Edge-tone effects and prosodic domain effects on final lengthening

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This study reports two experiments that investigate the edge-tones and domain-specific effects on final lengthening. The study shows that in Cypriot Greek the following occur: (a) lengthening applies primarily on the syllable nucleus not the syllable onset, which suggests variety specific effects of lengthening; (b) lengthening depends on the edge-tones, namely, polar questions trigger more lengthening than statements and *wh*-questions; (c) lengthening provides support for at least two distinct prosodic domains over the phonological word, the intonational phrase and the intermediate phrase; greater lengthening associates with the first and shorter lengthening with the latter; (d) finally, syllable duration depends on the syllable distance from the boundary, i.e. lengthening locally applies on penultimates and ultimates whereas antepenultimates are affected the least. Additionally, by pointing to the distinct lengthening effects of edge-tones and domain-boundaries, the aforementioned findings highlight the application of different lengthening devices.

Keywords: Prosodic structure; preboundary lengthening; edge-tone lengthening; Cypriot Greek

1. Introduction

1.1 Prosodic structure and lengthening

Phonological representation has for long preoccupied researchers. Chomsky and Halle (1968) envisaged representation as a string of segments that maps syntactic constituents on to phonetic representation. Yet, syntactic structure does not have a one–one relationship to acoustic representation; speakers break utterances in places that do not always correspond to syntactic constituent boundaries (Price, Ostendorf, Shattuck Hufnagel & Fong 1991; Shattuck-Hufnagel & Turk 1996). Additionally, phonology does not fully represent syntactic structures; for example, there are no distinct acoustic cues that show the depth of constituents' embedding (see also the discussion in Cooper & PacciaCooper 1980, pp. 6–14).

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Within Autosegmental Metrical (AM) Phonology, representation has become elaborate enough to account for the mismatch between phonetic representation and syntactic categories. AM phonology postulates a phonological component, the *prosodic structure,* which comprises of prosodic domains. Syntactic structures map to these prosodic domains (Selkirk 1984, 1995; Nespor & Vogel 2007; Truckenbrodt 2007; Wagner 2010).

There are various accounts of prosodic structure, but most researchers would agree that syllables (*σ*) are structured into prosodic or phonological words (*ω*), phonological or intermediate phrases (*ip*), and intonation phrases (*IP*) (Selkirk 1982, 1984, 1986, 1995; Truckenbrodt 1995; Shattuck-Hufnagel & Turk 1996; Nespor & Vogel 2007; Truckenbrodt 2007). Most importantly, prosodic structure accounts for phenomena that take place at the edges of prosodic domains. Prosodic hierarchy accounts for greater effects of pause duration and initial or final strengthening and lengthening (Fougeron & Keating 1997; Byrd & Saltzman 2003; Bombien 2011) that occur near the boundaries of higher-ordered domains rather than at lower ordered domains (Cooper & Paccia-Cooper 1980; Beckman & Edwards 1990; Wightman, Shattuck-Hufnagel, Ostendorf & Price 1992; Fougeron & Keating 1997; Turk & Shattuck-Hufnagel 2000; Nespor & Vogel 2007; Turk & Shattuck-Hufnagel 2007; Shue et al. 2010).

Greater final lengthening associates with the edges of higher-ordered prosodic domains such as *IP*s, and shorter lengthening associates lower order domains such as *ip*s and *ω*s (Fougeron & Keating 1997; Cho 2005; Cho, McQueen & Cox 2007; Kuzla, Cho & Ernestus 2007; Pan 2007). In an effort to elucidate the precise lengthening patterns that associate with the edges of prosodic domains, Wightman et al. (1992) investigated how speakers employ duration and pauses to signal phrasal boundaries. Based on vowel lengthening in phrase final syllables across different syllable structures, they found evidence for four distinct prosodic categories; nonetheless, they note that *IP*s and *ip*s are not distinguished only by lengthening but by intonation and pauses, among other cues. In a perceptual study, Gussenhoven and Rietveld (1992) suggest that English listeners expect longer syllable duration at higher-ordered prosodic domains. Studies such as these by Wightman et al. (1992) and Gussenhoven and Rietveld (1992) underline the complexity of lengthening patterns that mark the edges of prosodic domains.

In addition, many studies regard the syllable as the domain of lengthening (Turk & Sawusch 1997; Turk & White 1999; Turk & Shattuck-Hufnagel 2007). Wightman et al. (1992) argued that lengthening applies to final rhyme. Berkovits (1993) suggested that both the onset and the nucleus lengthen; yet, the effects are stronger for the nucleus. Thus, for Berkovits (1993) lengthening effects are a matter of degree. In their study of accentual lengthening, namely the lengthening that associates with pitch accents and marks post-lexical prominence, Turk and Sawusch (1997) proposed that its domain is larger than the vowel, the syllable nucleus, on the grounds that both consonants and vowels are lengthened under accent. They also found greater degrees of lengthening for consonants associated with the syllable onset than with the syllable coda, suggesting that lengthening is not evenly distributed throughout the domain. Replicating results by Turk and Sawusch (1997), Turk and White (1999) found accentual lengthening on onsets, and their results were corroborated by Cambier-Langeveld and Turk (1999).

Besides final lengthening, the edges of prosodic domains associate with the edge-tones: phrase accents and boundary tones. Beckman and Pierrehumbert (1986) suggested that phrase accents and boundary tones associate with intermediate and intonational phrases respectively. Thus, the right edge of an intonational phrase associates with two edge-tones: (a) a boundary tone designating the intonational phrase boundary and (b) a phrase accent designating the intermediate phrase boundary. Correspondingly, the right edge of a non-terminal intermediate phrase associates with only one edge-tone, the phrase accent (Beckman & Pierrehumbert 1986; Pierrehumbert & Beckman 1988). In Cypriot Greek (CG), as in English, the different tonal configurations of edge-tones manifest different melodies for statements, *wh*-questions, and polar questions. A short account of these effects is reported in the following.

1.2 Cypriot Greek tonal structure

CG statements have rising prenuclear pitch accents and peaks on focused words that may differ depending on the focus type. For example, (2) can be a statement:

(2) i Léna traudhá
/i ˈlena tɾauˈða/
the Lena.NOM.PLU sing-PRS.3SG
'Lena is singing/sings'

When (2) is uttered as an answer to the question 'what is going on?' it conveys broad focus.

The utterance's tonal contour in Figure 1 comprises of an L*+H pitch accent: a local minimum (L) associated with the first word's stressed syllable onset, followed by a local maximum (H) occurring a few milliseconds before the following stressed syllable's onset. Because (2) conveys broad focus, the nuclear pitch accent that marks the postlexically prominent constituent, i.e. the word 'traudhá,' is a downstepped peak (!H*) (Arvaniti & Baltazani 2005) (see Figure 1). The contour ends in an L phrase accent and an L boundary tone. To summarize, the declarative contour shown in Figure 1 is autosegmentally analysed as L*+H !H*L–L%.

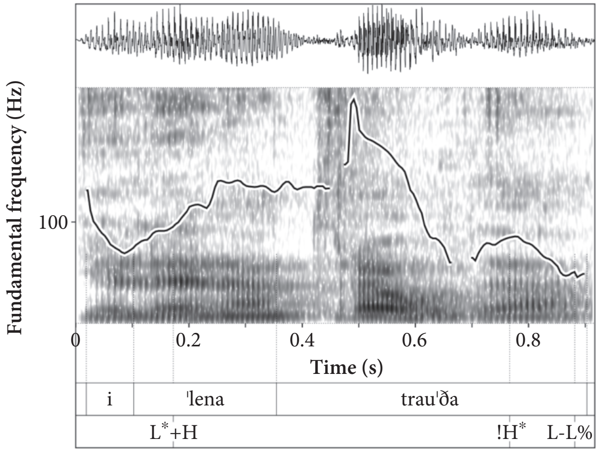

Figure 1. Waveform and f_0 contour of the utterance /i ˈlena trauˈða/ uttered as a declarative by a CG male speaker

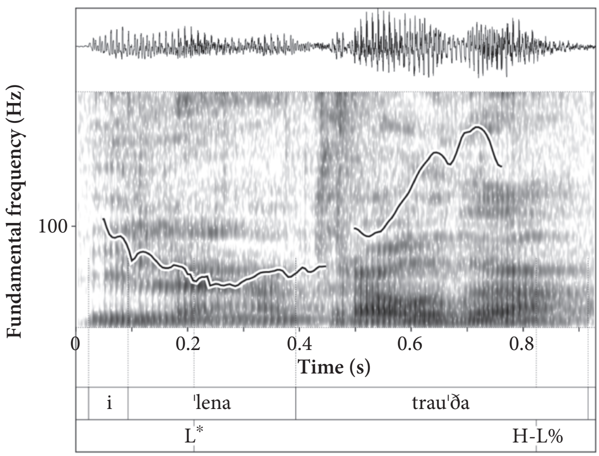

Figure 2. Waveform and f_0 contour of the utterance /i ˈlena trauˈða/ uttered as a polar question by a CG male speaker

