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THE ACOUSTIC CHARACTERISTICS OF GEMINATE CONSONANTS IN CYPRIOT GREEK

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ΠΕΡΙΛΗΨΗ

Η παρούσα μελέτη εξετάζει πειραματικά ορισμένα ακουστικά χαρακτηριστικά των διπλών συμφώνων της κυπριακής και τα συγκρίνει με αυτά των αντίστοιχων μονών. Τα σύμφωνα εξετάστηκαν σε περιβάλλον μεταξύ φωνηέντων σε δισύλλαβα ΣΦΣ(Σ)Φ ζευγάρια ελάχιστης αντίθεσης, τα οποία εμφανίζονταν σε προτάσεις μεταφορείς, και τονίζονταν είτε στην παραλήγουσα είτε στη λήγουσα. Οι προτάσεις διαβάστηκαν από τέσσερις φυσικούς ομιλητές της κυπριακής, επτά φορές σε τυχαία σειρά. Το υλικό ψηφιοποιήθηκε και καταγράφτηκαν διάφορες ακουστικές μετρήσεις, από τις οποίες φαίνεται καθαρά ότι ανεξάρτητα από τη θέση του τόνου, τα διπλά σύμφωνα της κυπριακής διακρίνονται από τα μονά χάρη στη συστηματικά μεγαλύτερη διάρκειά τους. Υπάρχουν επιπλέον και άλλα χαρακτηριστικά που διακρίνουν τα διπλά από τα μονά σύμφωνα. Αυτά είναι τόσο ακουστικά, όπως η παρουσία δασύτητας στα διπλά στιγμιαία, όσο και προσωδιακά, όπως η διαφορετική επιτονική ευθυγράμμιση. Αντίθετα, η επίδραση των διπλών στη χρονοργάνωση των γειτονικών φωνηέντων δεν αποδείχθηκε σημαντική, όπως αναμενόταν από παρόμοιες έρευνες σε άλλες γλώσσες με διπλά σύμφωνα.

1.INTRODUCTION

In Cypriot Greek (henceforth CYG), both voiceless obstruents and sonorants contrast in terms of length, in word-initial and word-medial intervocalic position, as in the minimal pairs [ˈpɛfti] ‘Thursday’ *vs*. [ˈpːɛfti] ‘s/he falls’ and [ˈɛvɐlɛn] he put’ *vs*. [ˈɛvɐlːɛn] ‘he was putting’[1]. Impressionistic descriptions of the acoustic properties of these sounds and discussion of their phonological status have been presented in the past, by Newton (1972), Charalambopoulos (1982) and Malikouti-Drachman (1987). These studies mention that geminates in CYG are generally longer in duration and that the geminate stops in particular are heavily aspirated. However, so far the only study that examines the Cypriot geminates acoustically is Arvaniti (1999), which deals exclusively with sonorants. Here we replicate Arvaniti’s study with new materials and speakers, and we extend her investigation by including not only sonorants but also stops, fricatives and affricates in our corpus, as well as two different stress conditions.

2. METHOD

2.1 Materials

The target segments (see Table 1) were in intervocalic position in disyllabic words, that formed minimal (or near minimal) pairs depending on whether the intervocalic

[1]Geminates can also be found postlexically, as in the example /tin ˈmilɐ/ ‘the fat’ *acc*. where the preceding [n] assimilates totally to the following [m] thus creating a geminate [mː], [tiˈmːilɐ]. These postlexical geminates are not part of this study.

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consonant was single or geminate. Half of these minimal pairs were stressed on their first syllable and the other half on their final syllable. The vowels preceding and following the target consonants were not controlled across test-words, but they were the same for each set of four test-words with the same intervocalic segment. The test-words were embedded in the carrier phrase: ['ipɛndu______ksɐfni'kɐ 'tʃɛfiɛn] 'she or he said to him ______ suddenly and left'.

Table 1: The test-words and their glosses.

