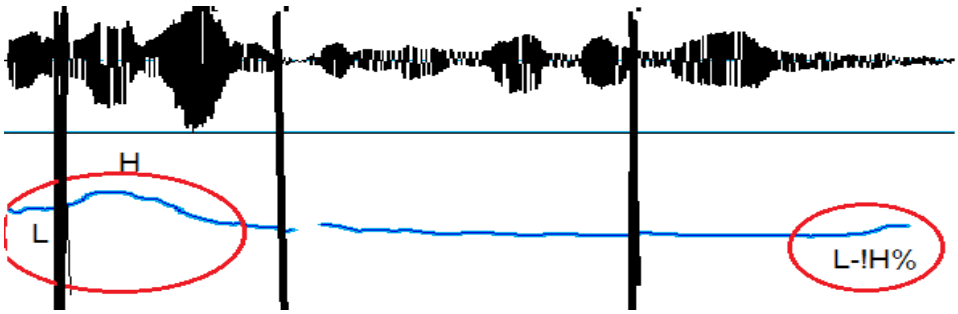
(4) /apo'pu peri'menume 'minima/
“Where are we waiting a message from?’’

(Figure 6) Spectrogram and F0 contour of the wh-question /apo'pu peri'menume 'minima/ “Where are we waiting a message from?” Vertical black lines show a clear difference between lexical words and red cycles point out the pitch accents



(5) /'ðe ma'loni ti'lina oma'nolis/
“Manolis doesn’t tell Lina off”

(Figure 7) *Spectrogram and F0 contour of the negation /'ðe ma'loni ti 'lina oma'nolis/ “Manolis doesn’t tell Lina off”. Vertical black lines show a clear difference between lexical words and red cycles point out the pitch accents*



In the general case for these types of sentences, there are no pre-nuclear accents since the nuclei, the wh-word and the negative particle, are in the utterance initial position. Also, as we have already mentioned, there is general agreement in the literature that there are also no post-nuclear pitch accents (Arvaniti & Baltazani 2005; Grice et al. 2000).

4.1. Aim

The aim of the study was to examine the effect of post-nuclear lexical stresses on the realization of the L*+H nuclear pitch accent.

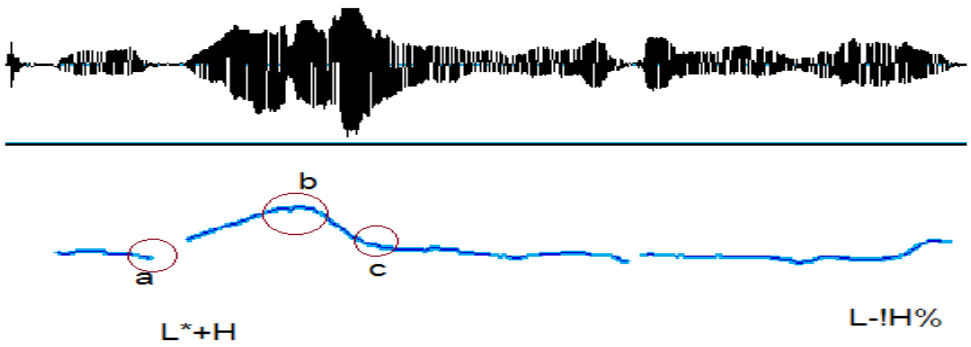
4.2. Method

Our study was based on the acoustic analysis of speech materials by three female native speakers of Greek. They were all 25. The materials consist of 10 wh-questions and 10 negations. The sentences were read from cards. In the data sets, the following parameters varied in a controlled manner: there were zero (9 sentences), one (12 sentences) or two (9 sentences) unstressed syllables in between the stressed syllable of the wh-word or the negation particle and the first post nuclear lexically stressed syllable (henceforth INTERSTRESS INTERVAL) .

