selected papers *of*

the 10th International Conference of Greek Linguistics

Edited by

Zoe Gavriilidou
Angeliki Efthymiou
Evangelia Thomadaki
Penelope Kambakis-Vougiouklis

Komotini 2012

AN ARTICULATORY STUDY OF WORD-INITIAL STOP GEMINATION IN CYPRIOT GREEK

Spyros Armosti

University of Cyprus

armostis@cantab.net

ΠΕΡΙΛΗΨΗ

Σε γλώσσες που επιτρέπουν άηχα διπλά κλειστά σύμφωνα στην αρχή των λέξεων, η ακουστική διάρκεια της κλειστής φάσης (που αποτελεί την κύρια ένδειξη για το διπλασιασμό των συμφώνων) δεν μπορεί να εντοπιστεί μετά από παύση (δηλ. στην αρχή του εκφωνήματος)· ωστόσο, αρθρωτικά η διάκριση εξακολουθεί να υπάρχει (Kraehenmann και Lahiri 2008), ενδεχομένως με προσωδιακή επιμήκυνση στην αρχή του εκφωνήματος. Η παρούσα έρευνα εξετάζει αν στη θέση αυτή διατηρείται η αρθρωτική διάκριση μεταξύ απλών και διπλών στην κυπριακή ελληνική. Παρουσιάζονται τα αποτελέσματα ηλεκτροπαλατο-γραφημάτων, που δείχνουν ότι η αρθρωτική διάκριση υφίσταται, αλλά υπόκειται σε περιορισμούς που σχετίζονται με τη θέση του τόνου. Η διάκριση είναι ωστόσο σαφώς ακουστικά αντιληπτή λόγω της μεγαλύτερης διάρκειας της δασύτητας του διπλού κλειστού.

Λέξεις κλειδιά: Κυπριακή ελληνική, διπλά σύμφωνα, αρθρωτική φωνητική.

1. Purpose of the study[*]

The contrast between geminate and singleton consonants is usually defined in terms of differences in the duration of the consonant. However, for a variety of languages, research on singleton vs. geminate contrasts has suggested that the gemination contrast is not signalled solely by durational differences; rather, the phonetic implementation of gemination may involve additional language-specific acoustic properties such as temporal and non-temporal characteristics of the consonant *per se* as well as its adjacent vowels.

In the literature focusing particularly on the gemination contrast of voiceless stops, the duration of the closure (CD) is considered to be the primary cue to the contrast. For example, Abramson showed that, in Pattani Malay, longer CD was the main phonetic correlate for word-initial geminates both acoustically (Abramson 1998), and perceptually (Abramson 1986). However, phrase-initially, where the silent occlusion of stops is acoustically and perceptually non-detectable, listeners successfully distinguished singleton from geminate stops by relying on two secondary cues, namely, RMS amplitude of the syllable whose onset was the target stop (Abramson 1991), and fundamental frequency of the vowel following the word-initial stop (Abramson 2004). In Cypriot Greek, aspiration functions as a strong acoustic correlate of stop and affricate gemination (cf. e.g. Armosti 2011a and the relevant literature reviewed therein).

In languages that allow word-initial voiceless geminate stops, the acoustic duration of the closure cannot be perceptually detected after a pause (i.e. phrase-initially); thus, if there are no secondary acoustic cues to gemination (such as the above-mentioned acoustic correlates), the contrast can be expected to be acoustically and perceptually neutralised. However, recent studies have shown that, even though the gemination contrast is neutralised acoustically and perceptually (in cases that no significant secondary cues to gemination exist), *articulatorily* the distinction still holds in languages such as Tashlhiyt Berber (Ridouane 2007), Tarifit Berber (Bouarourou *et al*. 2008), and Swiss German (Kraehenmann and Lahiri 2007; 2008). In these articulatory studies, it was shown that word-initial geminates were systematically longer in their articulation than their singleton counterparts, both phrase medially and initially (despite of the fact that in the latter case there was no acoustic difference in duration between singleton and geminate stops). An equally important finding of those studies was that

---

[*]I am grateful to Francis Nolan, Elinor Payne, Mary Baltazani, as well as to the anonymous reviewer of this paper for their valuable comments and suggestions.

stops were longer in phrase-initial position than in phrase-medial, a finding that was interpreted as prosodic lengthening (and strengthening in cases whereby it involved more linguopalatal contact).

Payne (2006) also reported that the acoustic and articulatory implementation of gemination in Italian involved longer consonant duration as well as greater linguopalatal contact and the use of different regions of articulators. Based on these findings, Payne (2006) analysed gemination in Italian as a fortitional (i.e. strengthening) process. While fortition characterising the gemination contrast can be considered a phonological process, fortition governed by prosodic factors (such as position in the word or phrase, stress, and intonational focus) can be considered a phonetic process, which is expected to be operative across languages.

Thus, lengthening and strengthening effects of prosodic factors on stops are expected to manifest acoustically and articulatorily in Cypriot Greek also. Furthermore, these phonetic effects may interact with possible strengthening effects that may accompany the phonological contrast of stop gemination. Since in Cypriot Greek, the gemination contrast of voiceless stops is acoustically and perceptually maintained even in absolute initial position because of the presence of long aspiration (which is a strong cue to gemination), it would be interesting to investigate whether the contrast is also articulatorily maintained phrase-initially (as was shown above for other languages).