	Penultimate stress				**Final stress**			
	Singleton		**Geminate**		**Singleton**		**Geminate**	
	Test word	**Gloss**	**Test word**	**Gloss**	**Test word**	**Gloss**	**Test word**	**Gloss**
/p/	'pɐpɐ	'pope'	'mɐpːɐ	'ball'	pɐ'pɐ	'daddy'	lɐ'pːɐ	'boiled rice'
/t/	'kɔtɐ	'hen'	'kɔtːɐ	'knock' *imp.*	pɔ'tɐ	'drinks'	kɔ'tːɐ	's/he knocks'
/k/	'fɐkɐ	'mouse trap'	'fɐkːɐ	'hit' *imp.*	kɐ'kɐ	'bad' *neut. pl.*	fɐ'kːɐ	's/he hits'
/s/	'pisi	'persuade' *subj.*	'pisːi	'stingy' *acc.*	mi'si	'half' *fem.*	ki'sːi	'ivy' *pl.*
/ʃ/	'xɐʃɐ	'being baggy'	'ɐʃːɐ	name of village	pɐ'ʃɐ	'fat' *fem.*	ɐ'ʃːɐ	'skin bags'
/tʃ/	'fitʒɐ	'sea weed'	'fitʃːɐ	'show off'	si'tʃɐ	'fig tree'	vi'tʃːɐ	'horse whipping'
/m/	'sɐmu	'Samos' *gen.*	'ɐmːu	'sand' *gen.*	pɐ'mu	'rest' *gen.*	mɐ'mːu	'midwife'
/n/	'kɐni	'it-does'	'kɐnːi	'gun barrel'	kɐ'ni	'enough'	kɐ'nːin	'shin'
/l/	'milɐ	'apples'	'milːɐ	'fat' *n.*	mi'lɐ	's/he speaks'	pi'lːɐ	surname
/r/	'vɐɾɐ	'beat' *imp.*	'mbɐrːɐ	'rod'	vɐ'ɾɐ	's/he beats'	fɐ'rːɐ	'pasture'

2.2 Speakers and Procedure

The sentences were read by four native speakers of CYG, three speakers from Nicosia and one from Larnaca; the former (two males, KR and DF, and one female, SP) were in their thirties, the latter (AY) was in her early twenties. The speakers read the sentences seven times from typed cards placed in random order. Speakers KR and AY were recorded in the anechoic chamber of the Cambridge University Phonetics Laboratory; DF and SP were recorded in a sound-treated booth of a Nicosia television station. The materials (all on digital tape) were re-digitized and spectrographically analyzed at the Ohio State University Phonetics Laboratory using Waves$^+$ on a Solaris Unix workstation.

2.3 Measurements and statistical analysis

Several measurements were obtained from simultaneous spectrographic and waveform displays. Here we present results from the following:

- The duration of the test consonant
- The duration of the preceding vowel
- The alignment of a L tone with regard to the test consonant (see below).

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The duration measurements followed standard criteria of segmentation (Naeser, 1970; Peterson & Lehiste, 1960). Separate measurements were taken for closure and VOT in stops, and for closure and fricated release in affricates. For word-initial stops (which were *not* target segments) VOT was included in the duration of the following vowel.

L tone alignment was effectively the distance (in ms) of a F0 dip (a putative L tone) from the onset of the target consonant, in test-words with final stress that showed the L+H accent found in both Standard and Cypriot Greek. Only test-words with intervocalic sonorants (/m, n, l/) were included for this measurement, as sonorants present smooth F0 contours that allow for reliable measuring. More specifically, Arvaniti & Ladd (1995) and Arvaniti *et al.* (1998) have shown that in Standard Greek the L tone of a bitonal L+H pitch accent phonetically aligns just before the onset segment of the stressed syllable it is phonologically associated with. Our aim was to see (a) whether similar alignment obtains in CYG, which has a similar type of L+H pitch accent, and (b) whether the presence of a geminate (which is phonologically seen as ambisyllabic; Malikouti-Drachman, 1987) would affect the alignment of the L tone. Concretely, we hypothesized that in test-words stressed on their final syllable and accented with a L+H pitch accent, the L tone would align with the onset of the singletons (which is also the onset of the syllable), but with the middle of the geminates (since the geminates are ambisyllabic). Thus, if L tone alignment differed depending on whether the intervocalic consonant was a singleton or a geminate, then tonal alignment could serve as a cue to gemination.

