The perception of plosive gemination in Cypriot Greek

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1. Purpose of the study

Cypriot Greek plosive and affricate geminates are rather unusual, as they are distinguished from singletons by both longer closure (i.e. the universal cue to gemination) and longer release. This situation caused a recent debate in the literature on which of the two is the main cue to gemination of Cypriot Greek plosives and affricates. Arvaniti and Tserdanelis (2000) argued that the duration of the closure (CD) serves as a salient cue to gemination (as is the case with other geminating languages, such as Italian and Turkish), while aspiration (Asp) was considered to be an enhancing cue (p. 562). Similarly, Muller (2001) regarded CD as the primary correlate to gemination in Cypriot Greek, with aspiration as a secondary cue, albeit a very important one. Botinis et al. (2004) also concluded that gemination is mainly achieved by an increase in CD, combined with an increase in aspiration. Christodoulou (2007), on the other hand, suggested that aspiration is the main cue to gemination of stops in Cypriot Greek, while closure duration is a secondary cue; this claim is based on the fact that the closure is inaudible phrase-initially, yet minimal pairs of word-initial geminate stops are robustly distinguished in phrase-initial position.

Most of the aforementioned studies were acoustic studies, therefore the cues to which they referred were *acoustic* cues; if one is to make any claims about the *perception* of those cues, this should only be done based on a perceptual study. Botinis et al. did conduct a perceptual study (along with their main acoustic one), which showed that aspiration was a robust perceptual cue to gemination in utterance-initial position. In this specific case, the absence of the CD cue (since it is unperceivable utterance-initially) makes aspiration the only audible cue to gemination; but this is not a definite proof that, in cases where the duration of the closure is in fact perceivable (like word-internally), aspiration is still the *main* perceptual cue to gemination. Actually, words with initial geminates are far fewer than words with internal geminates, a fact that makes the scenario of word-initial geminates appearing in phrase-initial positions unusual. Thus, in the vast majority of the occurrences of geminate stops, the closure is actually perceivable.

Muller did test the perception of word-initial gemination both in utterance-initial position and intervocalically, but her results should be treated with caution due to a fatal flaw in the design of the experiment regarding the stimuli selected. In her experiment the subjects heard the first syllable plus the lateral of the words /**tɛˈll**ɐɾɔn/ ‘*frame*’ and /**ttɛˈll**i̯ɐzzɔ/ ‘I wire’ (among others) and had to discern whether the syllable came from the one or the other word. Those test syllables were heard in utterance-initial position and in utterance-medial position, and it was hypothesised that in utterance-medial position (where both CD and Asp are present) the gemination contrast would be better perceived than in utterance-initial position (where the CD cue is perceptually absent). The results showed that there was no difference between the two positions, as in both cases the discrimination between singletons and geminates was very clear (something that implies that the presence or absence of the CD cue does not make a difference). However, the lateral in the second word undergoes palatalisation, hence the two test syllables [**tɛlː**] and [**t**$^{\mathbf{h}}$**ːɛʎː**] did not differ only with regard to their stop, but also with regard to the lateral. Thus, the listeners could distinguish the two syllables aided by an additional cue, that of the palatal lateral. This shortcoming means that the results regarding the perception of coronal gemination (and the perceptual primacy of Asp over CD) are not reliable.

A better way for a study to compare the perceptual weight of the closure vs. aspiration would be to test the target stops in word-internal position (so as to ensure that both cues are present) and to manipulate the duration of their closure and aspiration in order to explore the difference in perception that this durational alteration would cause (something that was not done in the previous studies). Such a perceptual study is the subject of this paper. In the sections that will follow, the design and conduct of the perceptual experiment will be presented, followed by the results and their analysis, which will lead to the discussion of the main question of this paper, namely what the relative perceptual importance of the various cues to gemination of Cypriot Greek stops is.

2. Method

In order to test the perceptual correlates of the gemination of word-internal stops, tokens of such stops were manipulated to produce stimuli with various durations of their closure and aspiration; these stimuli were then listened to by native speakers of Cypriot Greek, who were asked to respond whether they heard a singleton or a geminate stop.

The creation of the stimuli, the procedure of the test, and the analysis to which the results of the study were subjected, are presented in this methodological section.

2.1. Material

For the creation of the stimuli of the perceptual study, tokens of minimal pairs which differed in containing word-internal singleton or geminate stops were recorded. The method of recording these test tokens will be presented first.

2.1.1. Recording the test tokens

2.1.1.1. Test sentences

Two words forming a minimal pair based on the quantity of the alveolar stop they contained served as tokens for the recordings. The reason for the selection of only one place of articulation was to confine the resulting stimuli to a reasonable number, in order for the perceptual study not to become particularly long in duration, and hence tiring for listeners. The alveolar place of articulation was chosen as an intermediate point between the extremes of the labial and velar place. The tokens for the recording were the words [ˈpitɐ] (i.e. 'hose' imperative, singular) and [ˈpitʰːɐ] (i.e. 'pie'). The two tokens were embedded in a carrier phase as shown in Table 1.

Table 1: *The two test sentences*.

Test sentence 1	Εν είπα «πίτα», είπα «ράντισε».				
	ˈ	ˈ	ˈ	ˈ	ˈɾɐ
	εn	ipɐ	pitɐ	ipɐ	ndisɛ
	l	s	h	s	sp
	EG	aid-I	ose	aid-I	ray
	I didn't say 'hose', I said 'spray'.				
Test sentence 2	Εν είπα «πίττα», είπα «κκέικ».				
	ˈ	ˈ	ˈ	ˈ	ˈcʰː
	εn	ipɐ	pitʰːɐ	ipɐ	εik
	l	s	p	s	ca
	EG	aid-I	ie	aid-I	ke
	I didn't say 'pie', I said 'cake'.				

2.1.1.2. Speaker

The speaker recorded was EE, a female speaker of 'urban' Cypriot Greek from Nicosia (see Terkourafi, 2004, for the description of the urban variety of Cypriot Greek), who was a student at the University of Cambridge. At the time of the study she was 26 years old and had been living in the UK for four years. EE did not report any speech or hearing disorders.

2.1.1.3. Procedure of recording

Written instructions in Cypriot Greek were given to the speaker along with the two test sentences. The speaker was instructed to produce the sentences six times as naturally as possible at a convenient rate of speech, without accelerating.

The recording, which lasted about fifteen minutes, took place in the sound-insulated booth of the Phonetics Laboratory, University of Cambridge. The speaker was recorded using a Sennheiser, model MKH 40 P48, condenser microphone with cardiod characteristics and a Symetrix SX 202 microphone amplifier. The audio signal was recorded to hard disk through the line input of the audio interface of a Silicon Graphics O2+ workstation. The application software used for recording was Silicon Graphics' 'mediarecorder' configured for wav format, 22.05KHz sample rate and 16 bit sample width.

2.1.1.4. Stimuli

The stimuli for the perceptual study were created from the recordings of EE. From the test sentences of Table 1 only the first clause before the pause, i.e. 'I didn't say *pít(t)a*', was used as stimulus; this way the only element that would differentiate the two sentences would be the quantity of the alveolar stop in *pít(t)a*.

Of the two versions of the first clause, the one containing the singleton stop was selected, and, with the use of PRAAT scripts, the 'duration tier' (in PRAAT terminology) of the stop was manipulated to lengthen the closure duration of [t] by increments of 30 ms, in order to produce four stimuli ranging from 30 ms to 120 ms. The duration of the aspiration of each of these stimuli was manipulated again, in order to produce four stimuli of increasing duration of aspiration by steps of 20 ms, thus ranging from 10 ms to 70 ms. In manipulating the aspiration of the stops, the burst (i.e. approximately the first 10 ms of aspiration) was left intact, thus only the rest of the aspiration was manipulated durationally. With the manipulation of CD and Asp, 16 stimuli were created, one for each combination of CD and aspiration steps.