These aspects of the articulation of CyGr stop gemination are investigated in this paper. In particular, the acoustic durational contrast between singleton and geminate stops is expected to be mirrored at the articulatory level in terms of the length of articulation, even in utterance-initial position. Furthermore, singletons and geminates are expected to differ not only durationally, but also spatially, i.e. in terms of the location, shape, and size of the linguopalatal contact. Finally, both singletons and geminates are expected to be longer and stronger in strong prosodic positions, such as utterance-initial position and when stressed.

2. Method

2.1. Electropalatography (EPG)

To obtain the desired articulatory information, Electropalatography (EPG) was used. EPG is an instrumental technique for recording information about the tongue's contact with the hard palate during speech. In EPG, the subject is required to wear a thin acrylic palate that is uniquely designed to fit the roof of their mouth; the artificial palate is embedded with electrodes, which serve as sensors for tongue contact (see e.g. Hayward 2000). Each time an electrode is contacted by the tongue, a complete electrical circuit is created and the contact is recorded. The EPG records can then be analysed by the researcher in order to trace the contact patterns and infer tongue movements.

The system used was WinEPG (Articulate Instruments Ltd, Edinburgh, UK). In this system, the electropalate contains eight rows of electrodes, six electrodes on the first row (the one behind the front teeth) and eight on each of the other seven rows, making a total of 62 electrodes. These electrodes are spaced between the point behind the top front teeth (where they meet the gum) and the back of the hard palate. Rows 1–4 correspond to the alveolar and post-alveolar region (rows 1–2 correspond roughly to the alveolar region while rows 3–4 to the post-alveolar region), while rows 5–8 correspond to the palatal and velar region.

2.2. Material

The material for the study consisted of four disyllabic words containing a word-initial alveolar stop; each token was a different combination of gemination (SING vs. GEM) and stress (unstressed vs. stressed) as shown in Table 1.

		unstressed	stressed
singleton	token	<ταϐή> [tɐˈʃi]	<τάμαν>[ˈtɐmɐn]
	gloss	*ground sesame*	*vow*
geminate	token	<τταβάς>[tʰːɐˈvɐs]	<ττάβλιν>[ˈtʰːɐvlin]
	gloss	*stew*	*backgammon*

Table 1 The tokens used in the EPG study.

2.2.1. Carrier Phrase

The carrier phrase used was 'Come on, tell him ___ and it's enough' (<Άτε, πε του ___ τζαι κανεί.> = [ˈɐtɛ pɛ tu ___ t͡ʃɛ kɐˈni]).[1] By using this phrase, the target alveolar stop would be in utterance-medial and intervocalic position. In order to obtain the target stop in utterance-initial position, the same carrier phrase was used, but without its first part preceding the token: '___ and it's enough' (<___ τζαι κανεί.> = [___ t͡ʃɛ kɐˈni]).

2.3. Speaker

The speaker was YP, a male native speaker of Cypriot Greek from Nicosia, aged 23 at the time of the test. YP reported no speech impairments.

2.4. Procedure

2.4.1. Presentation of material

The test sentences containing the tokens under investigation were presented to the subject on a PC screen, one at the time (filler sentences were also used).

The material was presented in Greek spelling (see §2.2), using unofficial conventions for representing the sounds of Cypriot Greek that do not exist in Standard Greek (cf. Armosti *et al.* this volume). For instance, the caron (ˇ) was used in order to represent post-alveolar sounds (e.g. <ď> symbolises [ʃ]).

The subject was asked to produce each test sentence five times at a normal rate of speech. Thus, 40 repetitions were produced in total (2 levels of gemination × 2 levels of stress × 2 levels of utterance position × 5 repetitions). Time was provided prior to the recording for the subject to become accustomed to the palate.

2.4.2. Recording

The EPG recording took place in the sound-treated booth of the University of Cambridge, using the WinEPG system. The palate was scanned for tongue-to-palate information regarding electrode activation at a sampling interval of 10 ms. At the same time, the audio signal was recorded at 22.05 KHz sampling rate and 16 bit sample width.

2.5. Analysis

The analysis of articulatory data was done with the Articulate Assistant software (version 1.12). The acoustic data analysis was done with the PRAAT speech processing software using annotated text files and PRAAT scripts.

2.5.1. Measurements

Both temporal and spatial properties of the target segments were measured. In particular, the properties measured were the following:

---

[1] High vowels in word-final position often undergo lenition or deletion in CyGr (cf. Eftychiou 2008). However, in the tokens recorded for this study, the [u] in [tu] was never deleted (something that would have resulted in unwanted concatenation of two [t] sounds).

Temporal properties:
  (i)   The articulatory closing duration (Cld) of the stop. Cld was defined as the time interval from the first frame in which linguopalatal contact would occur before the consonant burst, until the first frame that full closure would be attained. In utterance-medial position, the stop was preceded by a vowel, an environment that often resulted in some amount of linguopalatal contact during the preceding vowel (as a coarticulatory effect from the previous consonant), and therefore there was no frame preceding the closing phase of the target stop for which the linguopalatal contact would be zero. In such cases, the onset of the closing phase was defined as the frame between the preceding vowel and the stop's full closure for which linguopalatal contact would be at its minimum.
  (ii) The articulatory seal duration (Sld) of the stop. Sld was defined as the period for which full closure of the stop was attained. Its onset coincided with the offset of the closing phase; the offset of Sld coincided with the acoustic burst observed in the waveform and spectrogram.
  (iii) The articulatory release duration (Rld) of the stop. Rld was defined as the time interval from the burst until the frame for which the linguopalatal contact would reach its minimum.
  (iv) The acoustic duration of the after closure time (ACT) as defined in Armosti (2011a). Here it coincides with aspiration.