Our analysis was based on the scaling and the alignment of the following points (using Praat, Boesma & Weenink 2009):

a) Initial Low, defined as the f0 level (in Hz) at the onset of the nuclear vowel, i.e. the stressed vowel of the wh-word or the negative particle marked ‘a’.
b) The scaling of the first peak, defined as the highest f0 point (in Hz) in the vicinity of the wh-word’s or negative particle’s stressed syllable marked ‘b’.
c) The scaling of the onset of the low plateau (first elbow), defined as the point that showed a clear change in slope between the fall after the nuclear peak and the low plateau marked ‘c’.
d) The distance (in ms) between the onset of the nuclear vowel and the peak.
e) The duration of the first lexically stressed post-nuclear vowel.
f) The distance (in ms) between the H peak and the onset of the first lexically stressed post-nuclear vowel.
g) The distance (in ms) between the onsets of the first lexically stressed post-nuclear vowel and the onset of the low plateau.

(Figure 8) *Spectrogram and F0 contour of the wh-question /me 'ti are'oni i'lina to 'miɣma/ “What is Lina diluting the blend with?”. Red cycles indicate the measured points of the contours*



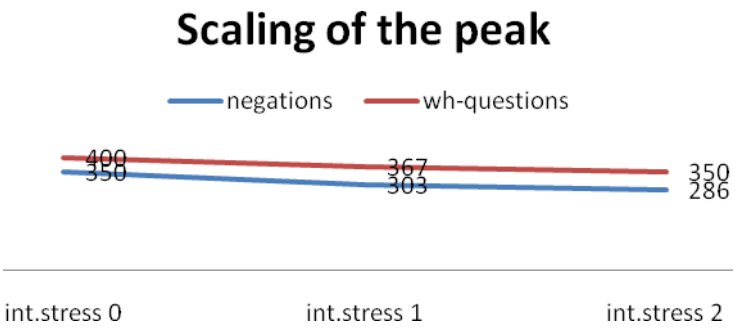
4.3. Results

4.3.1. Scaling

The scaling results show that the position of the first post-nuclear lexical stress affects the realization of the H tone in wh-questions and negations, which is higher when the following stress is closer.

Figure 9 shows the effect of the proximity of the stress following the nucleus. When there is no interstress interval the peak is scaled higher for both wh-questions and negations than the other two conditions in which there are one or two interval unstressed syllables.

(Figure 9) *Scaling of the peak (in Hz)*

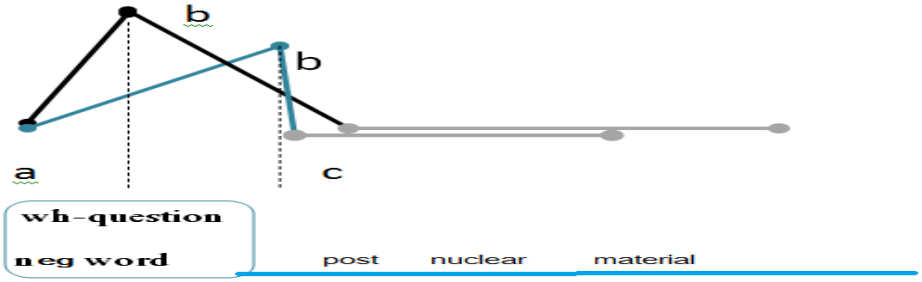


4.3.2. Alignment

Systematic differences were found in the alignment of the H tone. We expected the peak to align with the first post-nuclear vowel following the wh-word. The peak shows late alignment in many cases, as has been reported (Arvaniti et al. 1998), but also early alignment; but our results suggest moreover that its exact position can be influenced by the interstress interval and also, in some cases, by the boundary tone.

Figure 10 shows the two different alignments for the peak of wh-questions and negations. Table 3 shows that across sentence type, there were 20 instances of alignment within the stressed syllable of the wh-word or the negative particle (early alignment) and 40 instances of alignment after the stressed syllable of the wh-word or the negative particle (late alignment). The overwhelming majority of early alignment (18/20) occurred when the interstress interval was 0 or 1 syllables, that is, in cases of tonal crowding. On the other hand, late alignment was almost equally distributed in tonal crowding and non-tonal crowding conditions. Finally, across sentence type, late alignment was observed 2/3 of the times, for 40 out of the 60 experimental utterances. In the canonical stress interval condition, late alignment constituted the overwhelming majority (16/18 cases); more interestingly, as it turned out, in the tonal crowding condition, where we were expecting to find mostly early alignment, we found slightly more late than early alignment cases—18 early and 24 late alignment cases across negations and wh-questions. This unexpected result suggests than other factors might influence the peak alignment. We will return to this point later.