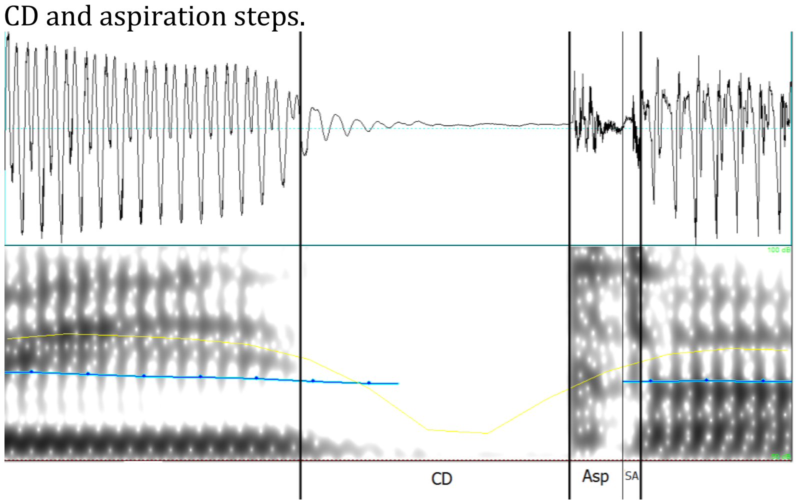

Figure 1: *The original singleton /t/ that served as the basis for the SING-set.*

If the only cues to gemination were to be found in the time domain, then the set of stimuli created would suffice to investigate the perception of those cues. However, in Armosti (2009) it was shown that, acoustically, there were non-durational cues to gemination, such as the intensity of aspiration. Therefore, by selecting the singleton stop to manipulate, there could be some bias caused by the intensity of the singleton stop. In order to account for the non-durational cues found within the consonant, a second set of stimuli was created, this time from the geminate stop,[23] by decreasing the duration of the closure and the aspiration in the reverse of what was done in the case of the first set of

[23] Apart from the spectral differences observable in Figures 1 and 2, the mean aspiration intensity was somewhat lower for the geminate (67 dB) than for the singleton (71 dB).

stimuli (the burst was again left intact). The set of stimuli created from the singleton stop will be hereafter referred to as 'SING-set', while the set created from the geminate stop will be referred to as 'GEM-set'.

A caveat should be mentioned regarding the naturalness of the two sets of stimuli: the spectral characteristics of the aspiration of the singleton (cf. Figure 1) are different from the spectral characteristics of the aspiration of the geminate (cf. Figure 2), thus any lengthening of the aspiration of the singleton would still result in aspiration which would be spectrally different from the aspiration of the geminate. The same holds for shortening the aspiration of the geminate: however short its aspiration may become, it would still carry some spectral characteristics of geminate aspiration, such as differences in high frequency noise. In this sense, an artificial conflict between the duration of the aspiration and its spectral properties is created in some cases. This unnaturalness of those stimuli should be taken into account in analysing the results.

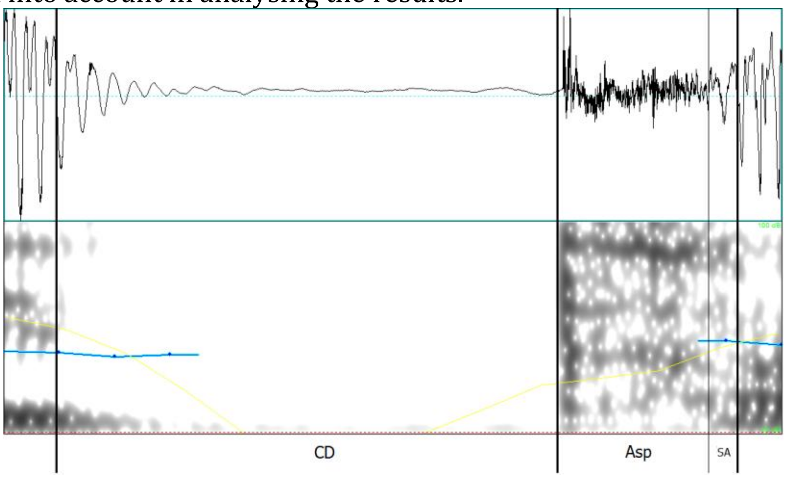

Figure 2: *The original geminate /tt/ that served as the basis for the GEM-set.*

Regarding the four steps of the manipulated CD and Asp, the reason for selecting the ranges 30 ms – 120 ms for the closure and 10 ms – 70 ms for the aspiration was that those ranges largely coincided with the respective ranges of closure and aspiration duration, as measured for the acoustic study of Armosti (2009) in the case of the word-medial unstressed alveolar stop: 35 ms – 125 ms for CD and 9 ms – 74 ms for aspiration. A graphical representation of these ranges can be seen in Figure 3.

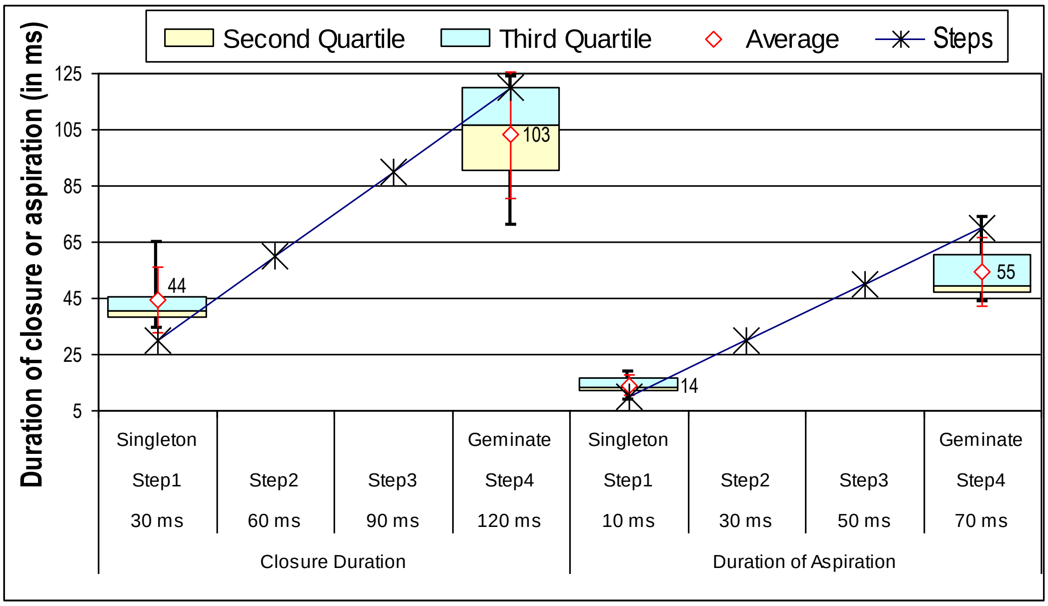

Figure 3: *The range of CD and Asp from the acoustic study of Armosti (2009) compared accordingly to the four steps of the stimuli of the present perceptual study.*

[Note: The thinner red lines within the box plots indicate a 95% Confidence Interval for the mean; the thicker lines outside the boxes show the first and fourth quartiles]

The 32 stimuli created (2 sets × 4 CD steps × 4 Asp steps) were subjected to one last manipulation: using PRAAT scripts, the manipulated consonant [t$^{(h)}$(ː)] of each stimulus was extracted and inserted in a single carrier phrase, namely 'I didn't say *píta*', in the place of the singleton alveolar stop of that phrase. The reason for this splicing was to eliminate, in the case of the 'GEM-set' of stimuli, any cues to gemination coming from the surrounding vowels (e.g. V1 or V2 duration, pitch, and formants), and, therefore, to concentrate on the properties of the consonant *per se.*

2.1.1.5. Listeners

The subjects of this perceptual study were 14 female and 16 male native speakers of Cypriot Greek. Their age range was from 21 to 34 (M = 26, SD = 2.9). The vast majority of the subjects were from Nicosia (N = 25); three were from Larnaca and two from Limassol. Most of the listeners were regular residents of Cyprus, while a few were students at the University of Cambridge at the time of the experiment. None of the subjects reported any hearing disorders.

2.1.2. Procedure

The experiment was designed using the DMDX Display Software and run on a portable computer. The task was preceded by an introduction, which aimed to familiarise the subjects with the procedure.

2.1.2.1. Presentation of stimuli

During the introductory phase of the experiment, two scenarios were presented in writing to the subjects, one for each test sentence (all the instructions were written in Cypriot Greek). For the '*píta*' case, the scenario was the following:

Maria told Costas to spray the flowers with water. Instead, Costas hosed the flowers forcefully and broke them.

Subsequently, the whole '*píta*' test sentence of Table 1 was heard, as the reply of Maria to Costas: 'I didn't say *hose*, I said *spray*'.

A different scenario was presented in writing for the '*pítta*' case:

Maria told Costas to bring her a cake. Instead, Costas brought her a pie.