Spatial properties:
  (v)   The amount of contact measured at the frame with the maximum electrode activation during the seal phase of the stop. It was measured as the percentage of electrodes activated in that frame for two areas:
    (a) the constriction area for the alveolar stop, defined as the first four rows from the front of the palate (R1–4).
    (b) the whole palate.
  (vi) The location, size, and shape of the contact. These properties were investigated mainly by visual comparison of the frames at which maximum contact was attained. The contact patterns can provide information about the location of contact on the passive articulator, and also can be suggestive of the involvement of the active articulator (cf. Pandeli 1993, 18–34). Apart from contact patterns, the depth of constriction was taken into account in order to extrapolate tongue configurations (after Payne 2000, 217; 2006, 88; cf. also Eftychiou 2004, 69). For instance, a depth of one row located at the front of the electropalate suggests an apical articulation, while a depth of 3 of 4 rows can be interpreted as an apico-laminal or laminal articulation.

2.5.2.   Statistics

Usually, in studies with many subjects, each subject is an experimental unit. In the present study there was only one subject due to the difficulty in finding subjects willing to undergo such a procedure; another equally restricting factor was the financial cost of creating artificial palates. Therefore, the experimental unit cannot be just one subject; instead, the individual repetitions served as the experimental unit, something that inevitably reduces the power of the statistical analysis (Cho and Keating 2001). Therefore, the results of the statistical analysis should not be treated as the basis of definite conclusions or generalisations.

Taking these caveats into account, six analyses of variance (ANOVA) were performed using the SPSS statistical software package. In each test, the dependent variable was one of the following:(i) the duration of the closing phase, (ii) the duration of the seal phase, (iii) the duration of the release phase, (iv) the after closure time (ACT), (v) the percentage of contact at the constriction area, and (vi) the percentage of contact for the whole palate. The two variables involving percentages were first transformed using the rationalised arcsine transformation, so as to become suitable for entering the statistical analysis (see Armosti 2010 for further particulars on this transformation method); all other variables were normalised into z-scores. The independent variables were three: (i) Gemination, with two levels (singleton vs. geminate), (ii) Stress (stressed vs. unstressed), and (iii) Position (utterance-initial vs. utterance-medial).

3. Results

3.1. Temporal parameters

3.1.1. **Closing duration**

The average closing duration of geminates and singletons was virtually the same (61 ms and 65 ms respectively), and was not affected by Stress. The position in the utterance was the only factor that played a significant role in the length of the closing phase of the stop, as utterance-initially the closing phase was 41 ms longer than utterance-medially [$F(1, 22) = 19.875$, $p < .0005$]; however, this result must be treated with some caution due to the difference in defining the beginning of the closing movement in the two positions in the utterance (see §2.5.1 above). No interactions were significant.

3.1.2. **Seal duration**

All three factors exhibited significant main effects on the duration of the seal phase. Geminates had longer Sld than singletons by 42 ms on average. In stressed syllables, Sld was 22 ms longer than in unstressed syllables.

factor	level	*M* (*SD*)	difference	significance
Gemination	SING	93 (45.7)	42	$F(1, 22) = 18.612$, $p < .0005$
	GEM	135 (28.6)		
Position	utterance-medial	85 (32.6)	58	$F(1, 22) = 34.446$, $p < .0005$
	utterance-initial	143 (28.8)		
Stress	unstressed	103 (48.9)	22	$F(1, 22) = 4.906$, $p = .037$
	stressed	125 (37.5)		
Gemination × Position				$F(1, 22) = 0.681$, $p = .418$
Gemination × Stress				$F(1, 22) = 4.984$, $p = .036$
Position × Stress				$F(1, 22) = 0.07$, $p = .793$
Gemination × Position × Stress				$F(1, 22) = 0.268$, $p = .61$

Table 2 Results for seal duration.

Regarding the Position factor, the Sld was on average 58 ms longer utterance-initially than utterance-medially. As shown in

Table 3, geminates had significantly longer Sld in both utterance positions—even though in utterance-initial position Sld is unperceivable.

Position	SING	GEM	difference	significance
utterance-initially	126 ms	160 ms	34 ms	$F(1, 12) = 5.19$, $p = .042$
utterance-medially	60 ms	111 ms	50 ms	$F(1, 10) = 19.261$, $p = .001$

Table 3 Comparison of geminate and singleton Sld in the two utterance positions.

The interaction between Gemination and Stress was significant, thus, it was explored further using a simple main effects analysis of the Sld within each level of the Stress factor. The results showed that in unstressed syllables geminates had significantly longer Sld by 64 ms [$F(1, 10) = 22.64$, $p = .001$]; geminates had longer Sld than singletons in stressed syllables, but this difference (20 ms) was non-significant.

3.1.3.   Release duration

In the case of the release phase, Gemination was the only factor that showed significant main effects, with geminates having longer Rld than singletons by 37 ms on average. There was a significant interaction between Gemination and Stress: a simple main effects analysis showed that the distinction in Rld between singletons and geminates was maintained in the unstressed condition[2] $[F(1, 10) = 33.977, p < .0005]$, but not in the stressed condition $[F(1, 12) = 2.577, p = .134]$.

3.1.4.   After closure time

Gemination was the only factor that showed significant main effects on ACT (as was the case with Rld), with geminates having longer ACT than singletons by 62 ms $[F(1, 22) = 326.343, p < .0005]$.