The quantified data for each target consonant were statistically analyzed by means of 3-way analyses of variance (speaker × segment type [single/geminate] × stress [stressed/unstressed]).

3. RESULTS

3.1 Target segment duration

STOPS AND AFFRICATES: Mean closure durations of the stops and the affricate are shown in Figure 1, separately for the two stress conditions. The closure duration for the geminates was longer than that of their singleton counterparts by approximately 36%; this difference was statistically significant for all segments except /k/ [for /p/ $F(1,3)=15.69$, $p<0.03$; for /t/ $F(1,3)=26.48$, $p<0.01$; for /tʃ/ $F(1,3)=29.92$, $p<0.01$]. *Post-hoc* Scheffé tests showed that the non-significant result for/ k/ was due to speakers DF and SP, who had the same closure duration for the singleton and the geminate; the other two speakers, however, did have longer closure for the geminate ($p<0.01$ in both cases). In all cases stop closure was longer in stressed than in unstressed syllables [for /p/ $F(1,3)=79.36$, $p<0.002$; for /t/ $F(1,3)=79.91$, $p<0.002$; for /k/ $F(1,3)=25.36$, p<0.02l; for /tʃ/ $F(1,3)=23.96$, $p<0.02$].

VOT was considerably longer (by 84% on average) for geminates than for singletons [for /p/ $F(1,3)=25.51$, $p<0.01$; for /t/ $F(1,3)=29.6$, $p<0.01$], as can be seen in Figure 2. Again /k/ was an exception to this pattern. *Post-hoc* Scheffé tests showed that the non-significant result for/ k/ was due again to speakers DF and SP, who had the same VOT for the singleton and geminate /k/; the other two speakers, however, did have longer closure for the geminate ($p<0.001$ in both cases). This different result for /k/ may be due to the test-word [ˈfɐkɐ]: opinions among native speakers were divided as to whether this word had a single or geminate [k]. It is quite possible that DF and SP pronounced this word with a geminate [kː], thereby biasing the results.

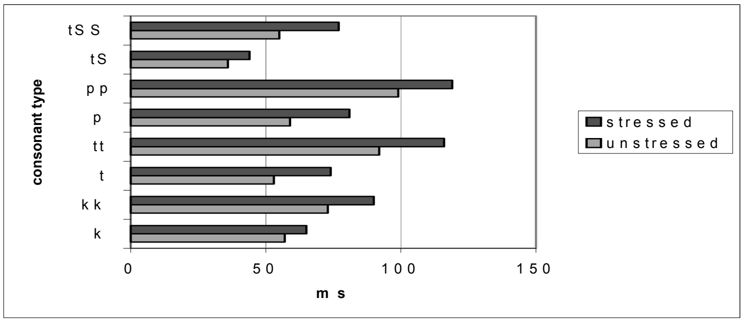

Figure 1. Mean closure durations for stops and the affricate /tʃ/; 'tS' and 'tSS' stand for [tʃ] and [tʃː] respectively.

Further, the VOT results of /p/ and /t/ showed interaction between stress and segment type [for /p/, $F(1,3)=11.42$, $p<0.04$; for /t/, $F(1,3)=22.5$, $p<0.01$]. *Post-hoc* Scheffé tests showed that the interaction was due to the fact that the VOT of the geminates was significantly lengthened in stressed syllables, while the VOT of the singletons remained unaffected. This result tallies with those reported for other languages, which show invariance of short-lag VOT—like that of the singleton CYG stop—in all contexts (e.g. Kessinger & Blumstein, 1997, for Thai and French; Fourakis, 1986, for Standard Greek).

Overall, our VOT results are consistent with previous impressionistic descriptions of CYG geminates as being heavily aspirated (Newton, 1972; Charalambopoulos, 1982). In addition, they show that geminate stops do not only have longer VOT than singletons, but also longer closure duration.