Following the written scenario, the '*pítta*' test sentence was heard, again as the reply of Maria to Costas: 'I didn't say *pie*, I said *cake*'.

After the presentation of the two scenarios, the subjects were informed that for the rest of the experiment they would only listen to the first half of what Maria said, i.e. the stimulus 'I didn't say *pít(t)a*', and would have to select what the second half was accordingly (see the complementary phrases of Table 2).

The purpose of this design was to induce the subjects to concentrate on the meaning and not so much on the phonetic form; by presenting the two complementary phrases of Table 2 (and not the stimuli *per se* in written form) as the two choices, the subjects would never see the crucial geminates written anywhere. Instead, they would hopefully think in terms of the complementary phrase primed by the stimulus.

Table 2: The stimuli and their primed responses.

stimulus	complementary phrase
I didn't say 'hose'	I said 'spray'
I didn't say 'pie'	I said 'cake'

Following the introduction, a small practice session consisting of six randomly pre-selected stimuli was run. The aim of this session was to familiarise the subjects with the procedure and not with the stimuli; in order to ensure that, this practice session was kept small, and no feedback was provided for the answers the subjects gave.

2.1.2.1. Experimental task

During the actual experiment, the 32 stimuli were randomised in a block, which was presented five times, each time with a different randomisation.

The subjects were asked to identify the stimulus they heard by selecting one of the two complementary phrases (see Table 2) that appeared on the screen immediately after the stimulus was played. Five seconds were provided for the subjects to respond by pressing one of two buttons on the keyboard to indicate their answer; if the subjects did not answer within the five seconds, the program would automatically continue with the next stimulus. After the subjects' response (or after five seconds had elapsed), one second of silence (during which the screen was cleared) followed before the next stimulus was played.

The stimuli were automatically randomised within the five blocks every time the experiment was run. Hence, there were 5 repetitions × 4 steps of CD × 4 steps of Asp × 2 SING/GEM sets = 160 repetitions. The subjects were allowed to have a short break after every block. The total time of the experiment was approximately 15 minutes.

2.2. Analysis

The raw results of the experiment were exported from DMDX in the form of a delimited text file, which was subsequently opened in MS Excel 2003 for processing.

2.2.1. Measurements

Two different measurements were taken for each repetition of the stimuli: (i) the kind of answer the subjects gave, and (ii) their response time. It is hypothesised that the stimuli that would sound more unnatural would require more time for the subjects to respond.

2.2.2. Statistics

The statistical analysis was run in SPSS. The variables and further particulars of the various analyses will be presented before each statistical test in the results section.

3. Results

Two main tests were performed in order to investigate the factors that played a role in the perception of gemination: (i) a Multivariate Analysis of Variance (MANOVA), which tested both the responses and the reaction times of the subjects, and (ii) a logistic regression, in order to determine a descriptive model for the perception of the various cues to germination.

3.1. MANOVA for responses and reaction times

3.1.1. Test variables

'Gemination scores' (see below for its calculation) and reaction times (RT) were the two dependent variables for the MANOVA. The independent variables were: (i) the closure duration, with four levels corresponding to the four steps (30 ms, 60 ms, 90 ms, and 120 ms), (ii) the duration of aspiration, with again four levels for the four steps (10 ms, 30 ms, 50 ms, and 70 ms), and (iii) the 'origin' with two levels, i.e. the SING-set and GEM-set of stimuli.

The 'gemination scores' were initially calculated as the percentage of identification of a stimulus as geminate out of its five repetitions; if a subject did not respond in time for a certain repetition of the stimulus, that repetition was not counted towards calculating the percentage. However, expressing the variable as percentages makes it unsuitable for statistical analysis, as proportional scales are not normally distributed around the mean. Studebaker (1985) proposed a data transformation especially for proportional scales (like the ones found in acoustic and perceptual studies, as he notes), which normalises the data, and hence makes them suitable for statistical analysis. This method is based on arcsine transformation, with a further linear transformation to make the transformed units numerically close to the original percentages (and thus easier to interpret than mere arcsine units). Studebaker named this method 'rationalized arcsine transform', and the units 'rationalized arcsine units' (rau).

The second dependent variable, i.e. reaction times, had to undergo a transformation also, as its distribution across the three dependent variables was skewed, therefore not normal. A power transformation was used in order to reduce the skewness of the data, and thus allow it to be used in the statistical analysis.[24]

3.1.2. General findings

The multivariate tests indicated that all three factors (Asp, CD, and Origin) significantly influenced the way the listeners responded to the stimuli [$F(6, 1856) = 115.324$ for CD, $F(6, 1856) = 144.578$ for Asp, $F(2, 927) = 305.771$ for Origin; $p < .0005$ in all cases]. As shown from their F values, the effect of CD and Asp on the two dependent variables was nearly the same. The univariate results for the two dependent variables will be presented separately.

3.1.3. Gemination scores

The three factors played a significant role on the identification of the stimuli as geminate or singleton, as shown from the results of the univariate tests on the 'gemination scores' (see Table 3).

Table 3: *The results for the gemination scores*.

Factor	F value	significance
CD	$F(3, 928) = 366.274$	$p < .0005$
Asp	$F(3, 928) = 526.168$	$p < .0005$
Origin	$F(1, 928) = 584.038$	$p < .0005$
Origin × CD	$F(3, 928) = 23.114$	$p < .0005$
Origin × Asp	$F(3, 928) = 48.975$	$p < .0005$
CD × Asp	$F(9, 928) = 16.861$	$p < .0005$
Origin × CD × Asp	$F(9, 928) = 18.634$	$p < .0005$

It appears that, at the perceptual level, not only the duration of aspiration, but also the duration of the closure plays a significant role in distinguishing between singletons and geminates.

[24] As noted in the literature, distributions of response times tend to be L-shaped, i.e. right-skewed (see Bradley, 1975, 1982). Even though such skewed distribution is difficult to be normalised, Box and Cox (1964) proposed a family of power transformations for the normalisation of those distributions: the Box-Cox formula is $y = (x^{\lambda}-1)/\lambda$, where x is the original distribution, y the transformed one, and λ the power of the transform (the zero power is taken to be the log$x$ logarithm); the more the original distribution is skewed to the right, the smaller the value of λ must be to obtain a near-normal transformation. Even though Box and Cox provided a sophisticated way to calculate an optimal λ, for the current study the common practice of trial and error (aided by visual inspection of the transformed distributions) was followed until a suitable transformation was found.

Table 4: *Analysed percentages of geminate identification of the stimuli*.

		Duration of aspiration			
		10 ms	30 ms	50 ms	70 ms
CD	30 ms	2%	18%	43%	52%
	60 ms	1%	32%	62%	78%
	90 ms	12%	71%	86%	91%
	120 ms	49%	90%	95%	97%

[Note: The darker the cell of the table, the more the stimulus was identified as geminate.]

Actually, as shown in Table 4, when CD was at its minimum (30 ms), the identification of the stimuli as geminates did not exceed the chance level regardless of the length of their aspiration (only when Asp was at its maximum, i.e. 70 ms, did the gemination score reach the chance level). The same was true for when aspiration was at minimum, i.e. 10 ms.

As shown in Table 3, the origin of the stimuli (i.e. whether the stimuli were created from a singleton or a geminate stop) had a significant impact on the way the two sets of stimuli were perceived, and, moreover, it interacted with the other two factors. This finding suggests that the perceptual weight of the CD and Aspiration cues was different for the two sets of stimuli. Therefore, the two sets should be explored separately.

3.1.3.1. The SING-set of stimuli

An ANOVA test with 'gemination scores' as its dependent variable, and CD and Asp as the two independent variables, was performed for the SING-set of stimuli. Once again, the two factors and their interaction were highly significant, as shown in Table 5.

Table 5: *Results of the gemination scores for the SING-set of stimuli*.

Factor	*F* value	significance
CD	$F(3, 464) = 253.921$	$p < .0005$
Asp	$F(3, 464) = 127.456$	$p < .0005$
CD × Asp	$F(9, 464) = 12.658$	$p < .0005$

It appears that CD was more important than Asp in the case of the SING-set of stimuli (as indicated by the difference in the *F* values in Table 5). The same conclusion can be drawn from Table 6: for the two smallest values of CD, only one stimulus was identified as geminate above chance level (CD = 60 ms, Asp = 70 ms); the rest of those cases did not exceed 30%, regardless of the length of aspiration.

Table 6: *Analysed percentages of geminate identification of the SING-set of stimuli*.