When (2) is uttered as a polar question, two distinct tonal patterns occur. First, when the post-lexically stressed syllable is located at a non-terminal constituent, the most prominent syllable associates with a low nuclear pitch accent. After the nucleus, a rise-fall that begins at the rightmost penultimate syllable marks the utterance's boundary (Grice, Ladd & Arvaniti 2000). The H- phrase accent – i.e. the final peak – aligns in CG with the ultimate syllable (Grice et al. 2000) (see Figure 2). Overall, this polar question contour is autosegmentally analysed as

L*H–L% (Grice et al. 2000).[1] Grice et al. (2000) argue that CG polar question phrase accents have a primary association with the boundary and contrast Standard Modern Greek (SMG) phrase accents that have an additional secondary association with the stressed syllable. It must be stressed that the final rise-fall does not convey prominence but only marks the question's right boundary. In stark contrast with the high nucleus of statements, post-lexical prominence in polar questions associates with a low plateau, an L*pitch accent. Second, when the last constituent of the utterance associates with post-lexical prominence, the post-lexically stressed syllable, indicated in Figure 3 with a T*, does not associate with a fall but falls within the final rise.

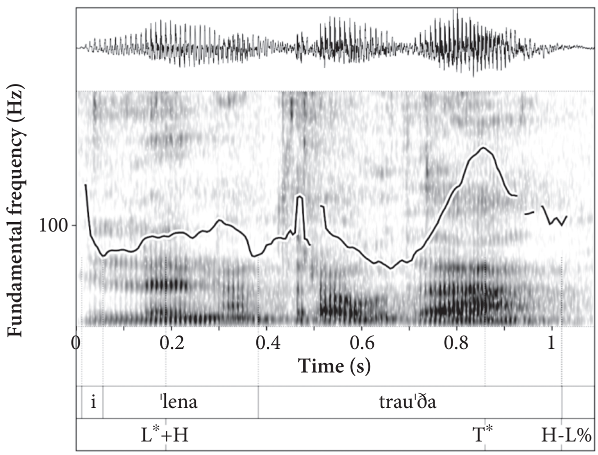

Figure 3. Waveform and f_0 contour of the utterance /i ˈlena trauˈða/ uttered as a polar question by a CG male speaker

Figure 4 shows the waveform and the spectrogram with the overlaid f_0 contour of the *wh*-question in (3).

(3) Pcos traudhá
/pcos tɾauˈða/
who sing-PRS.3SG
'Who is singing?'

1. L*H+L% (Baltazani & Jun 1999) and L*L+H- L% (Arvaniti, Ladd & Mennen 2006a) are other autosegmental representations that were proposed for the Standard Modern Greek polar question tune and can hold for CG polar question tune.

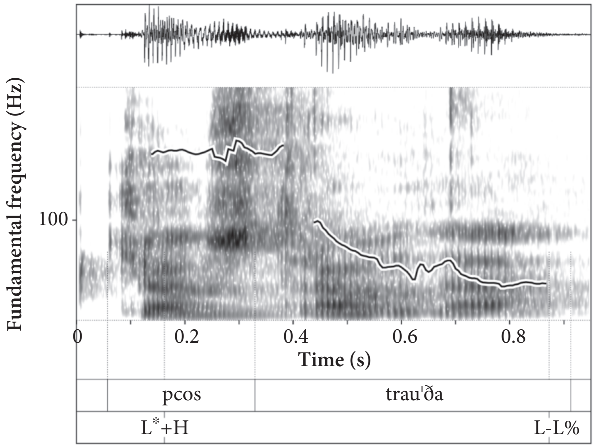

Figure 4. Waveform and f_0 contour of the *wh*-question /pcos trauˈða/ uttered by a CG male speaker

CG *wh*-question tune comprises of a peak (an L*+H accent) that associates with the *wh*-word followed by a fall to the end of the utterance. The fall is autosegmentally analysed as an L- phrase accent and an L% boundary tone; alternatively, as a boundary tone, a downstepped !H% that does not exceed the middle range of a speaker is employed (Arvaniti 2007).

To summarise, polar questions and statements in CG – as in Spanish and Italian – are identical in their segmental representation but differ in their tunes (Grice et al. 2000; Arvaniti et al. 2006a; Arvaniti, Ladd & Mennen 2006b; Baltazani 2007). *Wh*-questions differ from polar questions and statements in their segmental and prosodic structure.

1.3 Cypriot Greek

Greek and Turkish are the official languages of the Republic of Cyprus.[2] The local variety of Greek spoken in Cyprus is CG. Most CG speakers live in four major cities: Paphos, Limassol, Larnaca, and Nicosia, which is the capital of Cyprus. CG is often distinguished in urban Cypriot and village Cypriot (Newton 1972).

2. English is also employed in official documents to facilitate the interaction between the two speech communities. In 1974, a Turkish invasion to the island led to a subsequent de facto partition of the island. Since then, Turkish Cypriot is spoken in the northern part of the island whereas Cypriot Greek is spoken in the southern part. Even though the buffer zone restrictions have been relaxed since 2003, overall communication between Turkish Cypriots and Greek Cypriots remains sparse (Hadjioannou, Tsiplakou & Kappler 2011).

Urban Cypriot and village Cypriot form a continuum with the former spoken in urban areas whereas the latter is more basilectal (Tsiplakou, Papapavlou, Pavlou & Katsoyannou 2006). CG stands in a diglossic relationship with SMG (Hadjioannou et al. 2011, p. 510); levelling between urban CG and SMG also takes place (Grohmann & Leivada 2012; Rowe & Grohmann 2013). CG is employed in everyday interactions between CG speakers, and SMG is used in formal contexts.

1.4 The present study

The current study has four goals. First, it explores the lengthening effects of different edge-tones at the right boundary of *wh*-questions, polar questions, and statements. Second, by manipulating the strength of the boundary, the study examines the lengthening effects on prosodic boundaries, such as the right edges of *ip*s and *IP*s. Third, it investigates the distribution of lengthening on syllables, which have a different distance from the boundary. Fourth, it examines the distribution of lengthening on onsets and nuclei to assess the sub-syllabic effects of lengthening.

To address this study's goals, two experiments have been conducted. Experiment 1 examines the effects of the edge-tones (phrase accents and boundary tones) on stressed syllable duration. Experiment 2 examines lengthening effects preceding different prosodic boundaries. Specifically, the two experiments test four hypotheses.

Hypothesis A. Tonal structure triggers lengthening. In CG, statements and polar questions are identical in their segmental structure but differ in their tunes, and, since they are the same in their segmental structure, the tonal structure accounts for lengthening patterns.

Hypothesis B. Higher order prosodic domains trigger greater degrees of lengthening. Experimental studies suggest that syllables preceding boundaries of constituents are lengthened (e.g. Klatt 1976; Gussenhoven & Rietveld 1992; Nakai, Kunnari, Turk, Suomi & Ylitalo 2009; Michelas & D'Imperio 2012). Importantly, higher-ordered prosodic domains are expected to trigger greater degrees of lengthening than lower order domains (see Shattuck-Hufnagel & Turk 1996 for an overview). A direct consequence of Hypothesis B is that *IP*s that are higher in prosodic hierarchy trigger more lengthening than *ip*s which are lower in prosodic hierarchy. Another prediction that derives from this hypothesis is that different post-lexical syntactic constituents associate with prosodic domains. If different syntactic constituents associate with corresponding prosodic domains, they would trigger similar lengthening patterns; therefore, Hypothesis B would be confirmed. If syntactic constituents do not associate with prosodic domains, then they would independently associate with lengthening patterns; therefore, Hypothesis B would be rejected.

Hypothesis C. Syllables nearer to prosodic boundaries are lengthened. Stressed syllables show proportionally more lengthening as they approach prosodic domain boundaries (Turk & Shattuck-Hufnagel 2000, 2007). Thus, ultimate syllables are expected to be lengthier than penultimate and ultimate syllables.