3.2.   Spatial parameters

3.2.1.   Amount of contact

3.2.1.1   Amount of contact at the constriction area

In the case of the amount of contact at the constriction area (i.e. R1–4), no factor had significant main effects at $\alpha = .05$; however, the Gemination × Position interaction was significant $[F(1, 22) = 5.066, p = .035]$. A simple main effects analysis showed that the difference in the amount of contact between singletons and geminates was significant only utterance-medially, with geminates activating more electrodes than singletons by 10% on average $[F(1, 10) = 10.809, p = .008]$. In utterance-initial position, the production of singletons activated all electrodes in the constriction area at the frame of maximum contact, whereas the geminate activated only 88% of electrodes; this was an unexpected finding, however, this difference was non-significant $[F(1, 12) = 1.240, p = .287]$.

3.2.1.2   Amount of contact for the whole palate

The results for the amount of contact for the whole palate showed significant main effects of the Position factor only $[F(1, 22) = 6.480, p = .018]$, with consonants in utterance-initial position having more linguopalatal contact (80%) than consonants in utterance-medial position (71%). This can be regarded as a strengthening effect caused by the position of the consonant in the utterance.

3.2.2.   Location, size, and shape of contact

The location, size, and shape of contact are presented graphically using representative palatograms for each combination of the Gemination, Stress, and Position factors. In each case, two palatograms are presented: (i) an average palatogram of the seal phase and (ii) the palatogram at the frame of maximum contact. The palatograms for the seal phase represent the percentage of activation of each electrode over time averaged over all repetitions of the token; this percentage is indicated in the figures both numerically and by shades of grey (the darker the shade, the higher the percentage). The palatogram showing the frame of maximum contact was the one with the largest amount of electrode activation of all frames out of all repetitions of the token. Contact patterns and shapes will be analysed following Pandeli (1993) and Payne (2000; 2006).

---

[2] As the anonymous reviewer suggests, the Rld of [t] in [tɐˈʃi] may shorten due to the onset of approximation for the upcoming [ʃ] —whereas in [tʰːɐˈvɐs] the labiodental uses an independent articulation, thus not influencing the Rld of [tʰː]. This discrepancy may be causing the significant difference in Rld between the unstressed [t] and [tʰː].
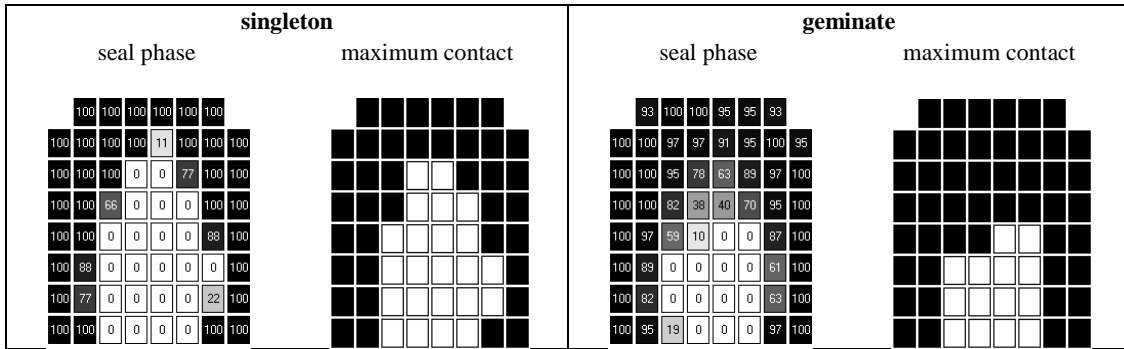
Figure 1 Palatograms of unstressed singletons and geminates utterance-medially.

In the utterance-medial unstressed case shown in

Figure 1, geminates showed more linguopalatal contact than singletons. Regarding the location of contact, for singletons, the main constriction lay along the first two rows (with R1 showing more contact than R2) indicating a possible apical articulation; in the case of geminates, the occlusion occurred at the first four rows, something that could indicate an apico-laminal articulation. The firm contact at the two lateral columns for both singletons and geminates could correspond to a 'cupped' (concave) tongue configuration, a shape of contact that is compatible with the apical and apico-laminal interpretation of the contact patterns.

In the utterance-medial stressed case (

Figure 2) both singletons and geminates exhibited slightly more contact when stressed than when unstressed. The stressed singletons showed a somewhat deeper contact than the unstressed singletons, something that could be interpreted as a more laminal contribution to the articulation. Regarding any differences between singletons and geminates, the geminates showed more contact at rows R3 and R4 (as was the case in the unstressed condition). These results are very similar with the findings of Payne (2006, 90–91) regarding word-initial voiceless stops in phrase-medial position.
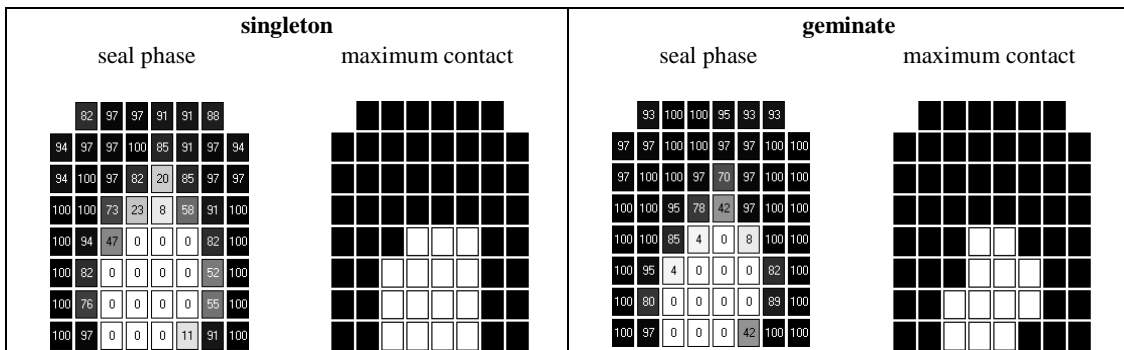