		Duration of aspiration			
		10 ms	30 ms	50 ms	70 ms
CD	30 ms	3%	5%	5%	17%
	60 ms	1%	12%	27%	59%
	90 ms	9%	44%	71%	83%
	120 ms	40%	81%	91%	93%

Games-Howell post hoc tests showed that the four levels of the CD factor were significantly different from one another ($p < .0005$ in all cases). The same was found for the four levels of the Asp factor, the only exception being the 30 ms and 50 ms steps, for which the difference failed marginally to attain significance ($p = .05$).

3.1.3.2. The GEM-set of stimuli

As was the case with the SING-set, the results of the ANOVA test for the GEM-set of stimuli showed highly significant main effects for the two factors (see Table 7).

Table 7: *Results of the gemination scores for the GEM-set of stimuli.*

Factor	*F* value	significance
CD	$F(3, 464) = 118.784$	$p < .0005$
Asp	$F(3, 464) = 492.788$	$p < .0005$
CD × Asp	$F(9, 464) = 24.271$	$p < .0005$

Contrary to the SING-set case, for the GEM-set of stimuli the Asp factor played a greater role than the CD factor in geminate perception, as can be inferred from the *F* values in Table 7. This finding can be observed in Table 8, where only four out of 16 stimuli were not identified as geminates above chance level. Games-Howell post hoc tests for CD showed that there was no statistical difference between the steps 30 ms and 60 ms, and the same was found for the steps 90 ms and 120 ms ($p = .134$ and $p = .052$ respectively). In the case of the Asp factor, only the last two steps (i.e. 50 ms and 70 ms) were not statistically different one from the other ($p = .7$).

Table 8: *Analysed percentages of geminate identification of the GEM-set of stimuli.*

		Duration of aspiration			
		10 ms	30 ms	50 ms	70 ms
CD	30 ms	1%	31%	81%	88%
	60 ms	1%	53%	96%	97%
	90 ms	15%	99%	100%	100%
	120 ms	57%	100%	100%	100%

3.1.3.3. Comparison of the two sets of stimuli

The observed difference between the two sets of stimuli may be due to non-temporal cues to gemination that reside in the aspiration of the GEM-set (and the absence thereof from the SING-set), as shown in §2.1.2. Figures 5 and 6 below present two stimuli of the same duration of closure and aspiration (30 ms CD + 30 ms Asp) but of different origin (SING-set vs. GEM-set). A mere visual inspection of the two figures reveals spectral differences in the aspiration of the two stimuli. If indeed the spectral quality of the aspiration of the GEM-set of stimuli is characteristic for the aspiration of geminate stops, then the longer the aspiration, the more salient the cues to gemination possibly become. This postulation may serve as an explanation for the observed primacy of the Asp factor over the CD factor in the GEM-set of stimuli, and the reverse in the SING-set. Apart from aspiration *per se*, the spectral quality of the superimposed aspiration (SA)[25] was different for the two sets of stimuli, as shown in the Figures 5 and 6. SA was shown to be an important acoustic cue to gemination in Armosti (2009), thus it could play a role in the perception of gemination also.

The two sets of stimuli also differed in the intensity of their aspiration. As shown in Figure 4, the stimuli of the SING-set were of higher intensity than the stimuli of the GEM-set regarding the two smaller steps of Asp duration (10 ms and 30 ms). When the length of aspiration was 50 ms, the stimuli of the two sets were of virtually of the same intensity (approximately 64 dB). For the longest step of Asp duration (70 ms), the intensity of the aspiration of the GEM-set was higher than the intensity of the aspiration of the SING-set.

[25] SA may be seen as the overlap of aspiration with the following vowel, indicating breathy voice; for definition of SA, see Armosti (2009), Mikuteit and Reetz (2007), and Clements and Khatiwada (2007).

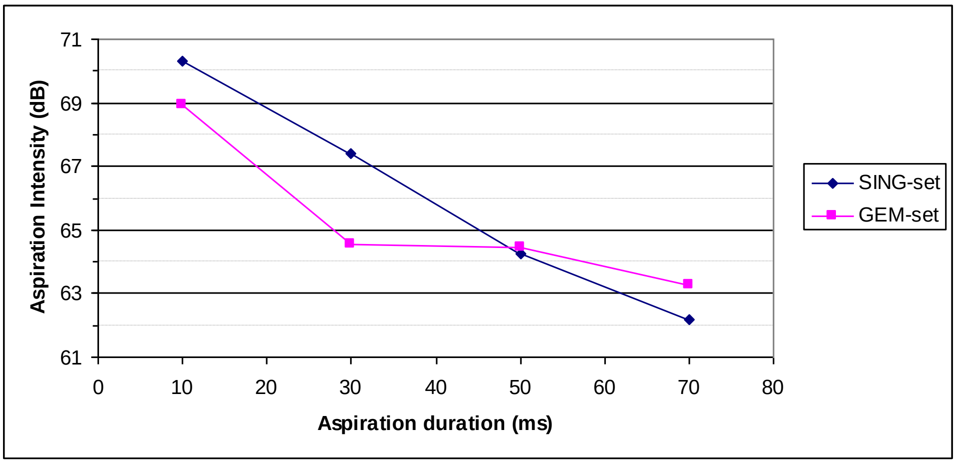

Figure 4: *The intensity of the aspiration of the stimuli as a function of the length of aspiration and the stimulus origin.*

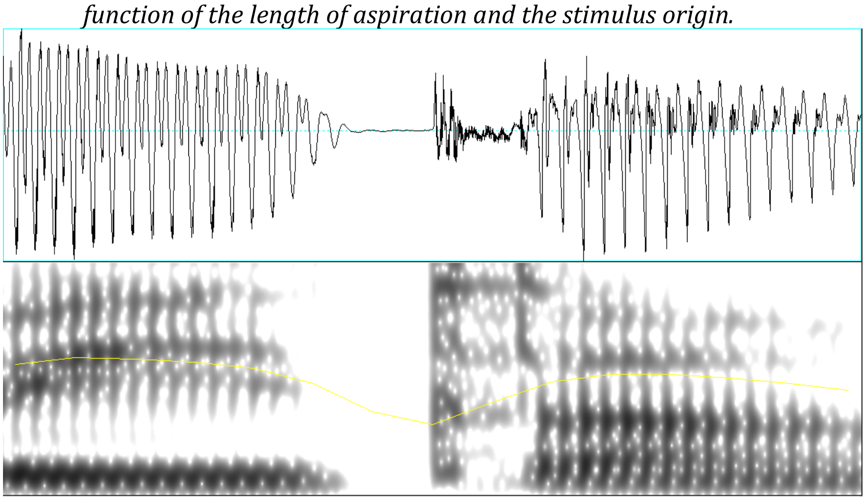

Figure 5: *Spectrogram and waveform of the stop in the "30 ms CD + 30 ms Asp" stimulus from the SING-set.*

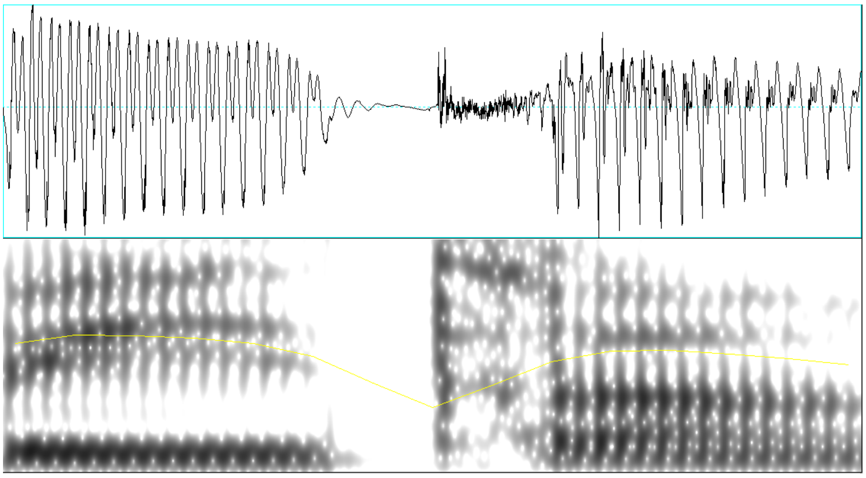

Figure 6: *Spectrogram and waveform of the stop in the "30 ms CD + 30 ms Asp" stimulus from the GEM-set.*

3.1.2. Reaction times

The univariate tests indicated that the Asp and Origin factors had significant main effects on reaction times, whereas the effects of CD were non-significant.