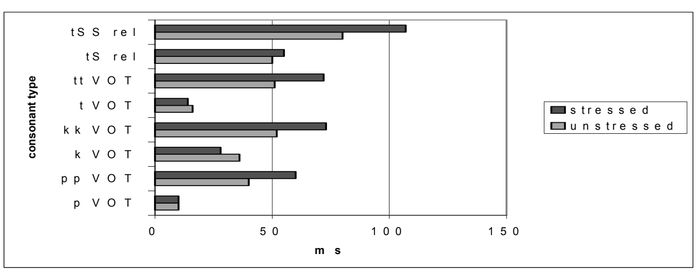

Figure 2. Mean VOT durations for stops and fricative portion for the affricate /tʃ/. As in Figure 1, 'tS' and 'tSS' stand for [tʃ] and [tʃː] respectively.

Finally, the fricative portion of the affricate /tʃ/ patterns exactly as the VOT of the voiceless stops: first, it is significantly longer for the geminate [tʃː] [$F(1,3)=22.58$, p<0.02]; second it exhibits interaction between consonant type and stress [F(1,3)=12.52, p<0.04], which is due to the fact that only the fricative portion of the geminate is lengthened in stressed syllables, while that of the singleton remains unaffected by stress (see also Figure 2).

SONORANTS: As shown in Figure 3, geminate sonorants were also longer than singletons by an average of 47%, a result similar to those reported by Arvaniti (1999) [for /m/ F(1,3)=95.62, p<0.002; for /n/ F(1,3)=12.13, p<0.04; for /l/ F(1,3)=281.38, p<0.001; for /r/ F(1,3)=157.5, p<0.001]. Stress, on the other hand, did not significantly affect the duration of the sonorants, except for /m/ [F(1,3)=13.06, p<0.04]; the other sonorants did show a trend in the same direction but without it reaching statistical significance. There were no interactions between stress and consonant type.

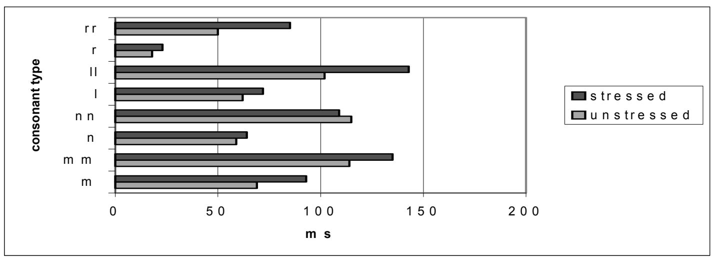

Figure 3. Mean durations of single and geminate sonorants, in stressed and unstressed syllables.

FRICATIVES: As shown in Table 2, the results for /s/ and /ʃ/ were consistent with those of the other target segments; that is, the geminates were significantly longer than the singletons by on average 24% [for /s/ F(1,3)=13.98, p<0.03; for /ʃ/ F(1,3)=311.42, p<0.001]. Unlike the sonorants, the fricatives were affected by stress, with both geminate and singleton fricatives being longer in stressed than in unstressed syllables [for /s/ F(1,3)=11, p<0.05; for /ʃ/ F(1,3)=14.77, p<0.03]. [

Table 2. Mean durations of single and geminate fricatives, in stressed and unstressed syllables.

	Geminate stressed	Singleton stressed	Geminate unstressed	Singleton unstressed
/s/	190	145	142	122
/ʃ/	170	138	148	93

3.2 Duration of preceding vowels

The complete set of vowel durations averaged across speakers is shown in Table 3. We found that even though there was a tendency for vowels to be shorter before geminates than singleton consonants, the effect was not consistent either within (or across) speakers or across consonant types. Specifically only the cases in bold and followed by an asterisk in Table 3 showed significant shortening of the vowel before a geminate consonant; and even these differences were not consistent across speakers and were in any case very small. These results agree with those of Arvaniti (1999), who also found that the geminates did not affect the duration of the vowel

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preceding them. On the other hand, they contrast with results for other languages, for which it has been reported that vowels consistently shorten before geminate consonants (most recently, Esposito and Di Benedetto, 1999, for Italian). Thus, the CYG data challenge the notion that preceding vowel duration is a cross-linguistically valid cue to geminate-singleton distinctions.

Table 3. Mean durations (in ms) and standard deviations for the vowels preceding the test-consonants.