Figure 2 Palatograms of stressed singletons and geminates utterance-medially.
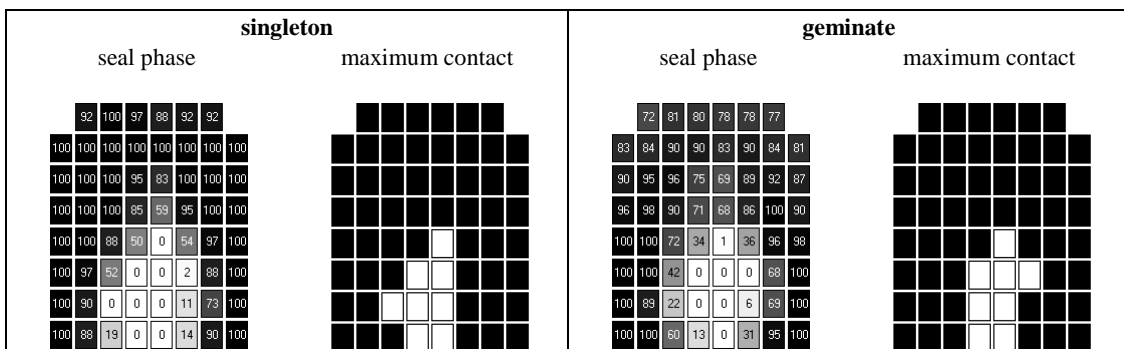

Figure 3 Palatograms of unstressed singletons and geminates utterance-initially.

The difference between the singleton and geminate palatograms in the utterance-initial unstressed case was reduced compared to the utterance-medial case, as shown in

Figure 3. Regarding the size of the contact, considerably more electrodes were activated utterance-initially than utterance-medially especially at the anterior area: for both singletons and geminates, the whole constriction area (R1–4) was completely occluded at the frame of maximum contaxt (cf. §3.2.1.1), while R5 showed substantial electrode activation (a finding that could be interpreted as a more laminal contribution to the articulation of the consonants in utterance-initial position). These patterns observed in the palatograms of maximum contact were reflected also in the palatograms showing mean electrode activation during the seal phase. This was especially true for the singleton, for which the frame of maximum contact was very similar with the average patterns shown in the seal phase palatogram (arguably due to the short duration of the singleton's seal phase, something that reduced contact pattern variation). In the case of the geminate, the increased length of its seal phase resulted in more variation of contact patterns both within the seal phase and across repetitions. This variation is reflected in the relatively lower average percentages of electrode activation observed in the palatogram of the average seal phase patterns for the geminate. These low percentages should not be interpreted as incomplete constriction in the case of the geminate (actually all tokens exhibited complete constriction), but rather as a reflection of contact pattern variation within and across tokens.

In the case of the utterance-initial stressed consonants, the palatograms shown in

Figure 4 revealed slightly more linguopalatal contact in terms of the size of the contact compared with their unstressed counterparts. The reduced percentage of electrode activation at the anterior area for the geminates was due to a particular repetition that showed no contact in the first two rows, i.e. the articulation was arguably purely laminal. Concerning the location of the contact, singletons and geminates were similar in showing complete occlusion along the first four rows.
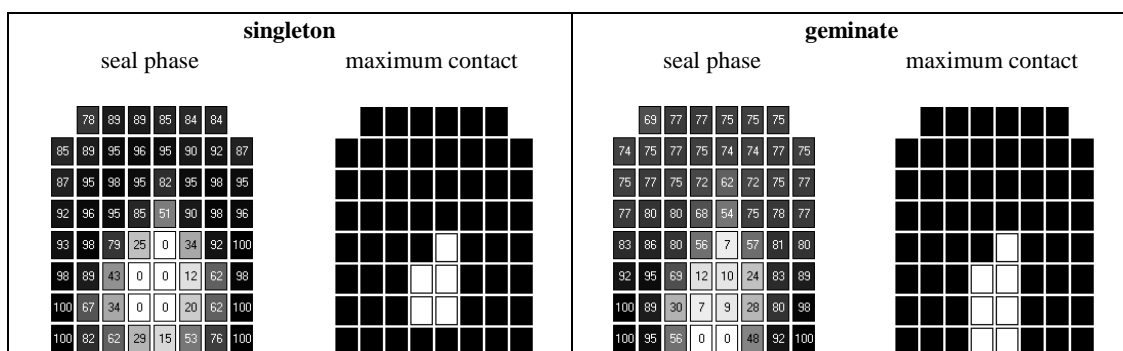

Figure 4 Palatograms of stressed singletons and geminates utterance-initially.

These findings revealed a strengthening effect (i.e. more linguopalatal contact) of the Gemination, Position, and Stress factors: geminates were stronger than singletons, segments in utterance-initial position were stronger than those in utterance-medial position, and stressed segments were stronger than unstressed segments.

3.3.   Gemination as a function of both Stress and Position

The comparison between geminates and singletons for each combination of the Position or the Stress factors was very revealing regarding the location and shape of the contact; this comparison would be revealing in the case of the rest of the variables also.