Table 9: *The results for reaction times*.

Factor	*F* value	significance
CD	$F(3, 928) =$	$p = .54$

	0.721	
Asp	$F(3, 928)$ = 3.192	p = .023
Origin	$F(1, 928)$ = 29.977	p < .0005
Origin × CD	$F(3, 928)$ = 14.339	p < .0005
Origin × Asp	$F(3, 928)$ = 7.568	p < .0005
CD × Asp	$F(9, 928)$ = 11.156	p < .0005
Origin × CD × Asp	$F(9, 928)$ = 4.748	p < .0005

Post hoc tests showed that the difference of each level of CD with any other was not significant in any case. For the Asp factor, only the pair 30 ms ~ 70 ms showed a significant difference, with the subjects reacting more slowly for the 30 ms step by 78 ms (p = .016).

However, all interactions between the three factors were found significant, and, moreover, planned contrasts revealed that the subjects responded significantly faster for the GEM-set than for the SING-set by 99 ms (p < .0005); therefore a separate analysis of the two sets of stimuli is again needed.

3.1.2.1. The SING-set of stimuli

An ANOVA test with RT as its dependent variable, and CD and Asp as the two independent variables was performed for the SING-set of stimuli. CD played a significant role for the speed of the subjects' reaction, whereas Asp did not (see Table 10).

Table 10: *RT results for the SING-set of stimuli.*

Factor	F value	significance
CD	$F(3, 464)$ = 5.428	p = .001
Asp	$F(3, 464)$ = 1.38	p = .248
CD × Asp	$F(9, 464)$ = 5.858	p < .0005

Post hoc tests showed that there was no difference between the four levels of the Asp factor; in the case of CD, the only significant difference was between the first step (30 ms) and the last two steps (p = .001 for the 90 ms step, and p = .041 for the 120 ms step). As shown in Figure 7, the subjects were faster at recognising the stimulus "60 ms CD + 10 ms Asp" as singleton (mean RT = 517 ms), and the stimulus "120 ms CD + 50 ms Asp" as geminate (mean RT = 549 ms). For smaller values of CD and Asp, the subjects tended to be faster at perceiving singletons, whereas, in perceiving geminates, they tended to be faster for bigger values of CD and Asp.

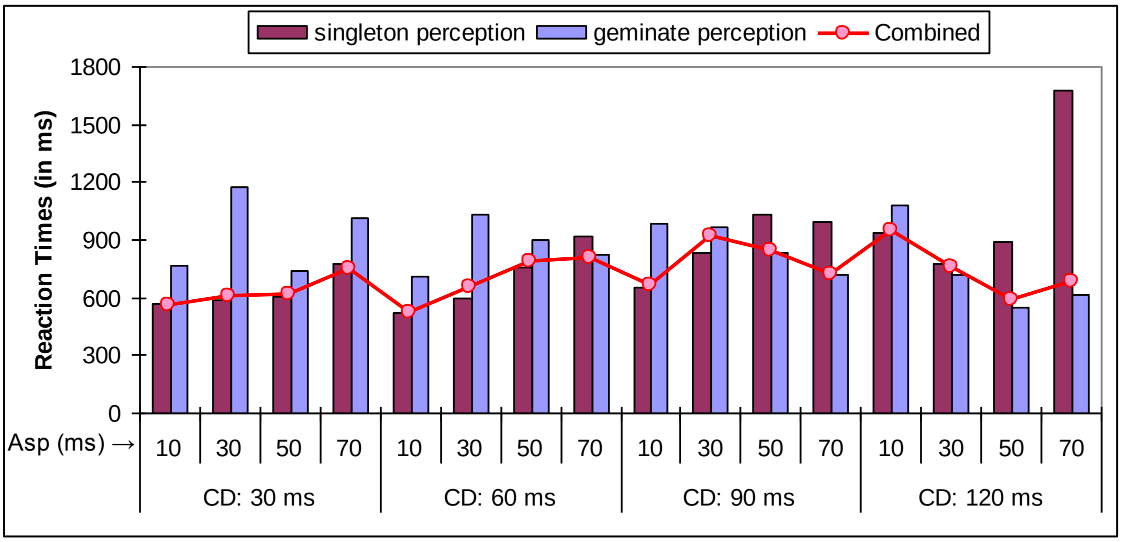

Figure 7: *Reaction times for the SING-set of stimuli.*
[Note: The bars represent the average RT for the perception of each stimulus as singleton or geminate. The line represents the average RT regardless of the perception of the stimulus.]

3.1.2.2. The GEM-set of stimuli

In the case of the GEM-set of stimuli, both CD and Asp significantly influenced the speed with which the subjects responded; moreover, the effect of the two factors was of the same size, as shown by the *F* values in Table 11.

Table 11*: RT results for the GEM-set of stimuli.*

Factor	*F* value	significance
CD	$F(3, 464) = 9.902$	$p < .0005$
Asp	$F(3, 464) = 9.894$	$p < .0005$
CD × Asp	$F(9, 464) = 10.315$	$p < .0005$

Post hoc tests showed that for the GEM-set, the longer the CD was, the faster the subjects replied, with the biggest step (120 ms) having significantly faster responses than the two smaller ones ($p < .0005$ for the 30 ms step, and $p = .041$ for the 60 ms step). The same was found for Asp: the longer the aspiration, the faster the subjects responded, with the biggest step (70 ms) having significantly faster responses than all the rest ($p < .0005$ for the 10 ms and 30 ms step; $p = .047$ for the 50 ms step). Thus the two factors seem to cause the same effect on RT, as shown by both the *F* values of the ANOVA tests, and by the post hoc tests.

As shown in Figure 8, the subjects were faster at recognising the stimulus “120 ms CD + 70 ms Asp” (i.e. the longest stimulus) as geminate (mean RT = 390 ms), and the stimulus “90 ms CD + 30 ms Asp” as singleton (mean RT = 510 ms).

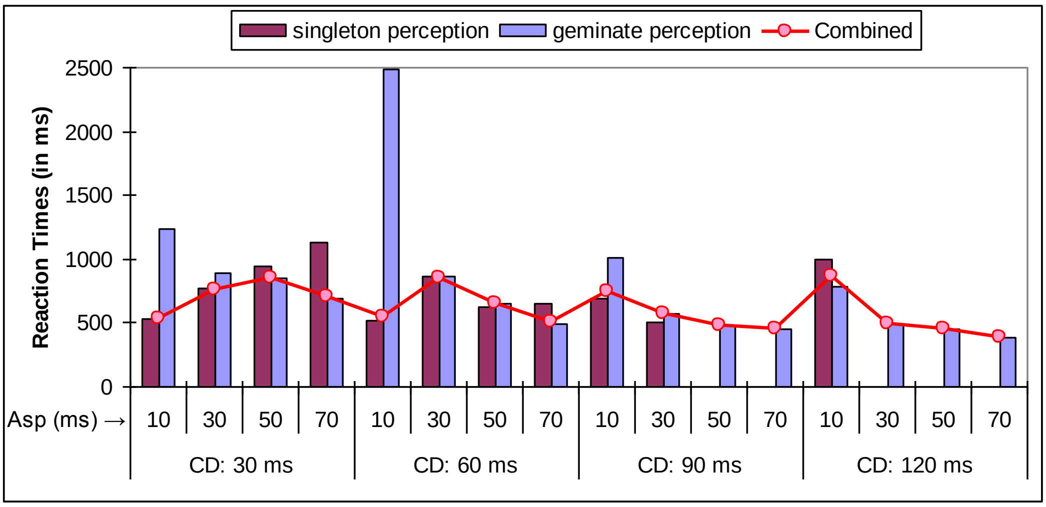

Figure 8: Reaction times for the GEM-set of stimuli.

3.1.2.3. Comparison of the two sets of stimuli

The results regarding RT for the two sets of stimuli showed a correspondence with the respective results for gemination scores (see §3.1.3). For the SING-set, only CD played a significant role for RT, while, for gemination scores, CD had a bigger effect than Asp. Moreover, the stimuli that were more recognised either as singleton or geminate in Table 6 were the ones with the fastest reaction times (see Figure 7).