Hypothesis D. Lengthening proportionately affects onsets and nuclei. This hypothesis tests the following claim made by Byrd and Saltzman (2003)'s π-gesture model: lengthening proportionally affects both the syllable onset and the syllable nucleus. Specifically, Byrd and Saltzman (2003) suggest that in speech production "constriction gestures of whatever sort will undergo lengthening if they are active during the domain of π-gesture activation (i.e. if they overlap the π-gesture)." The predictions made by this model have been confirmed many times in the literature. For example, Oller (1973) showed that the onset, the nucleus, and the coda undergo lengthening in a syllable. Also, Krivokapić (2007, p. 11) in accordance with Byrd and Saltzman (2003) suggests that the domain of lengthening is the syllable not the nucleus.

2. Experiment 1

Experiment 1 investigates the lengthening effects of edge-tones.

2.1 Methodology

2.1.1 *Speech material*

Experiment 1 examines the effects of edge-tones on stressed syllables. Three keywords were chosen with three CV syllables each. The designated target syllable is the stressed syllable [la] in antepenultimate, penultimate, and ultimate position: [ˈla.pi.θɔs] 'Lapithos,' [pi.ˈla.ðis] 'Pyladis,' and [ma.ju.ˈla] 'Majula.' By choosing the same segments, effects from other factors – such as different intrinsic durations – are avoided (Lehiste 1970; Klatt 1976).

To test Hypothesis A that suggests an effect of edge-tones (phrase accents and boundary tones) on stressed syllable duration, two carrier phrases were created: a sentence uttered as a declarative and as polar question and a sentence uttered as a *wh*-question (see Table 1). Statements' ultimate syllables associate with a nuclear pitch accent, a phrase accent, and a boundary tone (!H*L–L%) whereas polar questions' ultimate syllables associate with a phrase accent and a boundary tone (L+H– L%). In all three cases, the *keyword* is located at the utterance's right edge.

Table 1. Utterances associated with different edge-tones. The example keywords are underlined

Statement	*Wh*-question	Polar question
[ipa ti ˈlːeksi pi.ˈla.ðis] ‘I told the word Pyladis.’	[pcos su ˈipe ti ˈlːeksi pi.ˈla.ðis] ‘Who told the word Piladis?’	[ipa ti ˈlːeksi pi.ˈla.ðis] ‘Did I say the word Pyladis?’

2.1.2 *Speakers*

Twenty native speakers of CG participated in the experiment. The speakers grew up in two main urban areas of Cyprus: Nicosia and Larnaca and were speakers of urban CG. All speakers were university students in their mid-twenties. None of the speakers reported any speech or hearing problems.

2.1.3 *Procedure*

The experimental material was recorded in a soundproof room at the University of Cyprus. A Zoom H4n audio recorder was used, and the recordings were coded as single mono sounds (sampling frequency: 22050 Hz) and transferred to a PC for further analysis using a compact SD card. The Praat 5.3.32 acoustic analysis software (Boersma 1993) was used. Each item was typed in Standard Modern Greek orthography, and each prompt was presented twice in random order before a participant. In an effort to force the same pace to all participants, each prompt was presented every four seconds using Microsoft PowerPoint 2010.

Before the recording procedure, the speakers were instructed to read the utterances in their normal tempo. Statements and polar questions read aloud without context trigger in SMG nuclear stress at the utterance’s right edge (Arvaniti & Baltazani 2005; Arvaniti 2007); the same holds for CG. Thus, statements and polar questions were uttered with the nuclear pitch accent at the rightmost constituent. For *wh*-questions the nucleus is always on the *wh*-word, namely the word /pcos/. A corpus of 360 utterances was created (20 speakers × 3 environments/contexts × 3 keywords × 2 repetitions).

2.1.4 *Acoustic measurements*

Test materials were manually segmented and labelled by using simultaneous inspections of waveforms and wide-band spectrograms (see Figure 5).

The duration of the stressed syllable [la] and the duration of the segments [l] and [a] were measured. The overall segmentation followed standard criteria outlined by Peterson and Lehiste (1960) and the segmentation guidelines proposed by Turk, Nakai, and Sugahara (2006). Most specifically, for /l/, the onset

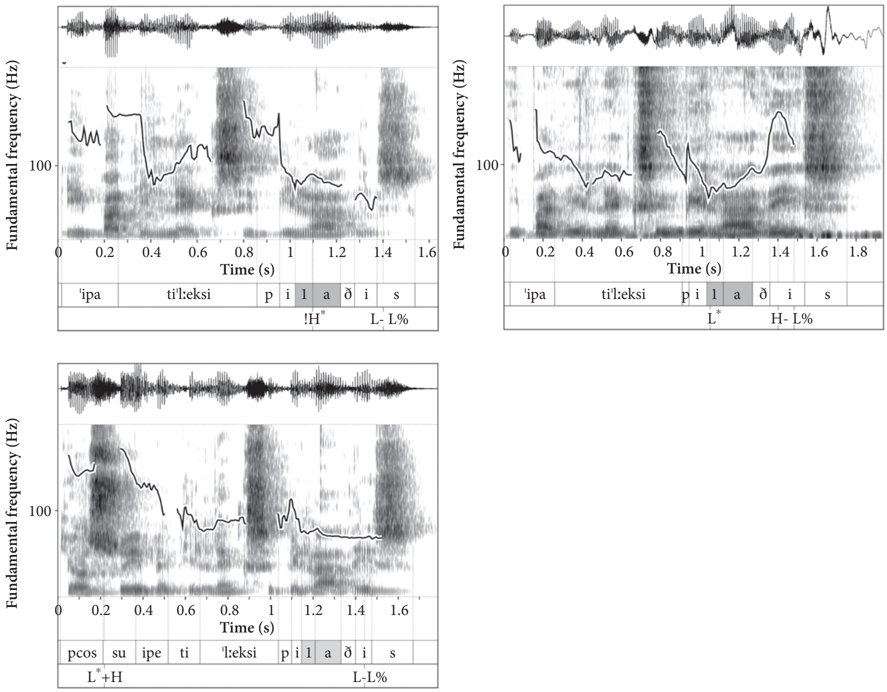

Figure 5. Waveform and the spectrogram with overlaid f_0 contour of the utterance /ˈipa ti ˈlːeksi piˈlaðis/ uttered as statement (panel a) and as a polar question (panel b) and of the *wh*-question /pcos su ˈipe ti ˈlːeksi pi.ˈla.ðis/ (panel c). The vertical bars indicate the segmental boundaries in the keyword. The grey shading indicates the target syllable

and offset were marked by sudden discontinuities in the formants that facilitated its segmentation.

2.1.5 *Statistics and analysis*

The onset duration, the nucleus duration, and the syllable duration constituted the experiment's dependent variables. The independent factors were (a) *syllable position* (ultimate, penultimate, and antepenultimate) and (b) *context* (statement, *wh*-question, and polar question). The statistical analysis was implemented in R, a strong, highly functional open-source language and environment for statistical computing and graphics (R Core Team 2012). The ezANOVA function from the 'ez' package was employed for the analysis; this function facilitates the analysis of data from factorial experiments, including within-Ss designs (a.k.a. 'repeated measures'), between-Ss designs, mixed within-and-between-Ss designs (Lawrence 2011). Specifically, two-way repeated measures ANOVA were conducted and reported. Before running the ANOVA, tests for sphericity violation were performed. In cases where Mauchly's test indicated that the assumption of sphericity had been violated, the degrees of freedom were corrected using Greenhouse-Geisser estimates. *Post hoc* tests with Bonferroni corrections were also reported. Since Bonferroni correction is a rather conservative approach, it reduces the risk of Type I error, which falsely assumes that a genuine effect exists in the population. However, as an obvious disadvantage of its evaluative arsenal, the Bonferroni correction increases the probability of rejecting an effect that actually exists (i.e. a Type II error).

2.2 Results

First, we present the lengthening effects on stressed syllables and then lengthening effects on onsets and nuclei.

2.2.1 *Stressed syllable duration*

The mean duration for antepenultimate, penultimate, and ultimate syllables in statements, *wh*-questions, and polar questions is shown in Figure 6.