Test Cons.	**Stressed vowels**				**Unstressed vowels**			
	Singleton		**Geminate**		**Singleton**		**Geminate**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
/p/	112.9	17.3	107.1	13.7	90.2	9.1	82.5	7.4
/t/	109.3	20	101.5	17.7	85.9	7.8	77.6	9.7
/k/	**107.2***	**16.8**	**100.7***	**12.9**	**95.4***	**10.7**	**84.5***	**12.9**
/tʃ/	82.4	11.7	82.3	16.8	57.8	10	82.4	11.2
/m/	**118.3***	**21.5**	**110.0***	**19.5**	**112.7***	**13.6**	**106.1***	**6.4**
/n/	132.3	21.6	121.3	18.6	98.2	9.9	101.5	11.8
/l/	92.6	14.2	94.5	15.3	75.5	15.3	83	16.9
/r/	**153.2***	**23.2**	**139.6***	**25.8**	**139.2***	**17.3**	**106***	**13.5**
/s/	98.6	17.1	80.2	12.0	92.4	25.3	65.1	13.5
/ʃ/	112.9	14.9	126.9	25.7	97.5	14.1	98.7	9.5

3.3 Tonal Alignment

The tonal alignment results confirmed our hypothesis, by showing that in words with intervocalic geminate sonorants (/m, n, l/) in stressed position the L tone aligned on average 34 ms *after* the onset of the geminate, whereas in words with intervocalic singletons, L aligned on average 9 ms *before* the onset of the consonant. The two types of alignment are illustrated in Figure 4. This finding lends support to the view that geminates in CYG do not function as simple onsets of a stressed syllable but are ambisyllabic, playing the role of both coda to the preceding syllable and onset to the following one.

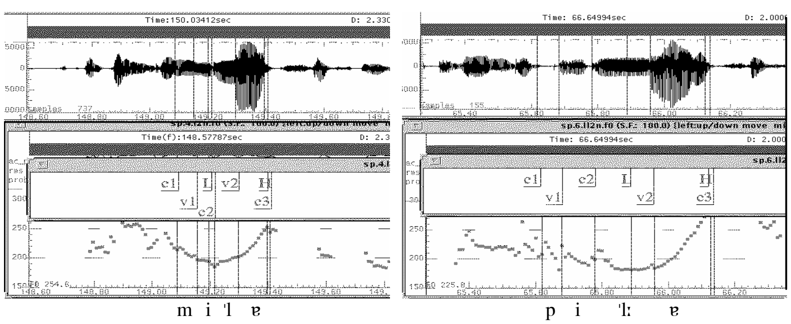

Figure 4. Low tone alignment. The vertical lines marked *c1*, *v1*, *c2*, *v2*, *c3* demarcate the onset of the named segment in the test-words. The line marked *L* shows the position of the L tone of the L+H pitch accent.

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3.4 Some additional observations

Our data also showed that there must be additional cues to gemination, although we do not currently have quantitative data to support this observation. However, we did note that single stops and affricates were often lenited intervocalically, while the geminates never did. For instance, in Figure 5 the closure for the singleton intervocalic [tʃ] in the word [si'tʃɐ] 'fig tree' is weakly voiced throughout; in contrast, the closure for the geminate [tʃ:] in the word [vi'tʃ:ɐ] 'horse whipping' is almost completely voiceless. We can also observe in Figure 5 that the fricative portion for the geminate affricate [tʃ:] is not only longer but also has much higher amplitude than that of the singleton; this difference is suggestive of a more fortis articulation for the geminate.

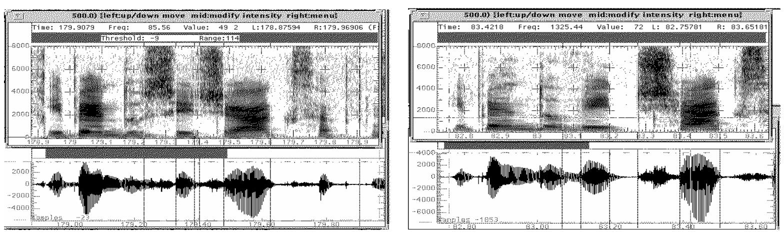

Figure 5. Left: voicing during closure in the singleton affricate [tʃ].
Right: amplitude increase in fricative release of the geminate affricate [tʃ:].