In §3.1.3.3 it was suggested that the two sets of stimuli differed with regard to a possible presence of non-temporal cues to gemination residing in the aspiration of the GEM-set. The absence of those cues in the SING-set could explain the primacy of the CD factor over the Asp factor observed for the SING-set: since the subjects did not hear those non-temporal cues they expected to find in the aspiration of the stops, they concentrated more on the CD cue, and, therefore, their answers and speed of answering were primarily regulated by the amount of CD they heard.

As for the GEM-set, both factors had a significant role on both the answer given and the speed of answering, even though, for the former, Asp had a greater effect than CD, whereas, for the latter, the two factors had almost the same effect. Accordingly, the stimuli that were faster identified as singleton were of both short CD and aspiration (as shown in Figure 8), while, among them, the ones that were more identified as singletons were the ones of primarily shorter aspiration (see Table 8). Similarly, the stimuli that were faster identified as geminate were of both long CD and aspiration, while, among them, the ones that were more identified as geminates were the ones of primarily longer aspiration.

These findings lend support to the view that the longer the aspiration of the GEM-set, the more salient the non-temporal cues to gemination are, a situation that appears to enhance the aspiration cue relatively to the CD cue. Thus, the subjects focused more on the duration of aspiration (and arguably on the non-temporal cues thereof) and less on CD in identifying the stimuli as singleton or geminate. However, Asp and CD influenced equally the speed of answering, as the longer they were, the faster the subjects answered (see §3.1.4.2), a fact that implies that, even though the aspiration cue was enhanced by the presence of non-temporal cues, CD was still an important cue to gemination. The importance of CD in the identification of the stimuli as singleton or geminate might have been reduced by the presence of those extra cues, but, nevertheless, CD was important enough a cue to provide more confidence (or confusion) to the subjects, hence influencing their speed of answering.

3.2. Modelling the perception of plosive gemination in CyGr

After having identified the factors that play a role in the perception of the stimuli, determining the exact way in which they contribute to that perception was considered to be of interest in order to investigate the relative importance of those cues.

To pursue this investigation, it was necessary to explore the data to identify all possible cues that may influence the perception of a stimulus as a singleton or geminate. The importance of those cues was subsequently evaluated using a logistic regression analysis.

3.2.1. Exploring the data

The aim of the regression analysis was to provide an insight into what acoustic cues the listeners focused on in perceiving an alveolar stop as geminate or singleton. In section 0, three factors, namely CD, Asp, and Origin, were identified as important. Origin was a factor specific to the experimental design of this study: it was meant to distinguish between the two sets of stimuli produced by manipulation of the stop duration according to the source utterance used as the basis of the manipulation. Since the aim of the regression analysis was to infer a model for the perception of alveolar stops based on acoustic cues found in the signal, such an artificial factor as the Origin factor could not be considered for this investigation.

However, it was postulated in section 3.4.1.3 above that the significant contribution of the Origin factor to the perception of the stimuli may be due to cues accumulating in the aspiration portion of the GEM-set. Those cues may be the intensity of aspiration and the length of superimposed aspiration.[26] Those two cues were found in the acoustic study of Armosti (2009) to differ significantly between singletons and geminates.

Another cue to gemination found in Armosti (2009) was the total duration of the stop. For the perceptual experiment, a graphical representation of geminate perception with relation to total segment reveals apparent correlations. As shown in Figure 9, the geminate perception of the stimuli of the SING-set increased proportionally to the increase of the total stop duration. In the case of the GEM-set, the increase of geminate perception was again proportional to the increase of total stop duration; the only exceptions were the stimuli with the shortest aspiration (i.e. 10 ms), for which there was a dramatic drop in geminate identification. However, the drop was not random: the identification of stimuli from the GEM-set as geminate in those cases was virtually the same as the identification of stimuli of the same total duration from the SING-set (these cases are indicated with circles in Figure 9). Thus, these drops in the GEM-set can be seen as an exception to the apparent pattern followed by both sets, namely that the total duration of the stop is proportional to its perception as geminate. Therefore, total stop duration was considered to be included in the regression analysis.

[26] For the creation of the stimuli, SA was considered to be part of aspiration and not of the following vowel; therefore the length of SA was subject to the overall manipulation of the duration of aspiration.

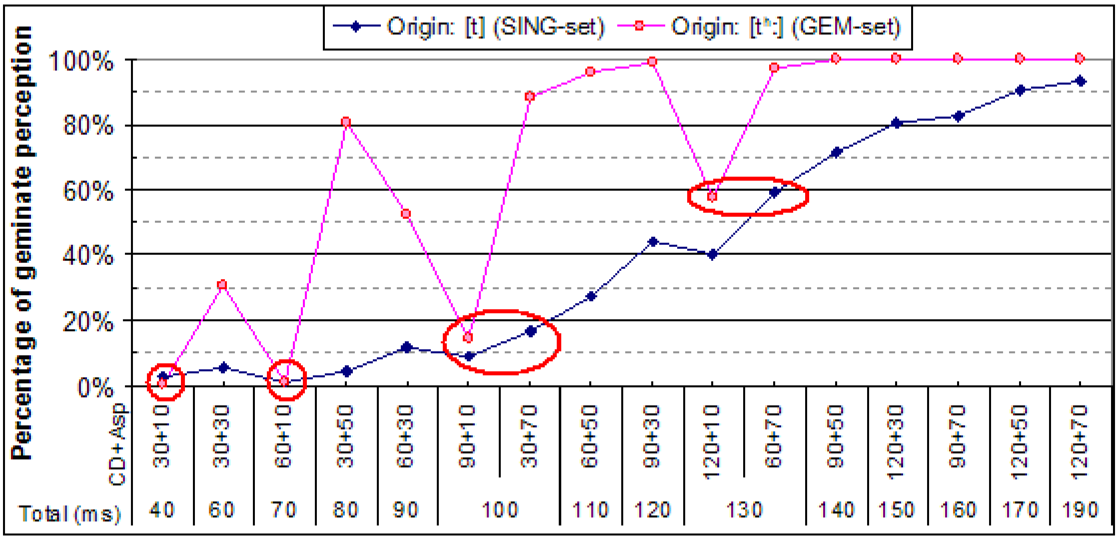

Figure 9: *Percentages of geminate identification of the stimuli over total segment duration*.

Apart from cues at the segmental level, the acoustic analysis of Armosti (2009) showed that there are some important cues at the supra-segmental level, be they absolute (such as the 'aspiration plus the following vowel' sequence, i.e. HV2), or relative (such as the V2:HV2 and V2:CV2 ratios).[27] Even though, for the perceptual experiment, V2 was kept the same in all stimuli, the manipulation of the duration of CD and aspiration caused changes in the supra-segmental timing as well. As a result, these changes in HV2, V2:HV2, and V2:CV2 could influence to some degree the perception of the stimuli. Thus, these cues were considered for the regression analysis also.

With the addition of the supra-segmental cues, eight cues in total were regarded as useful for the regression analysis (and were therefore obtained by segmenting and measuring the properties of the stop and V2 of the stimuli): (i) CD, (ii) duration of aspiration (DUR_{Asp}), (iii) intensity of aspiration (INT_{Asp}), (iv) total segment duration (DUR_{Total}), (v) duration of SA, (vi) HV2, (vii) V2:HV2, and (viii) V2:CV2. However, it was expected that some of these variables could be closely connected (i.e. correlated) with one another (such as aspiration with HV2); this situation is called 'multi-colinearity', and could produce problems for the regression analysis that would follow.

One way to avoid (or reduce) multi-colinearity is to merge cues that correlate with one another into a single factor. The statistical method to achieve this is called 'principal component analysis' (PCA). PCA essentially extracts underlying factors[28] from clusters of variables (in this case, from the eight acoustic cues). The analysis extracted two factors, as can be seen from Figure 10: one correlated highly with the total consonant duration and V2:CV2, while the other correlated highly with the duration of aspiration, the aspiration intensity, HV2, and V2:HV2; CD and SA did not correlate with any other variable, hence they were excluded from the two factors.

The clustering of those specific variables into the two factors can be meaningful: the first factor is relevant to the whole duration of the segment, whereas the second factor is closely related to properties of the aspiration. Therefore, the two factors were named 'Total Segment Factor' and 'Aspiration Factor' respectively. Principal component analysis

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[27] V2:HV2 is the ratio of V2 to the HV2 sequence; V2:CV2 is the ratio of V2 to the 'whole stop plus V2' (i.e. CV2) sequence. These ratios where shown in Armosti (2009) to be acoustic correlates to gemination.