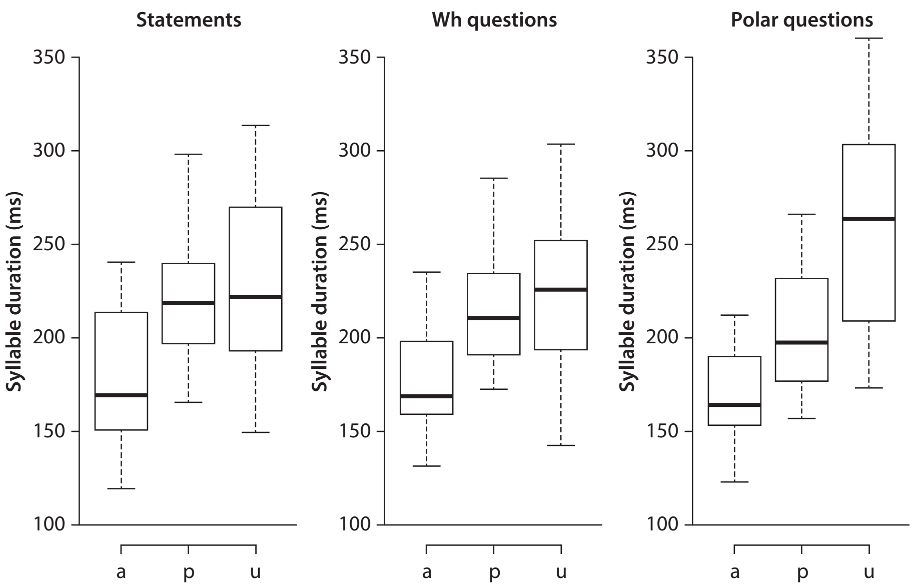

Figure 6. Stressed syllable duration (in ms) in antepenultimate (a), penultimate (p), and ultimate (u), uttered in three contexts as statements (panel A), *wh*-questions (panel B), and polar questions (panel C)

The experimental modification resulted in different durational patterns that elucidate the interaction between segmental duration and edge-tones. First, syllables differ in their length depending on their position in the keyword. Overall, the stressed ultimate and penultimate syllables are longer than antepenultimate syllables in all contexts (see Figure 6). This is a straightforward effect of final lengthening.

The *syllable position* has significant effects on stressed syllables duration, $F(1.33, 25.44) = 82.29$, $p < .001$, $\eta^2 = .35$, with Greenhouse-Geisser correction. The interaction *syllable position* × *context* also has significant effects on syllable duration, $F(2.77, 52.76) = 22.27$, $p < .001$, $\eta^2 = .06$, with Greenhouse-Geisser correction.

Second, Bonferonni post hoc tests suggest that antepenultimate, penultimate, and ultimate syllables in statements do not have significantly different duration from *wh*-questions. In fact, Bonferonni post hoc tests suggest that antepenultimate syllables have the same duration in all contexts. This finding indicates strong effects of tonal structure on syllable duration. Specifically, since in polar questions the tonal rise begins at the penultimate syllable, the stressed antepenultimate syllables are not affected by the edge-tones.

Third, the mean duration of the ultimate syllables ($M = 257.1$, $SD = 54$) in polar questions significantly exceeds the ultimate syllables' mean duration in *wh*-questions ($p < .001$) and statements ($p < .001$). Because all measured syllables in the three contexts were at the right edge of *IPs*, this difference in lengthening cannot be attributed simply to final lengthening. Since CG statements and polar questions are identical in their segmental material and differ only in their edge-tones, we can safely conclude that it is the edge-tones associated with the ultimate syllables that trigger this difference in lengthening. Furthermore, the effect of the edge-tones has a local effect on the ultimate syllables, thus the penultimate and antepenultimate syllables do not have lengthening effects. Therefore the results suggest two lengthening effects: (a) final lengthening associated with the boundary and (b) tonal lengthening associated with the edge-tones.

2.2.2 *Stressed consonant duration*

Consonants were marginally longer in antepenultimate syllables (ultimate consonants < penultimate consonants < antepenultimate consonants). Nevertheless, *syllable position* (ultimate, penultimate, antepenultimate) and *context* (polar questions, statements, and *wh*-questions) do not lead to significantly different duration for consonants (see Appendix A).

2.2.3 *Stressed Vowel Duration*

The results for vowels are summarised in Figure 7.

Overall, the vowel duration is more sensitive to experimental modifications than the consonant duration. Specifically, vowels in antepenultimate syllables are considerably shorter than vowels in penultimate and antepenultimate syllables (see Figure 7; Appendix A shows vowel mean duration).

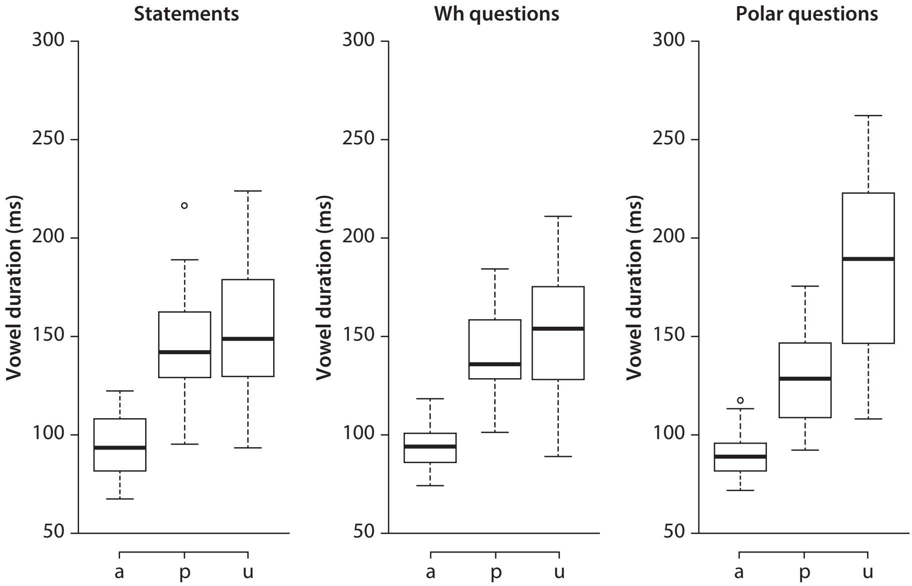

Figure 7. Stressed vowel duration (in ms) in antepenultimate (a), penultimate (p), and ultimate (u), uttered in three contexts as statements (panel A), *wh*-questions (panel B), and polar questions (panel C)

The polar question's ultimate vowels have the longest duration (M = 185.35, SD = 44.55). An ANOVA test reported with a Greenhouse-Geisser correction shows that the *syllable position* $F(1.41, 26.93) = 148.87$, $p < .0001$, $\eta^2 = .59$ has statistically significant effects on vowel duration; the interaction *syllable position* × *context* also has statistically significant effects on vowel duration, $F(1.784, 33.90) = 34.50$, $p < .0001$, $\eta^2 = .13$. Importantly, Bonferroni post-hoc tests show that vowels in ultimate syllables of polar questions differ significantly from vowels in ultimate syllables of statements ($p < .0001$) and *wh*-questions ($p < .0001$).

In summary, consonant duration remains relatively constant whereas vowel duration varies more due to the experimental modifications. Nonetheless, another question remains: how do vowels and consonants correlate with the overall syllable duration? An answer to this question is provided by the correlations shown in Figure 8 and discussed below.

There was no correlation between vowel duration and consonant duration (Figure 8, panel A), which suggests that vowels and consonants do not share the same lengthening patterns. Vowel duration and syllable duration are strongly correlated (Figure 8, panel B). Thus, syllable duration reflects vowel duration whereas consonant duration has a small correlation with syllable

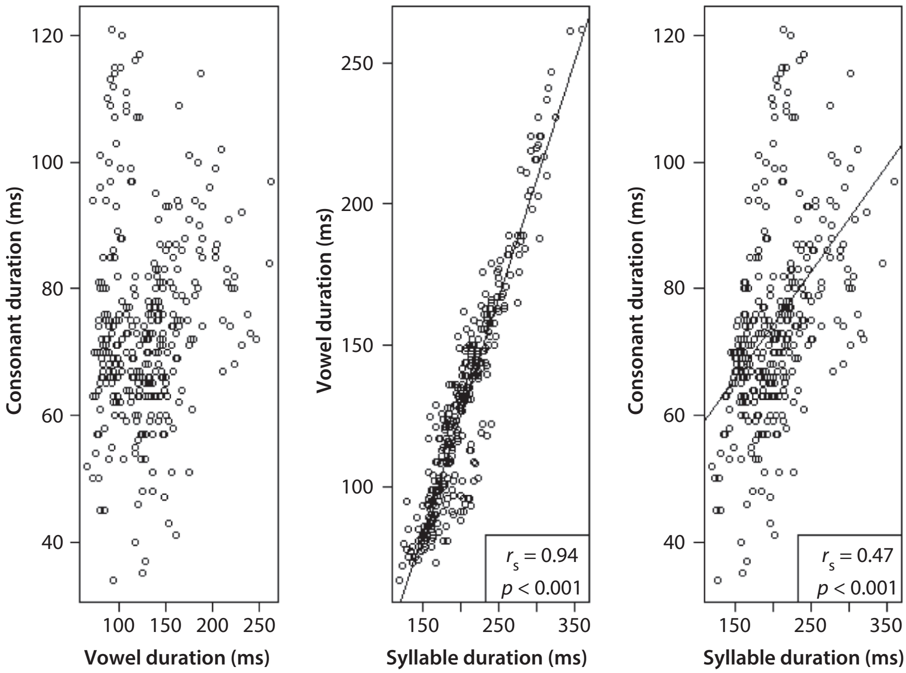

Figure 8. Correlations of consonant duration and vowel duration (panel A), vowel duration and syllable duration (panel B), and consonant duration and syllable duration (panel C)

duration (Figure 8, panel C). Even though correlation does not support causation, drawing on the preceding findings it is legitimate to claim that in CG syllable duration reflects the nucleus duration.