In the case of the utterance-medial unstressed segments, the geminate differed from the singleton with respect to three properties: (i) ACT, with geminates exhibiting 56 ms longer ACT than singletons; (ii) Sld; and (iii) Rld (in the latter two cases the difference was 67 ms).
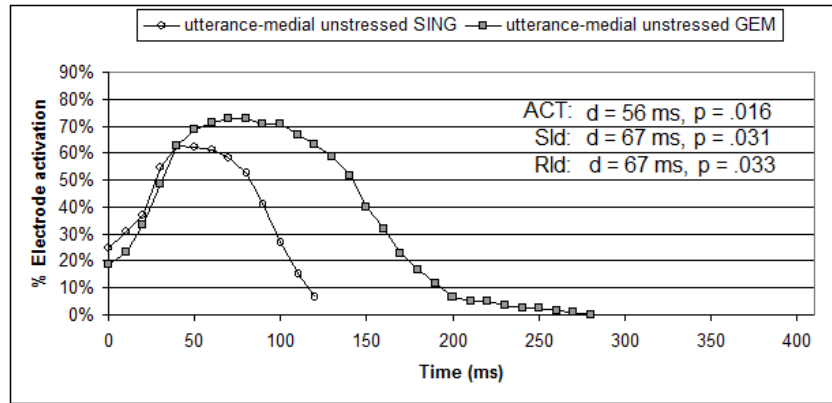
Figure 5 Average distributions of electrode activation over time
for the utterance-medial unstressed singleton and geminate.

[Note: The additional information in graphs 5–8 shows the variables for which the difference (*d*)
between the geminate and the singleton is significant in the specific Stress and Position conditions.]
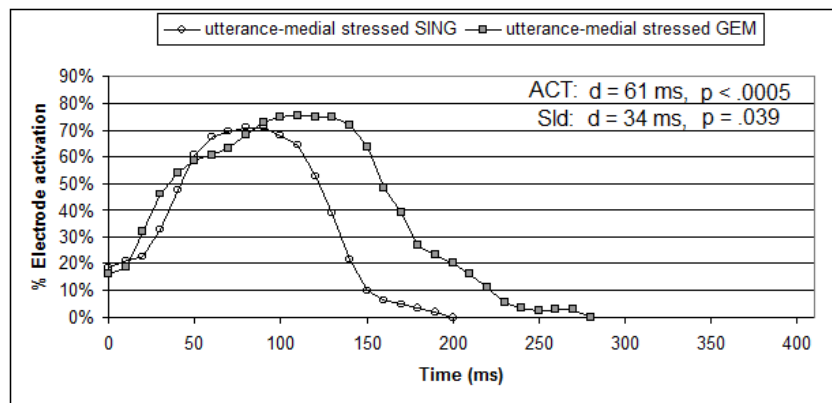

Figure 6: Average distributions of electrode activation over time for the utterance-medial
stressed singleton and geminate.

A visual comparison of Figures 5 and **6** immediately reveals a lengthening effect of stress on the utterance-medial singleton (stress increased total articulatory gesture by 67%, Sld by 86%, and Rld by 58%), but not so much on the geminate (total articulatory gesture and Sld were virtually unaffected by stress; stress caused only Cld to increase by 62%). This strengthening of the singleton resulted in a small reduction of its difference from the geminate, as only two properties showed significant differences between the two segments:[3](i) ACT, which was longer for the geminate; and (ii) Sld, which was longer for the geminate.

In the case of the unstressed segments in utterance-initial position (Figure 7), both the singleton and the geminate were substantially longer than their utterance-medial counterparts. The geminate remained statistically distinct from the singleton: the same three properties that differentiated it from the singleton in utterance-medial position (ACT, Rld, and Sld) kept the two unstressed segments distinct utterance-initially as well.

---

[3] An additional property that could arguably distinguish geminates from singletons utterance-medially is the acoustic duration of the closure (CD); however, because CD was not possible to measure utterance-initially, it was excluded from the analysis of both positions.
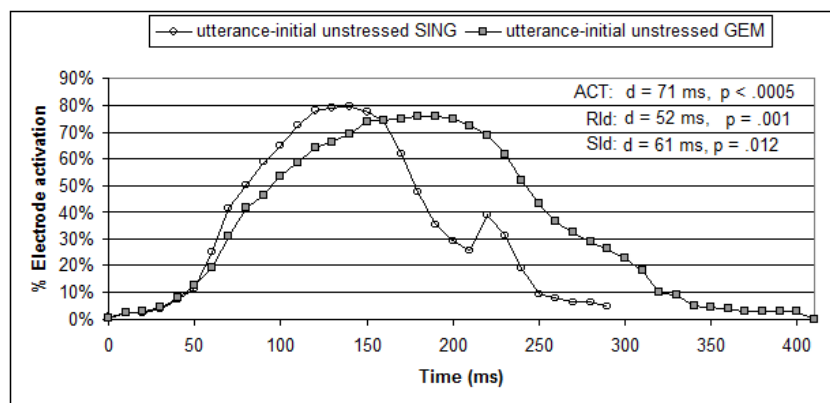
Figure 7: Average distributions of electrode activation over time
for the utterance-initial unstressed singleton and geminate.