[28] Strictly speaking, the outcome of principal component analysis is called 'component' and not 'factor' (which is the outcome of factor analysis). Nevertheless, the term 'factor' is sometimes used generically to include the sense of 'component' also.

yielded component score coefficients for each of the two factors, which were imported into their respective formulae (see Equations 1 and 2).

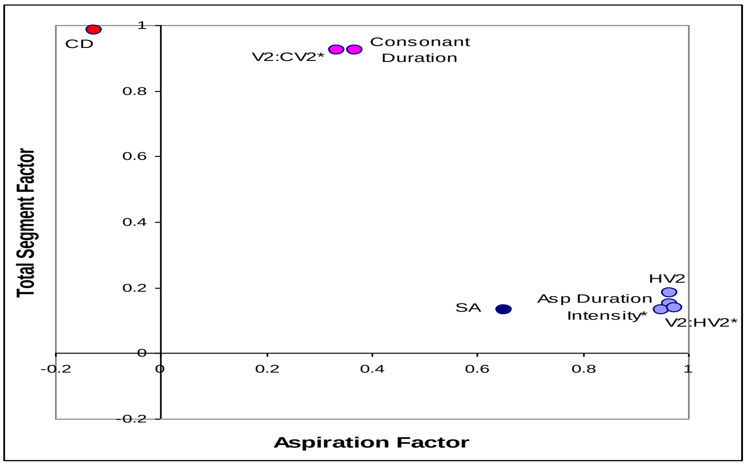

Figure 10: *Component plot of the two extracted factors*.
[Note: The variables indicated with an asterisk (*) show negative correlation with their main factor; however, for the analysis it is the absolute correlation values that are important, therefore those variables were transposed for the clustering to become more apparent.]

$$\text{Aspiration Factor} = 0.256\ DUR_{Asp} + 0.005\ DUR_{Total} - 0.251\ INT_{Asp} + 0.252\ HV2 - 0.259\ V2{:}HV2 + 0.006\ V2{:}CV2$$

Equation 1: *Formula for calculating the 'Aspiration Factor'*

$$\text{Total Segment Factor} = 0\ DUR_{Asp} + 0.498\ DUR_{Total} + 0.014\ INT_{Asp} + 0.019\ HV2 + 0.007\ V2{:}HV2 - 0.510\ V2{:}CV2$$

Equation 2: *Formula for calculating the 'Total Segment Factor'*

With the extraction of the two factors from six variables (out of the eight original variables), and with the two remaining uncorrelated variables (CD and SA), the logistic regression analysis could then be performed on four variables.

3.2.2. Logistic regression

The aim of the logistic regression was to model the exact way in which the factors identified above contribute to the perception of the stimuli as singleton or geminate. The output of the regression analysis was a formula consisting of the acoustic variables (or 'predictors', as they are called in regression analysis) and their weights; that formula can predict the probability of a certain stimulus being perceived as geminate, after the acoustic properties of that stimulus have been entered into the formula.

Thus, the independent variables (i.e. the predictors) entered in the analysis were: (i) CD, (ii) the Aspiration Factor, (iii) the Total Segment Factor, and (iv) SA duration. The method used was block entry regression, in which the predictors are entered one after the other (or in blocks); thus, the way in which each variable contributed to the overall model could be examined.

The analysis showed that all predictors improved the model, except for the Total Segment Factor, which reduced the percentage of correct prediction of the model. A careful examination of the correlations between the four predictors revealed that the Total Segment Factor correlated highly with CD (r = -.999), and the Aspiration Factor (r = -.997). Correlation between predictors is undesirable in regression analysis, thus the Total Segment Factor had to be removed from the analysis. The remaining predictors were all significant in their contribution to the model, as shown in Table 12.

Table 12: *The results of logistic regression*.

					95% CI for exp *b*	
	b	***(SE)***	**Sign.**	**exp *b***	**Lower**	**Upper**
Included						
CD	0.035	(0.001)	< .0005	1.036	1.033	1.039
Aspiration Factor	0.11	(0.005)	< .0005	1.116	1.105	1.127
SA	0.197	(0.03)	< .0005	1.218	1.149	1.29
Constant	-5.9	(0.176)	< .0005	0.003		

Note: R^2 = .345 (Hosmer & Lemeshow), .378 (Cox & Snell), .506 (Negelkerke).
Model $\chi^2(3)$ = 2278.384, $p < .001$. Percentage of correct prediction: 79.2%.

The percentage of correct prediction of the model was 79.2%. The resulting formula from the regression analysis is shown in Equation 3.

$$P(\text{gem}) = \frac{1}{1 + e^{-(-5.9 + 0.035 CD + 0.11 AspirationFactor + 0.197 SA)}}$$

Equation 3: *Logistic regression formula*.

If the Aspiration Factor in Equation 3 is substituted by its components of Equation 1, then an expanded formula including all eight cues can be derived (see Equation 4).

$$P(\text{gem}) = \frac{1}{1 + e^{-(-5.9 + 0.035 CD + 0.028 DUR_{Asp} + 0.001 DUR_{Total} - 0.027 INT_{Asp} + 0.028 HV2 - 0.028 V2{:}HV2 + 0.001 V2{:}CV2 + 0.197 SA)}}$$

Equation 4: *Expanded regression formula*.

If the acoustic properties of a given stimulus are entered in Equation 4, then the probability of that stimulus being perceived as geminate is generated. For instance, if the properties of the "30 ms CD + 10 ms Asp" stimulus from the SING-set (i.e. DUR_{Total} = 40 ms, INT_{Asp} = 70 dB, HV2 = 96 ms, V2:HV2 = .9, V2:CV2 = .69, SA = 4 ms) are entered in the equation, then the probability of that stimulus being perceived as geminate would be 4.52% (i.e. 95.34% chance to be perceived as singleton). This result is actually very close to the observed result of Table 6 (which was 2.67%).

Testing the predictions of the model against the actual responses of the subjects is a good way to assess the accuracy of the model. However, a model should not only be assessed on the grounds of its true positives (in this case, the success in identifying a geminate), but also of the false positives (i.e. identifying a singleton as a geminate). A method of assessing both aspects of model accuracy is the 'Receiver Operating Characteristic' (ROC) analysis. This analysis produces a ROC curve, which is a visual index of the accuracy of the model.

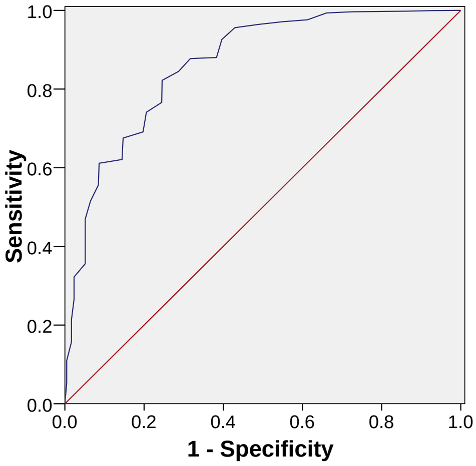

Figure 11: *ROC curve for assessing the regression model*.

The resultant ROC curve is shown in Figure 11. The term 'sensitivity' refers to the accuracy of the model in predicting true positives, i.e. that a geminate is indeed a geminate. The term 'specificity' refers to the accuracy in predicting true negatives, i.e. that a singleton is indeed a singleton. For ROC plots, the reverse of true negatives, i.e. false positives (singletons predicted to be geminates), are used; hence the horizontal axis is named '1 - specificity'.

The area under the curve represents the probability that the result of Equation 4 for a randomly chosen geminate will exceed the result for a randomly chosen singleton. In other words, the area measures discrimination, that is, the ability of the test to correctly classify singleton and geminate stimuli. The diagonal reference line represents the scenario where the model is not better than guessing, i.e. the discrimination of the two cases is based on chance (the area under the reference line is .5, i.e. 50% chance). The further the ROC curve lies from the diagonal line, the more area it covers, therefore the more accurate the test is. In this study, the area under the curve was .86, which is a good level of accuracy. The asymptotic significance associated with the area statistic was less than .05, which means that using the model is better than guessing.

3.2.2.1. Relative weight of predictors

As mentioned earlier in section 1, previous studies have argued about the relative importance of the CD and aspiration cue to gemination, claiming that one or the other is the primary one. However, arguing about the possible primacy of the one or the other cue should be principally associated with perception rather than production; even though these studies did make inferences regarding the perceptual importance of those cues, their results were in most cases based purely on acoustic data. The present study is the only one that has investigated the perception of those cues through manipulation of their duration, and therefore its claim to reveal the relative importance of those cues has greater validity.