2.2.4 *Discussion*

Experiment 1 by providing support for edge-tone effects on stressed syllable duration, corroborates Hypothesis A that tones at the utterance's right edge determine syllable duration. Specifically, since polar questions and statements in CG differ only in their tonal structure, the difference in ultimate syllable duration in polar questions and statements is attributed to the different tones that associate with these syllables. Moreover, Experiment 1 suggests that stressed penultimate and ultimate syllables that are adjacent to the boundary are lengthened in all contexts whereas antepenultimate syllables that are further apart from the boundary are considerably shorter (Klatt 1975; Wightman et al. 1992; Byrd, Kaun, Narayanan & Saltzman 2000). These findings are clearly an effect of final lengthening and provide support for Hypothesis C.

Most importantly, lengthening applies principally on vowels, which are susceptible to experimental modification. Consonants on the other hand have relatively constant duration, which does not alter because of the experimental modifications. In essence, syllable duration patterns reflect vowel duration patterns. Experiment 1 showed that tonal patterns trigger different lengthening effects; the following experiment examines the effects of prosodic boundaries on lengthening.

3. Experiment 2

Experiment 2 examines the lengthening effects, which associate with the edges of prosodic domains.

3.1 Methodology

3.1.1 *Speech material*

This experiment tests the effects of domain boundaries on the duration of stressed syllables. Three keywords have been chosen with three CV syllables each. The designated target syllable is the stressed syllable [la] in antepenultimate, penultimate, and ultimate position: [ˈla.pi.θɔs] 'Lapithos,' [pi.ˈla.ðis] 'Pyladis,' and [ma.ʝu.ˈla] 'Majula.' Four carrier phrases were created one for each condition (see Table 2).

Table 2. Four carrier sentences comprising the experimental material; the example keywords are underlined

Final Boundary	Conjoined NP	Secondary Clause	List
[ipa ti ˈlːeksi <u>pi.ˈla.ðis</u>]	[ipa ti ˈlːeksi <u>pi.ˈla.ðis</u> ce leˈmoni]	[ipa ti ˈlːeksi <u>pi.ˈla.ðis</u> pri ˈfːio]	[ipa ti ˈlːeksi <u>pi.ˈla.ðis</u> leˈmoni ce laˈvi]
'I told the word Pyladis.'	'I told the word Pyladis and lemon.'	'I told the word Pyladis before I leave'.	'I told the word Pyladis, lemon and grasp'.

To assess the effects of prosodic structure on lengthening, the utterances were constructed as polar questions, which ensures that all utterances are produced with the same edge-tones: a peak on the final syllable and a fall. To control for the effects of nuclear pitch accents on lengthening, the nucleus was produced on the rightmost constituent.

Four different structures were tested for lengthening effects on three syllable CV words: (a) the utterance's right edge (Final Boundary); (b) a phrase boundary followed by a conjoined noun phrase with an 'and' conjunction (Conjoined

NP); (c) a phrase boundary followed by a secondary clause (Secondary Clause); and lastly, (d) a phrase boundary followed by a list of elements (List). The four boundaries are expected to trigger different lengthening effects. Most importantly, if Hypothesis B is correct, higher-ordered prosodic boundaries should trigger greater degrees of lengthening than lower prosodic boundaries. Thus, the *final boundary,* which corresponds to *IP* boundary, is expected to trigger greater degrees of lengthening than Conjoined NPs, Secondary Clauses, and List of Elements that correspond to *ip* boundaries. However, if Hypothesis B is wrong, each constituent should trigger different lengthening patterns.

Moreover, Experiment 2 aims to assess Hypothesis C, which suggests that syllables nearer to the boundaries are longer. If Hypothesis C is correct, then ultimate syllables should be longer than penultimate syllables, and penultimate syllables should be longer than antepenultimate syllables (antepenultimate < penultimate < ultimate). This effect should apply both to intonational and intermediate boundaries.

Finally, Experiment 2 aims to examine Hypothesis D assumption that syllable onsets and nuclei lengthen proportionally. Experiment 2 did not confirm hypothesis D, if Experiment 2 findings corroborate Experiment 1 findings, then this hypothesis should be rejected.

3.1.2 *Speakers*

Twenty native speakers of CG participated in the experiment. The speakers grew up in Nicosia and Larnaca and were speakers of urban CG. All speakers were university students in their mid-twenties. None of the speakers reported any speech or hearing problems.

3.1.3 *Procedure*

The experimental material was recorded in a soundproof room at the University of Cyprus. A Zoom H4n audio recorder was used, and the recordings were coded as single mono sounds (sampling frequency: 22050 Hz) and transferred to a PC for further analysis using a compact SD card. The Praat 5.3.32 acoustic analysis software (Boersma 1993) was used. Each item was typed in Standard Modern Greek orthography, and each prompt was presented twice in random order before a participant. In an effort to force the same pace to all participants, each prompt was presented every four seconds using Microsoft PowerPoint 2010. Before the recording procedure, the speakers were instructed to read the utterances in their normal tempo. For Experiment 2, a sample of 480 utterances has been recorded (20 speakers × 4 environments/contexts × 3 keywords × 2 repetitions).

3.1.4 *Acoustic measurements*

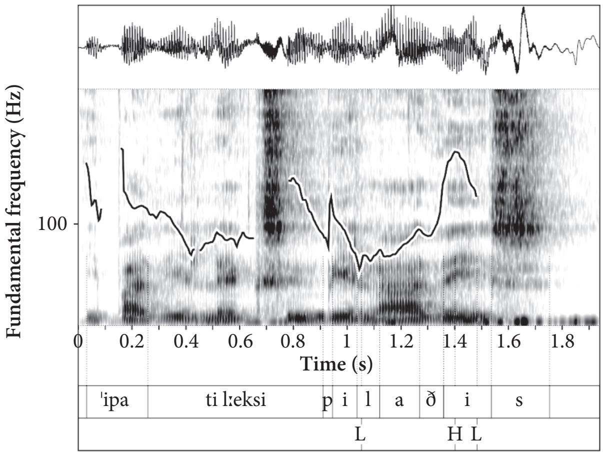

Figure 9. Waveform and f_0 contour of the utterance /ˈi pa ti ˈlːeksi piˈlaðis/ uttered as a polar question. The vertical bars indicate the segmental boundaries in the keyword. The L indicates a local minimum and the H a local maximum associated with the keyword

Test material was manually segmented and labelled by using simultaneous inspections of waveforms and wide-band spectrograms (see Figure 9). The stressed syllable [la] duration and the syllable's constituting segments [l] and [a] duration were measured. The segmentation followed standard criteria outlined by Peterson and Lehiste (1960) and the segmentation guidelines proposed by Turk et al. (2006). Most specifically, for /l/, the onset and offset were marked by abrupt discontinuities in the formants that facilitated its segmentation.

3.1.5 *Statistics and analysis*

The duration of the onset, the nucleus, and the syllable constituted the experiment's dependent variables. The independent factors were (a) *syllable position* (ultimate, penultimate, and antepenultimate) and (b) *boundary type* (final sentence boundary, preceding conjunction, preceding secondary clause, and preceding other elements in a list). The statistical analysis was implemented in R, a strong, highly functional open-source language and environment for statistical computing and graphics (R Core Team 2012). The ezANOVA function from the 'ez' package was employed for the analysis. Specifically, two-way repeated measures ANOVA were conducted and reported. Before running the ANOVA, tests for sphericity violation were performed. In cases where Mauchly's test indicated that the assumption of sphericity had been violated, the degrees of freedom were corrected using

Greenhouse-Geisser estimates. *Post hoc* tests with Bonferroni corrections were also reported.

3.2 Results

In this section, the results concerning preboundary effects on stressed syllables' duration are presented first; the results concerning lengthening effects on onsets and nuclei follow.

3.2.1 *Stressed syllable duration*

The stressed syllables' mean duration in antepenultimate, penultimate, and ultimate position uttered in four contexts is shown in Figure 10.