In the utterance-initial stressed case, the two curves in Figure 8 were very similar. No articulatory property showed any significant difference between the two segments; only the acoustic variable, namely ACT, distinguished geminates from singletons, with geminates exhibiting longer ACT than singletons.
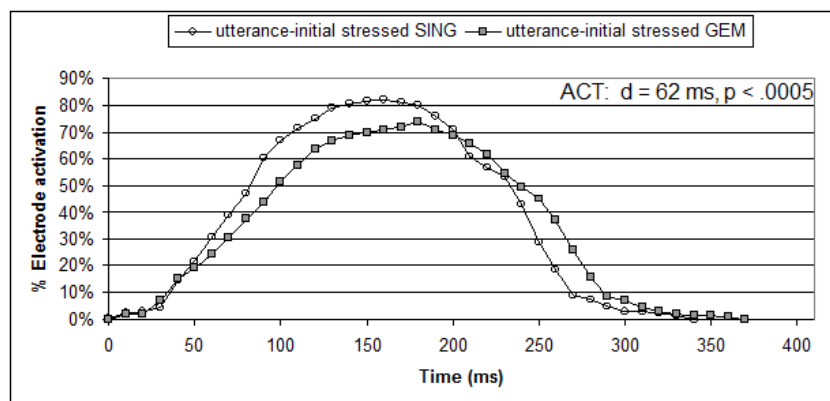

Figure 8: Average distributions of electrode activation over time
for the utterance-initial stressed singleton and geminate.

4. Discussion

The present study aimed to investigate the articulatory differences between word-initial singleton and geminate alveolar stops in relation to stress and their position in the utterance. The main hypothesis was that, in utterance-initial position, where the acoustic closure cannot be perceptually detected, the articulation of the geminates would still be distinct from that of singletons. This hypothesis was partially supported by the results of the present study: while in utterance-medial position the articulatory gestures of the two segments were durationally distinct in both stress conditions, in utterance-initial position they were distinct only when unstressed. In other words, in prosodically dominant conditions (i.e. in utterance-initial position and when stressed) the oral articulation of geminates was virtually the same as that of singletons. This finding is peculiar considering that, in Italian for instance, the same prosodic conditions actually enhanced the gemination contrast (Payne 2006). However, Kraehenmann and Lahiri (2008) found that in Swiss German, like in Cypriot Greek, the articulatory difference between geminates and singletons decreased utterance-initially (but, unlike Cypriot Greek, the contrast was never articulatorily neutralised).

This articulatory neutralisation of the singleton vs. geminate contrast in stressed utterance-initial position can be accounted for in terms of the strength of the Stress and Position factors. Consonants in domain-initial position undergo strengthening of their oral articulation, as shown in studies for a number of languages, (see e.g. Cho and Keating 2001 for Korean). Cypriot Greek is no exception

regarding domain-initial strengthening (and lengthening): utterance-initial stops, when compared with utterance-medial stops, exhibited more linguopalatal contact over the whole palate, and longer Cld and Sld. Stress was a second factor that caused strengthening and lengthening effects on stops. Such effects of stress on alveolar stops were also found to occur in Italian (Payne 2006). In the present study, the presence of stress caused a lengthening of the stop's seal duration. The combination of the levels of Position and Stress can be thought to result in lengthening and strengthening of the segments in a somewhat cumulative manner.

This gradient increase in length and strength resulted in the articulatory neutralisation of the gemination contrast observed in the graphs of section 3.3, wherein the segments became articulatorily longer and stronger according to the following order of conditions: utterance-medial unstressed < utterance-medial stressed < utterance-initial unstressed < utterance-initial stressed. In the utterance-medial unstressed case, i.e. the weakest one, the difference between singletons and geminates was maximised. In the utterance-medial stressed case, the singleton lengthened more than the geminate, a fact that reduced the articulatory difference between them (especially at their release phase); however, the difference between the geminate and singleton seal duration was still significant. In the utterance-initial unstressed case, the singleton showed a substantial increase in duration and in the amount of linguopalatal contact; nevertheless, the articulatory difference between the singleton and geminate was not reduced compared with the utterance-medial unstressed case, as the geminate showed a substantial lengthening as well. In the utterance-initial stressed case, i.e. the strongest one, the geminate could not increase in length or strength any further, as approximately 350–400 ms length and 80% amount of contact over the whole palate appear to be the limits of the stop's enhancement by Stress and Position—limits which had already been reached in the utterance-initial unstressed case. The singleton had reached the 80% limit of the amount of contact in the utterance-initial unstressed case, hence it could not strengthen either, but there was room for more lengthening. Thus, the singleton in the utterance-initial stressed case reached the length limit too, and the two segments became articulatorily indistinguishable.

Despite that articulatory neutralisation, the difference between geminates and singletons could be acoustically (and perceptually) maintained in all cases, as the ACT of geminates was always longer than the ACT of singletons. Thus, even though the singleton~geminate contrast was articulatorily marked in most cases by means of oral articulations, the laryngeal articulation of the stops was the only consistent property in maintaining the contrast: after the stop's burst, the glottis was kept spread for longer in the case of the geminate than in the case of the singleton. This finding could be potentially interpreted as an indication that the contrast is not one involving gemination, but rather aspiration. However, since this neutralisation occurred in only one prosodic condition (i.e. in utterance-initial, stressed condition), while in the (admittedly less rare) utterance-medial position the gemination contrast was articulatorily maintained by means of more than one cues (unrelated to aspiration), it cannot be concluded that the contrast is one of aspiration throughout all cases. Besides, when all cues are available in the signal, the duration of the closure is too important an acoustic cue not to be considered central to the contrast (as shown in Armosti 2011a). Furthermore, in the perceptual study of Armosti (2010) it was shown that closure duration is a very important perceptual cue to CyGr gemination. Finally, aspiration as a cue is not incompatible with a gemination analysis, because, as argued by Armosti (2011b), aspiration is shown in many occasions to correlate with phonological weight.