4. DISCUSSION AND CONCLUSION

In this study we have shown that there are clear durational differences between geminate and single consonants in CYG, with geminates being consistently longer than the singletons, irrespective of stress. For stops, in particular, this lengthening affects both closure duration and VOT; thus the results partly vindicate Newton (1972) and Charalambopoulos (1982), who described the geminate Cypriot stops as aspirated, but also show that aspiration is not the only correlate of gemination in Cypriot Greek stops; i.e. these consonants cannot be simply described as "aspirated".

We have also found a possible additional cue for geminates in accented syllables, namely the considerably later alignment of the L tone with respect to the onset of the accented syllable when the onset consonant is a geminate. On the other hand, we did not find evidence for a consistent effect of the geminates on the duration of the preceding vowel, unlike studies in other languages with geminate consonants. Taken together these results appear somewhat contradictory, in that the alignment data imply that geminates are ambisyllabic (c.f. Malikouti-Drachman, 1987), whereas the vowel duration data suggest the opposite. We believe that the answer lies in the phonology on the geminates, specifically in the fact that they are non-moraic yet long (Arvaniti & Tserdanelis, in prep.*a*).

Finally, we observed that there are possibly further cues to gemination, such as the intervocalic lenition of singleton stops and the higher amplitude of the fricative

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portion of the geminate affricate. We are currently in the middle of a more comprehensive acoustic analysis of this corpus of data (including spectral and amplitude measurements; Arvaniti & Tserdanelis, in prep.*b*), which we hope will shed further light onto the issue of the phonetic and phonological nature of Cypriot geminates in particular and geminate consonants in the world's languages more generally.

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REFERENCES

Arvaniti, A. 1999. Effects of speaking rate on the timing of single and geminate sonorants. *Proceedings of the XIVth International Congress of Phonetic Sciences*, vol. 1: 599-602. San Francisco.

Arvaniti A. & Ladd, D. R. 1995. Tonal alignment and the representation of accentual targets. *Proceedings of the XIIIth International Congress of Phonetic Sciences*, vol. 4: 220-23. Stockholm.

Arvaniti, A., Ladd, D. R. & Mennen, I. 1998. Stability of tonal alignment: the case of Greek prenuclear accents. *Journal of Phonetics* 26, 3-25.

Arvaniti, A. & G. Tserdanelis in preparation *a*. Cypriot Greek and the phonetics and phonology of geminates.

Arvaniti, A. & G. Tserdanelis in preparation *b*. On the acoustics of geminates: evidence from Cypriot Greek.

Charalambopoulos, A. 1982. Συμφωνικός «διπλασιασμός» και δασύτητα στην Κυπριακή [Consonant "doubling" and aspiration in Cypriot] (in Greek). *Studies in Greek Linguistics* 3, 237-255.

Esposito. A. & Di Benedetto 1999. Acoustical and perceptual study of gemination in Italian stops. *Journal of the Acoustical Society of America* 106: 2051-2062.

Fourakis, M. 1986. An acoustic study of the effects of tempo and stress on segmental intervals in Modern Greek. *Phonetica* 43: 172-188.

Kessinger, R. H. & Blumstein, S. E. 1997. Effects of speaking rate on voice-onset time in Thai, French and English. *Journal of Phonetics* 25: 143-168.

Malikouti-Drachman, A. 1987. Η αντιπροσώπευση των διπλών συμφώνων στα νέα ελληνικά [The representation of double consonants in Modern Greek] (in Greek). *Studies in Greek Linguistics* 8, 275-291.

Naeser, M. 1970. Criteria for the segmentation of vowels on duplex oscillograms. Technical Report No. 124, Wisconsin Research and Development Center for Cognitive Learning.

Newton, B. 1972. *Cypriot Greek: Its Phonology and inflections.* The Hague: Mouton.

Peterson, G. E. & Lehiste, I. 1960. Duration of syllable nuclei in English. *Journal of the Acoustical Society of America* 32, 693-703.