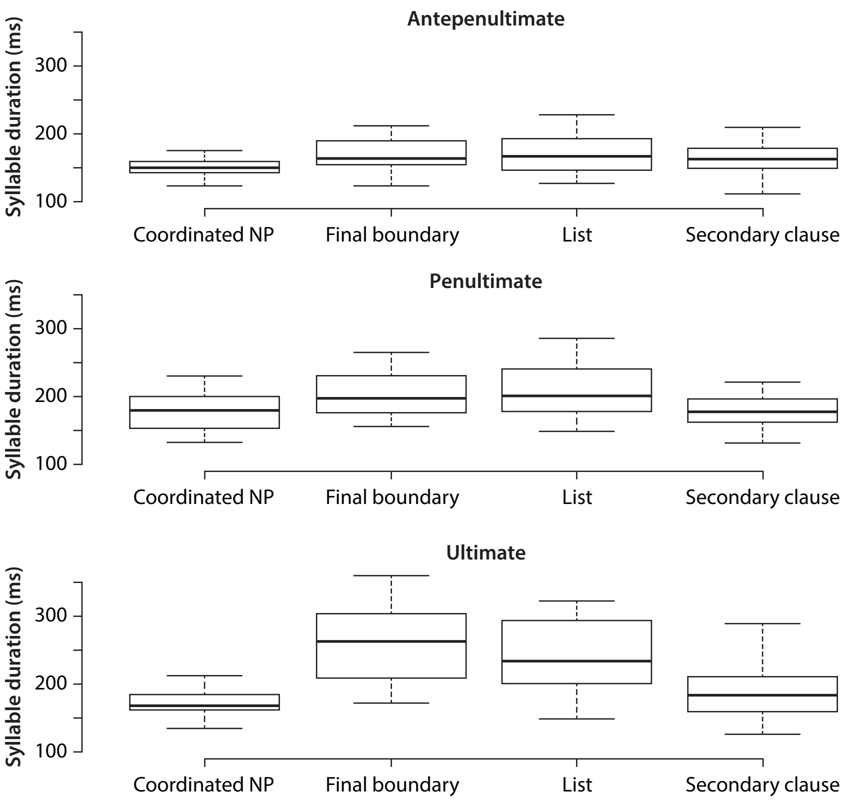

Figure 10. Stressed syllable mean duration (in ms) in antepenultimate (panel A), penultimate (panel B), and ultimate position (panel C) uttered in four different contexts

The effect of *boundary type* on syllable duration was statistically significant, $F(2.22, 42.18) = 30.42$, $p < .001$, $\eta^2 = .25$, with Greenhouse-Geisser correction. In other words, syllables differ in their duration depending on the boundary type: Final Boundaries and Lists associate with greater lengthening on ultimate syllables than Coordinated NPs and Secondary Clauses.

The effect of *syllable position* on syllable duration was also significant, $F(1.26, 23.94) = 82.45$, $p = .001$, $\eta^2 = .31$, with Greenhouse-Geisser correction. Ultimate syllables are longer than penultimate syllables, and penultimate syllables are longer than antepenultimate syllables (antepenultimate < penultimate < ultimate). However, in Coordinated NPs the penultimate syllables were marginally longer than ultimate syllables. Overall, the *boundary type* × *syllable position* interaction on syllable duration was statistically significant, $F(3.24, 61.56)= 25.43$, $p < .001$, $\eta^2 = .13$, with Greenhouse-Geisser correction.

Antepenultimate syllables have the same duration (*n.s.*) in Final Boundaries, Secondary Clauses, and Lists. Antepenultimate syllables in Coordinated NPs (p < .05) were considerably shorter ($M = 149$, $SD = 13$) than antepenultimate syllables in the other cases ($M = 170$).

Bonferroni post hoc tests suggest that penultimate and ultimate syllables in Final Boundaries and Lists have the same duration (*n.s.*), which suggests that they associate with the same prosodic domain. In addition, penultimate and ultimate syllables in Secondary Clauses and Coordinated NPs have the same duration (*n.s.*). These findings corroborate Hypothesis B that higher-ordered prosodic boundaries trigger greater degrees of lengthening than lower-ordered prosodic boundaries and Hypothesis C that syllables nearer to the boundaries are longer. The following discussion addresses syllable onset and nucleus lengthening.

3.2.2 *Stressed consonant duration*

Figure 11 shows the mean consonant duration in antepenultimate, penultimate, and ultimate position uttered in four different contexts.

Overall, consonants have the same mean duration in antepenultimate and ultimate position (74 ms). Nevertheless, consonants in penultimate syllables are marginally shorter (71 ms). The results show that the effect of *boundary type* on consonant duration was statistically significant, $F(2.19, 41.61) = 9.84$, $p < .05$, $\eta^2 = .09$, with Greenhouse-Geisser correction. The effects of *syllable position* on consonant duration were also statistically significant, $F(2, 38) = 2.90$, $p < .05$, $\eta^2 = .02$. In addition, the *boundary type* × *syllable position* interaction on consonant duration was significant $F(2.64, 50.16) = 9.78$, $p < .05$, $\eta^2 = .05$, with Greenhouse-Geisser correction.

Nonetheless, the reported effect sizes indicate that the effects are exceptionally small ($\eta^2 < .1$), which suggests that these findings have resulted from the

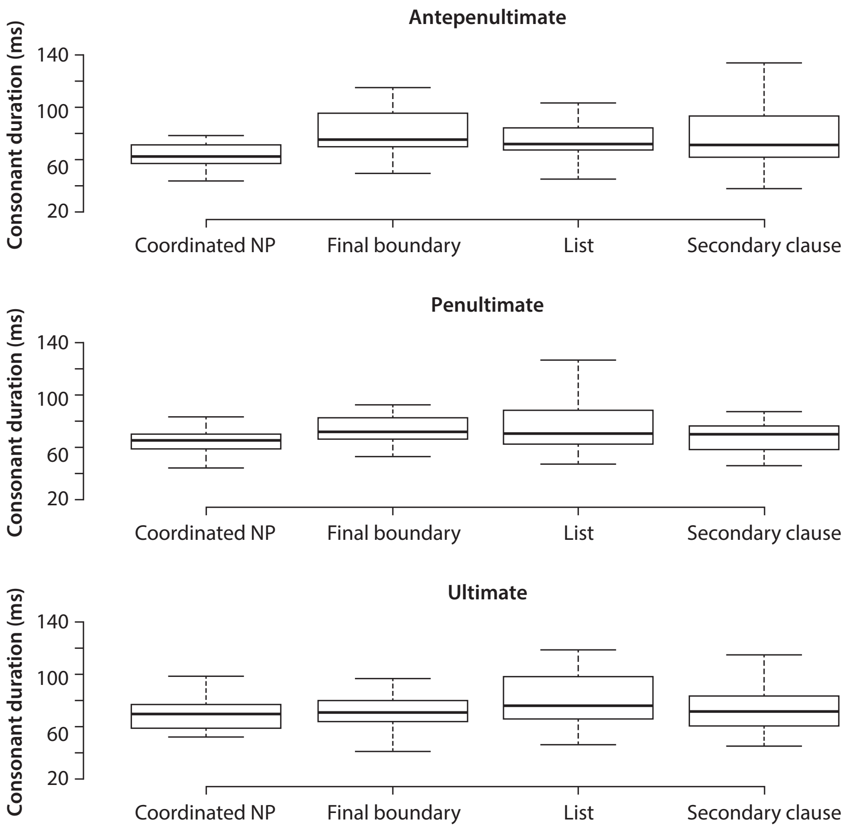

Figure 11. Stressed consonant duration (in ms) in antepenultimate (panel A), penultimate (panel B), and ultimate syllables (panel C) uttered in four different contexts

inter-speaker variation rather than the experimental design. Therefore, following a rather conservative approach, we consider that there is no effect of independent variables on consonant duration. This approach is grounded on the preceding experiment's findings that showed no effects of *syllable position* (ultimate, penultimate, antepenultimate) and *context* (polar questions, statements, and *wh*-questions) on consonant duration.

3.2.3 *Stressed vowel duration*

Lengthening patterns of stressed vowels are shown in Figure 12.