The observation that geminates are not always distinct from singletons in terms of their oral articulation, and that the difference between the two segments is reduced in stronger combinations of Stress and Position, could be interpreted as an indication that the target oral gesture of singletons and geminates is the same, but articulatory undershoot takes place for weaker consonants (i.e. singletons, unstressed consonants, and consonants in utterance-medial position); because the oral gestures for weaker consonants are executed in less time, the contact with the palate can be incomplete, the occlusion (Sld) and release (Rld) shorter. This aspect is worth investigating in the future.

5. Conclusions

The EPG investigation of word-initial geminate and singleton alveolar stops revealed that even in utterance-initial position, where the closure is unperceivable, geminates were still articulatorily longer than singletons. However, this was true only in the unstressed case, as stress and utterance position seem to have enhancing effects on the duration and strength of the consonants.

These enhancing effects of stress and utterance position indicate that there can be some gradience in the binary geminate~singleton contrast, in the sense that the length and strength of the stops are

susceptible to these prosodic factors; a consequence of this gradience is the articulatory neutralisation of the geminate~singleton contrast under the combined influence of stress and utterance position. Nevertheless, the contrast is always preserved acoustically (and perceptually) by means of the duration of the stop's aspiration.

References

Abramson, Arthur S. 1986. "The perception of word-initial consonant length: Pattani Malay." *Journal of the International Phonetic Association*16: 8–16.

Abramson, Arthur S. 1991. "Amplitude as a Cue to Word-Initial Consonant Length: Pattani Malay." In *Proceedings of the 12th International Congress of Phonetic Sciences* (Aix-En-Provence, France, 19–24 August 1991), 98–101.

Abramson, Arthur S. 1998. "The complex acoustic output of a single articulatory gesture: Pattani Malay word-initial consonant length." In *Papers from the Fourth Annual Meeting of the Southeast Asian Linguistics Society, 1994*, edited by U. Warotamasikkhadit & T. Panakul, 1–20. Tempe, Arizona: Program for Southeast Asian Studies, Arizona State University.

Abramson, Arthur S. 2004. "Toward prosodic contrast: Suai and Pattani Malay." In *Proceedings of the International Symposium on tonal aspects of languages: Emphasis on tone Social Sciences*, B. Bel & I. Marlien, 1–4. Beijing, China: The Institute of Linguistics, Chinese Academy of Social Sciences.

Armosti, Spyros, Marianna Katsoyannou, Kyriaki Christodoulou, and Charalambos Themistocleous. this volume. Τάσεις των Κυπρίων ως προς τη γραπτή απόδοση των μεταφατνιακών συμφώνων της κυπριακής. *Proceedings of the 10th International Conference of Greek Linguistics*.

Armosti, Spyros. 2010. "The perception of plosive gemination in Cypriot Greek." In *On-line Proceedings of the 4th International Conference of Modern Greek Dialects and Linguistic Theory*, edited by A. Ralli, B. D. Joseph, M. Janse, & A. Karasimos, 33–53.

Armosti, Spyros. 2011a. "The phonetics of plosive and affricate gemination in Cypriot Greek." Ph.D. diss., University of Cambridge.

Armosti, Spyros. 2011b. "Aspiration and gemination in Modern Greek varieties: the case of Cypriot Greek." In *Νεοελληνική Διαλεκτολογία* 6. Athens: Athens Academy.

Bouarourou Fayssal, Béatrice Vaxelaire, Rachid Ridouane, Fabrice Hirsch, and Rudolph Sock. 2008. "Gemination in Tarifit Berber: X-ray and acoustic data." *Proceedings of the 8th International Seminar on Speech Production* (Strasbourg, 8–12 December 2008), 117–120.

Cho, Taehong, and Patricia A. Keating. 2001. "Articulatory and acoustic studies of domain-initial strengthening in Korean." *Journal of Phonetics*29: 155–190.

Eftychiou, Eftychia. 2004. "A phonetic investigation of Cypriot Greek consonants in connected speech." M.Phil. diss., University of Cambridge.

Eftychiou, Eftychia. 2008. "Lenition Processes in Cypriot Greek." Ph.D. diss., University of Cambridge.

Hayward, Katrina. 2000. *Experimental phonetics*. England: Pearson Education Ltd.

Kraehenmann, Astrid, and Aditi Lahiri. 2007. "Non-neutralizing quantity in word-initial consonants: articulatory evidence." In *Proceedings of the 16th International Congress of Phonetic Sciences*, edited by J. Trouvain & W. Barry, 465–468.

Kraehenmann, Astrid, and Aditi Lahiri. 2008. "Duration differences in the articulation and acoustics of Swiss German word-initial geminate and singleton stops." *Journal of the Acoustical Society of America* 123(6): 4446–4455.

Pandeli, Helen. 1993. "The articulation of lingual consonants: an EPG study." PhD diss., University of Cambridge.

Payne, Elinor. 2000. "Consonant gemination in Italian: phonetic evidence for a fortition continuum." Ph.D. diss., University of Cambridge.

Payne, Elinor. 2006. "Non-durational indices in Italian geminate consonants." *Journal of the International Phonetic Association* 36(1): 83–95.

Ridouane, Rachid. 2007. "Gemination in Tashlhiyt Berber: an acoustic and articulatory study." *Journal of the International Phonetic Association* 37: 119–142.