(Figure 10) *Alignment (in ms) of peak H*

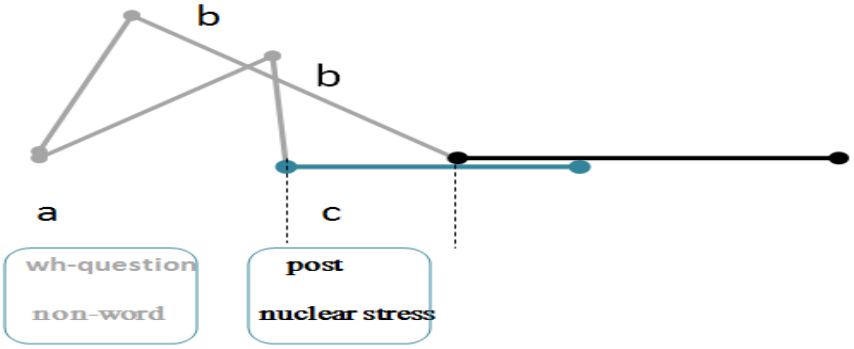


(Table 3) *Number of sentences in the alignment of the peak in each condition*

	Negative		Wh-questions		Total
Interstress interval	0, 1 syll	2 syll	0, 1 syll	2 syll	
Within stressed syll	8	1	10	1	20
After stressed syll	13	8	11	8	40

Figure 11 shows the alignment of the low plateau when there are unstressed syllables between the nucleus and the stress of the following word. The low plateau starts in or slightly before the stressed syllable when the interstress interval is 2 syllables for 17 out of 34 sentences. In contrast, when the interstress interval is zero or one unaccented syllable (the black line), the low plateau starts after the stressed syllable for 24 out of 26 sentences.

(Figure 11) *The alignment of the low plateau (in ms)*



(Table 4) *Number of sentences in the alignment of the low plateau in each condition*

	Negative		Wh-questions		Total
Interstress interval	0, 1 syll	2 syll	0, 1 syll	2 syll	
In/before stressed syll	7	7	11	9	34
After stressed syll	14	2	10	0	26

Our initial hypothesis for the alignment of the peak of the nuclear pitch accent was partially confirmed. However, the results were more complex than anticipated, as shown in Table 3 above. We saw that the two different patterns of alignment, early versus late, could not be explained as phonetic results of tonal crowding since we found many cases of late alignment even under tonal crowding. An alternative explanation is that we are dealing with two different pitch accents, L*+H (late alignment) and L+H* (early alignment). These results need to be studied further with a more extensive list of data.

5. GENERAL DISCUSSION

This paper has presented an examination of the realization of the L*+H and the factors that affect it.

In the three pilot experiments we conducted, we saw that the phonetic realization of L*+H is influenced by the distance from neighboring pitch accents. When there are two or more syllables between pitch accents, L and H appear in their canonical positions. In contrast, when there are fewer than two unstressed syllables intervening, the scaling and alignment of the H tone are affected.

Furthermore, our results suggest that the L*+H has a different phonetic realization in statements and polar questions. Our production data on the pre-nuclear pitch accents of Greek polar questions and statements have shown scale and alignment differences between them. On the other hand, in the perception experiment, results showed that listeners did not always discriminate between polars and statements during the pre-nuclear pitch stretch.

Finally, as far as wh-questions and negations are concerned, the distance between lexical stresses has been found to be one of the factors affecting the realization of the L*+H. Specifically, in conditions of tonal crowding we found that the nuclear accent peak often aligns earlier and is scaled higher than in canonical conditions. These results however were not consistent, suggesting the interplay of more factors regulating the alignment of this peak, a question that we leave open for further research.

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