An evaluation of the relative importance of the predictors can be reached by comparing their coefficients in the regression formula, as the one with the greater coefficient contributes more to the model. However, the coefficients are not directly comparable if the predictors do not come from the same underlying distribution. As shown in Figure 3 in section 3.1.2, the values of the duration of the closure and aspiration fall into ranges of different size (the range of aspiration is smaller than the range of CD); therefore, a small increase in aspiration may have a different effect compared to the same increase in CD. Moreover, if these two factors were to be compared with the intensity of aspiration, no comparison could be made, as intensity is measured in different units than duration. A method to avoid these obstacles in comparing different predictors is the standardisation of their distributions; this method ensures that the distributions will have the same mean ($M = 0$) and standard deviation ($SD = 1$).

The predictors were therefore standardised and the regression analysis was run again with the new variables. The results of the analysis are shown in Table 13. The new regression coefficients for CD and the Aspiration Factor were more similar (1.28 and 1.328 respectively) than before (cf. Table 12). These values are also shown in the new regression formula (Equation 5). Their exponential values in Table 13 represent the odds of geminate against singleton perception after a change of one standardised unit of the predictor. Thus, if CD increases by one standardised unit, the odds of perceiving a geminate are 3.6 times higher than perceiving a singleton; when the Aspiration Factor increases by one standardised unit, then the odds are 3.8. This means that the two predictors influence the perception of geminates in almost the same way, with the Aspiration Factor exhibiting marginally more perceptual weight.

Table 13: *The results of the standardised logistic regression*.

	b	***(SE)***	**Sign.**	**exp b**	**95% CI for exp b**	
					Lower	**Upper**
Included						
CD	1.28	(0.047)	< .0005	3.597	3.279	3.946
Aspiration Factor	1.328	(0.059)	< .0005	3.775	3.363	4.237
SA	0.229	(0.051)	< .0005	1.257	1.138	1.388
Constant	0.331	(0.039)	< .0005	1.393		

Note: R^2 = .353 (Hosmer & Lemeshow), .385 (Cox & Snell), .515 (Negelkerke).
Model $\chi^2(3) = 2333.929$, $p < .001$. Percentage of correct prediction: 79.2%.

$$P(\text{gem}) = \frac{1}{1+e^{-(0.331+1.28CD+1.328AspirationFactor+0.229SA)}}$$

Equation 5: *Standardised regression formula*.

The Aspiration Factor, though, is a combination of other variables (such as the duration and intensity of aspiration). The studies that contrasted closure and aspiration did so at a durational level only (they compared CD not with aspiration, but with VOT, which is by nature a durational cue). To allow for a comparison of the perceptual weight of all cues, the regression formula had to be expanded, as shown in Equation 6.

$$P(\text{gem}) = \frac{1}{1+e^{-(0.031+1.28CD+0.34DUR_{Asp}+0.007DUR_{Total}-0.333INT_{Asp}+0.334HV2-0.344V2{:}HV2+0.009V2{:}CV2+0.229SA)}}$$

Equation 6: *Standardised expanded regression formula*.

The regression coefficients and their exponential values are shown in Table 14, which ranks the predictors according to the absolute values of the coefficient *b*. It becomes obvious that, at the durational level, CD has by far more perceptual weight than aspiration: the change in odds for CD is 3.6, whereas for DUR_{Asp} is only 1.4. This means that an increase of CD by one standardised unit induces geminate perception at a much greater degree (around 2.5 times) than the same increase in the duration of aspiration. Actually, the duration of aspiration has virtually the same perceptual weight with V2:HV2, HV2, and INT_{Asp}. Of these four predictors, V2:HV2 is marginally more important, albeit negatively correlated with geminate perception.

Table 14: *The ranking of the predictors according to their perceptual weight*.

Rank	Factor	coefficient	GEM odds	SING odds
		b	Exp *b*	1 / Exp *b*
1	CD	1.28	3.597	0.278
2	V2:HV2	-0.344	0.709	1.411

3	DUR_{Asp}	0.34	1.406	0.711
4	HV2	0.334	1.397	0.716
5	INT_{Asp}	-0.333	0.717	1.395
6	SA	0.229	1.257	0.796
7	V2:CV2	0.009	1.009	0.991
8	DUR_{Total}	0.007	1.007	0.993

4. Discussion

The main objective of this paper was to investigate the relative importance of acoustic cues in the perception of alveolar stops as singleton or geminate. This was achieved mainly with the logistic regression analysis, which was supported by the results of the multivariate analysis of variance.

The main finding was that, at a purely durational level, CD was a more important cue to gemination than aspiration (see Table 14). This was mainly shown by the regression analysis when the various constituents of the Aspiration Factor were isolated, so as to discern the perceptual weight of the duration of aspiration regardless of the rest of the cues related to aspiration (such as the intensity of aspiration). In a way, this separation was also achieved in designing the experiment: the stimuli that originated from the singleton stop (i.e. the SING-set of stimuli) were deprived of the non-temporal cues to gemination, and, therefore, only the durational dimension of the aspiration and closure could play a role in the perception of geminates. Indeed the MANOVA test showed that for the SING-set both the duration of the closure and aspiration played a significant role in the answer the subjects gave, with CD being somewhat more important than Asp. Moreover, Asp did not play a role in the speed with which the subjects responded for the SING-set, whereas CD did play a significant role. Therefore, the lack of any non-temporal cues to gemination in the SING-set induced the subjects to rely on CD more than Asp in both the answer they gave and their reaction times.

However, this separation of the duration of aspiration from the rest of the cues that relate to aspiration is only artificial, as, in reality, a geminate stop in Cypriot Greek differs from a singleton not only in terms of the duration of the aspiration and closure, but regarding other acoustic cues, as was shown in Armosti (2009). Those cues were preserved in the stimuli that originated from the geminate stop (i.e. the GEM-set of stimuli), and, indeed, the analysis showed that, even though both CD and Asp were significant in the perception of the stimuli of the GEM-set as geminate or singleton, the effect of Asp was bigger than CD; regarding reaction times, both cues were significant, but had virtually the same effect. When the various aspiration-related cues were treated as a single factor in the regression analysis, similar results were found: both CD and Aspiration were significant predictors in the perception of the stimuli, with Aspiration having marginally more perceptual weight than CD.

A secondary finding was that relative supra-segmental timing is not only *acoustically* an important cue to gemination (as shown in Armosti 2009), but also *perceptually*, as the V2:HV2 ratio was found to be the second most important predictor in geminate perception. However, since V2 remained artificially the same for all stimuli, the importance of this finding may be questioned.

Regardless of the limitations of the present study concerning V2 and the unnaturalness of some stimuli, its results are consistent with the findings of previous (acoustic) studies, namely that not only aspiration, but also CD has a contrastive role in the plosive system in Cypriot Greek (and, therefore, there is a gemination contrast in Cypriot Greek plosives, and not merely an aspiration contrast).

5. Conclusion

This paper provided important findings regarding the debate about which cue should be considered primary for the perception of stops in Cypriot Greek. In particular, it showed that both CD and aspiration are important *perceptual* cues to gemination, with aspiration exhibiting marginally more perceptual weight than CD. Interestingly, the duration of aspiration *per se* (i.e. without considering the other cues related to aspiration, such as its intensity) is substantially of less importance than the duration of the closure. However, since aspiration influences perception not only by its duration, but also by the other cues related to it, the finding regarding aspiration as a combination of cues (i.e. that it is slightly a better predictor for gemination than CD) should be of more relevance to the debate.

Regardless of which of the two elements of the stop is more important for the perception of gemination, what this study has demonstrated about CD is that it cannot be denied that CD is an important perceptual cue to gemination in Cypriot Greek—nearly as important as aspiration. This finding can serve as a further indication towards analysing the plosive system of Cypriot Greek as one contrasting (unaspirated) singletons with (aspirated) geminates, rather than merely unaspirated with aspirated plosives. If the latter had been the case (as Davy and Panayotou, 2004, and Charalambopoulos, 1982, argued), then CD would not have exhibited such a perceptual weight.

Consequently, the perception of plosive gemination in Cypriot Greek is partly determined by CD, i.e. the universal main cue to gemination; however, in Cypriot Greek aspiration serves as a marginally more important cue than CD.

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