Figure 12 provides an overview of vowel lengthening patterns. Overall, vowels in antepenultimate syllables are comparatively shorter than in other syllable positions (antepenultimate < penultimate < ultimate). Vowels in ultimate syllables in Final Boundaries (M = 185.35, SD = 44.55) and Lists (M = 159.35, SD = 31.48) are lengthened whereas vowels in ultimate syllables of Coordinated NPs and Secondary Clauses do not undergo lengthening. Penultimate syllables in Lists

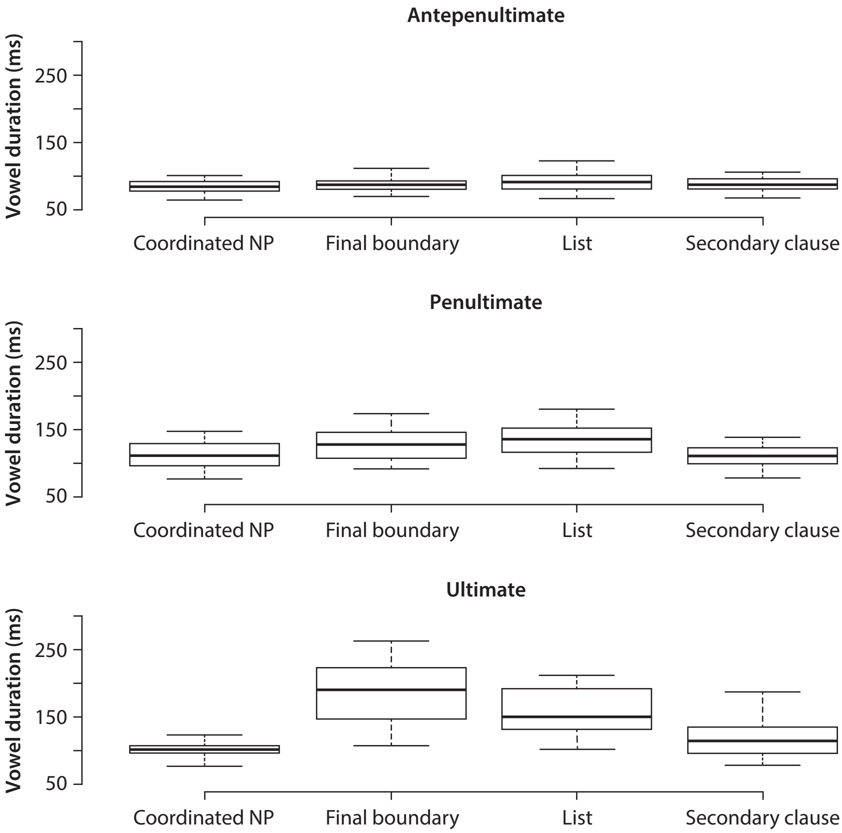

Figure 12. Stressed Vowel duration (in ms) in antepenultimate (panel A), penultimate (panel B) and ultimate (panel C), uttered in four different contexts

(M = 134.53, SD = 23.38) and Final Boundaries (M = 129.70, SD = 24.83) follow in mean duration. The shortest vowels are those in antepenultimate syllables.

The effects of *boundary type* on vowel duration were statistically significant ($F(1.60, 30.38) = 38.54$, $p < .001$, $\eta^2 = .31$). The effects of *syllable position* on vowel duration were also significant ($F(1.07, 20.25) = 126.47$, $p < .001$, $\eta^2 = .50$). In addition the effects of *boundary type* × *syllable position* interaction on vowel duration were significant ($F(3.19, 60.75) = 44.94$, $p < .001$, $\eta^2 = .27$), which means that there are different effects depending on the vowel's distance from the boundary and from the boundary type. Bonferroni post hoc tests suggest that all vowels in antepenultimate syllables have the same duration, which implies that pre-boundary lengthening affects vowels in penultimate and ultimate syllables but not vowels in antepenutltimate syllables.

In summary, experimental modifications affect predominantly the vowel duration whereas consonant duration remains relatively constant. The correlations of consonant duration, vowel duration and syllable duration are shown in Figure 13.

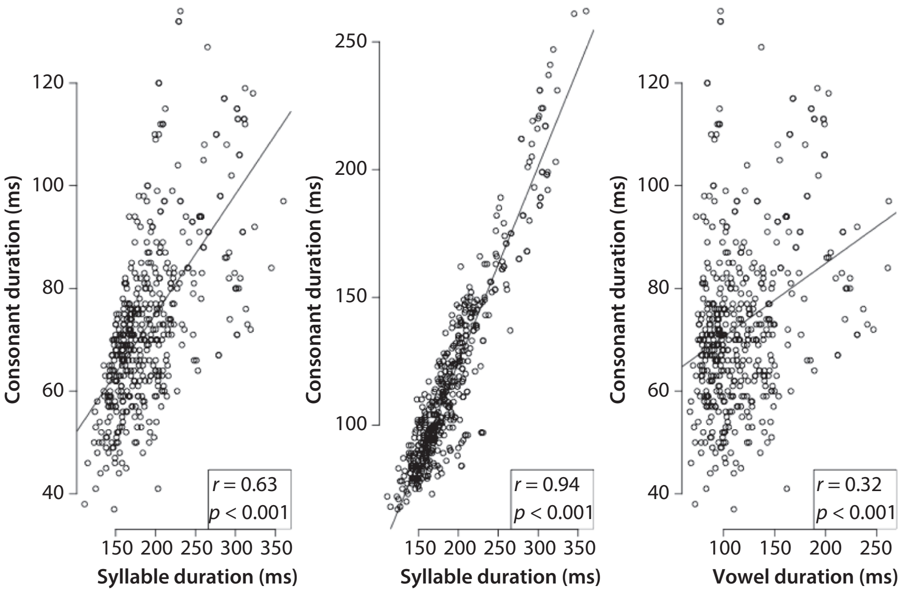

Figure 13. Correlations of consonant duration and syllable duration (panel A), vowel duration and syllable duration (panel B), and consonant duration and vowel duration (panel C)

All correlations are positive (see Figure 13). Importantly, there is a large correlation between syllables and vowels (panel B), which suggests that both lengthen in a similar manner. In addition there is a medium correlation between syllables and consonants (pane A), which suggests that both consonants and syllables undergo pre-boundary lengthening. The correlation between consonants and vowels (panel C) is smaller than in the aforementioned correlations. Since the effects of lengthening on consonants and vowels are not proportional, Hypothesis D is not supported.

3.2.4 *Discussion*

Experiment 2 shows that there is a twofold distribution of duration in penultimate and ultimate syllables: (a) they are longer in Final Boundaries and Lists and (b) shorter in Coordinated NPs and Secondary Clauses. These results suggest that in CG there are two post-lexical domains over the prosodic word, namely *ip*s and *IP*s. More specifically, lengthening patterns fall into two major groups: (a) Lists and Final Boundaries and (b) Coordinated NPs and Secondary Clauses. The first group associates with domains equal to the *IP* and the second group associates with domains lower than the *ip*. The ultimate syllables of the first group are longer than the ultimate syllables of the second group. These findings corroborate *Hypothesis B*; namely, they show that stressed syllables of words preceding the *IP*'s right edge are longer than stressed syllables preceding an *ip*'s right edge (Byrd & Saltzman 2003; Byrd & Riggs 2008). In addition, since syllables become longer as they approach the boundary (ultimate syllables ⟩ penultimate syllables > antepenultimate syllables), the Hypothesis C is confirmed. Finally, there are different lengthening effects on onsets and nuclei: onsets show minor lengthening effects whereas in IP boundaries, nuclei display major preboundary lengthening effects. Finally, since onsets and nuclei are not proportionally lengthened, *Hypothesis D* is questioned.

4. Final discussion

The current study displays that CG like many other speech varieties exhibits final lengthening. Notably, it demonstrates that lengthening applies primarily to syllable nuclei whereas syllable onsets remain relatively constant. In addition, it elucidates the effects of edge-tones and prosodic domain boundaries on final lengthening. Specifically, it shows that two types of lengthening apply at the right edge of post-lexical domains: (a) *pre-boundary lengthening* that marks the edges of prosodic domains and varies depending on boundary strength and (b) *edge-tone lengthening* that associates with the effects of edge-tones. The two types of lengthening trigger different overlaying effects that account for the lengthening patterns at the edges of prosodic domains. Overall, these results provide support for the following: (a) lengthening applies asymmetrically within syllable constituents, the syllable onsets and the syllable nuclei; (b) lengthening depends on the syllable distance from domain boundaries; (c) lengthening is greater at higher-ordered prosodic domains than at lower ones; and (d) lengthening interacts with the tonal composition superimposed on the tone-bearing syllable. The implications of these findings are discussed in the following.

(*a*) *Lengthening applies asymmetrically within syllable constituents.*

An important finding of this study is that consonants in CG remain relatively constant whereas vowels lengthen significantly. However in SMG, a closely related variety to CG, onset consonants preceding *IP* and *ip* boundaries lengthen. For example, in her study Kainada (2009) found that "the effect of boundary strength was significant for the onset, rime and whole pre-boundary syllable" (Kainada 2009, p. 70). These findings point to variety specific effects of lengthening at the edges of prosodic domains. Namely, in CG – unlike SMG – there are singletons and geminates; thus, to sustain their discrete phonetic length from geminates, singletons maintain relatively constant duration.

Importantly, similar effects for vowels have been reported in quantity languages. In Finnish half-long vowels – which are phonemically short vowels but because they follow a light syllable become relatively long – undergo less lengthening than long vowels. Nakai et al. (2009) argue that the limit on half-long vowels lengthening preserves their identity in the short vs. long phonemic contrast (Nakai et al. 2009; Nakai et al. 2012). More specifically, Nakai et al. (2012) argue that "quantity languages regulate the use of duration for non-phonemic purposes because of the high functional load of duration at the phonemic level." Our contention is that CG, a non-quantity language variety, behaves in a similar manner to quantity languages and preserves the phonemic contrast between geminate and non-geminate consonants. Subsequently, an upper bound limit for singletons exists in CG and it is preserved and safeguarded from preboundary effects and edge-tone lengthening effects.

These findings seem to challenge Byrd and Saltzman (2003) speech timing model. Specifically, they suggested that both syllable onsets and syllable nuclei would undergo lengthening if they fall within the domain of the π-gesture, which is a "clock-rate" device related to the prosodic structure of the utterance. The π-gesture modulates the temporal unfolding of an utterance near the edges of prosodic domains and results in deceleration of the clock-rate (Byrd & Saltzman 2003). However, since onsets in CG are not symmetrically subject to lengthening, the assumption that syllable onsets and syllable nuclei proportionally undergo lengthening is not valid. Therefore, π-gesture model cannot account for the CG onset duration; distinct devices must be postulated in order to account for the lengthening effects on nuclei and onsets. For example, one way to accommodate the model to the findings is to regulate the application of the π-gesture based on segmental parameters so as to constrain segments' durational variability. Nevertheless, at this point it is not clear to us how the model can capture the sub-syllable durational variability in CG.

(*b*) *Lengthening depends on the syllable distance from the domain boundaries.*

Syllables that are nearer to the boundary are lengthier than syllables that are farther from it. Consequently, lengthening is stronger in CG ultimate syllables and weaker in penultimate syllables. This effect highlights the progressive nature of lengthening in CG. Similar findings were reported for other language varieties (Klatt 1975; Wightman et al. 1992; Berkovits 1993, 1994; White 2002; Byrd & Saltzman 2003).

(*c*) *Lengthening is greater at higher-ordered prosodic domains than at lower ones.*

Pairs of syntactic constituents uttered as polar questions induce similar degrees of preboundary lengthening: (a) utterances and list elements and (b) coordinated

NPs and subordinated secondary clauses. These results suggest that there are only two types of prosodic boundaries: firstly, the more prominent boundaries, utterance final boundaries or boundaries of elements in lists that induce greater degrees of lengthening; secondly, the less prominent boundaries, coordinated syntactic constituent boundaries and subordinated secondary clause boundaries that induce lower degrees of lengthening. Arguably, these findings provide evidence for only two prosodic domains over the phonological word in CG (Selkirk 1984; Truckenbrodt 1995; Shattuck-Hufnagel & Turk 1996; Truckenbrodt 2007). The first prosodic domain corresponds to *IP* boundaries that associate with greater degrees of lengthening and the latter to *ip* boundaries that associate with lesser degrees of lengthening (Wightman et al. 1992; Cambier-Langeveld 1997). Similar findings were reported for other languages such as Dutch (Hofhuis, Gussenhoven & Rietveld 1995; Cambier-Langeveld 1997), Hebrew (Berkovits 1993, 1994), and Jordanian Arabic (de Jong & Zawaydeh 1999). Moreover, this analysis is in accord with Arvaniti and Baltazani (2005) who argue in favour of two post-lexical prosodic domains in SMG: the *ip* and the *IP* (for American English, see also Beckman & Pierrehumbert 1986; Pierrehumbert & Beckman 1988).

(*d*) *Lengthening interacts with the tonal composition superimposed on the tone-bearing syllable.*

The penultimate and ultimate syllables have greater lengthening in polar questions than in statements whereas antepenultimate syllables have the same duration in polar questions and statements. Notably, the edge-tones associated with the polar questions' and statements' right edge account for these findings; in polar questions the penultimate syllables constitute the locus of the final rise's (H–L%) beginning and the ultimate syllables the locus of its peak and fall. Consequently, penultimate syllables and ultimate syllables are lengthened more in polar questions than in statements. In addition, antepenultimate syllables, which in polar questions do not associate with edge-tones, display similar lengthening patterns in polar questions and statements. Therefore, lengthening is an essential cue for the distinction between statements and polar questions.

A consequence of these findings is that prosodic structure alone does not account for lengthening effects that take place at the edges of prosodic domains. Most importantly, tonal structure needs to be taken into account as a contributing factor to lengthening. The effects of edge-tones are comparable to the effects of pitch accents on syllable duration. Namely, accented syllables in English and Greek declaratives are longer than stressed syllables (Botinis 1989; Ladd 2008; Calhoun 2010) and stressed syllables are longer than unstressed syllables (unstressed syllables < stressed syllables < post-lexically stressed syllables)

(Beckman 1986; Botinis 1989; Dimitrova & Turk 2012). In brief, the *edge-tone lengthening*, which associates with phrase accents and boundary tones and *accentual lengthening*, which associates with pitch accents highlight the lengthening and intonation interface.

Nevertheless, to provide an extremely controlled environment, the experimental designs have been very conservative in that only stressed syllables were examined and only one syllable make-up, i.e. the CV syllable /la/. Therefore, more research is needed to assess the effects of lengthening on unstressed syllables and on syllables more complex in their make-up. Finally, the effect of lengthening on syllables that precede and follow the stressed syllables and the lengthening effects on syllables that follow the prosodic boundary should be also investigated.

5. Conclusions

The current study is to our knowledge the first study that specifically addresses lengthening patterns in CG and the interaction of lengthening with prosodic boundaries and tonal structure. Prosodic structure remains one of the most fundamental and insightful assumptions that underpins AM phonology, yet it does not solely account for the lengthening effects at the edges of prosodic domains (Berkovits 1993, 1994; Byrd & Saltzman 2003; Nakai et al. 2009; Katsika 2012). As it is argued in this study, tonal structure also contributes to lengthening in CG. Subsequently, different durational layers govern lengthening: preboundary lengthening, which associates with prosodic domains and edge-tone lengthening, which associates with the edge-tones. The layers interact with the sub-syllable constituents, namely the syllable nucleus and the syllable onset. Overall, the synergy of tonal structure and prosodic boundaries accounts for lengthening effects at the edges of domains. Moreover, lengthening depends on syllables' distance from the boundary: syllables that are nearer to the boundary are lengthier than syllables that are farther from it. Specifically, final lengthening is not constrained in the final syllable but extents to penultimate syllables. This effect highlights the progressive nature of lengthening in CG, an effect also evident in other languages (Berkovits 1993, 1994; White 2002).

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Appendix A

Mean and SD of syllable, consonant, and vowel duration (in ms) across three contexts and three syllable positions (Experiment 1).

	Polar questions		Statements		*Wh*-Questions	
	Mean	SD	Mean	SD	Mean	SD
			Syllable Duration			
Antepenultimate	170	22	176	33	176	26
Penultimate	204	33	221	35	215	29
Ultimate	257	54	227	45	226	40
			Consonant Duration			
Antepenultimate	80	15	81	22	82	19
Penultimate	73	11	73	12	73	12
Ultimate	71	12	72	18	72	13
			Vowel Duration			
Antepenultimate	89	11	95	16	95	11
Penultimate	130	25	147	28	141	21
Ultimate	185	45	154	31	152	31

Appendix B

Mean duration and standard deviation of syllable, consonant, and vowel duration (in ms) across four contexts and three syllable positions (Experiment 2).

	Coordinated NP		Final boundary		List		Secondary clause	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
				Syllable Duration				
Antepenultimate	149	13	170	23	170	27	169	28
Penultimate	179	26	204	33	211	39	180	20
Ultimate	174	19	257	54	242	47	195	49
				Consonant Duration				
Antepenultimate	63	9	81	15	75	14	80	25
Penultimate	65	12	74	11	75	20	68	12
Ultimate	70	12	71	13	82	20	74	19

(*Continued*)

Appendix B. (Continued)

	Coordinated NP		Final boundary		List		Secondary clause	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
	Vowel Duration							
Antepenultimate	86	9	89	11	95	16	88	8
Penultimate	114	19	130	25	135	23	111	15
Ultimate	103	13	185	45	159	32	120	32

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