Spatio-Temporal and Kinematic Study of Moroccan Arabic Coronal Geminate Plosives

Chakir Zeroual[1, 2], Philip Hoole[3], Adamantios I. Gafos[4,5].

1Faculté Polydisciplinaire de Taza-Morocco; 2Laboratoire de Phonétique et Phonologie (UMR 7018, Paris); 3Institut für Phonetik, Munchen, 4Haskins Laboratories, 5New York University.

chakirzeroual@yahoo.fr, hoole@phonetik.uni-muenchen.de, Adamantios.Gafos@nyu.edu

Abstract

Moroccan Arabic (MA) geminate coronals are produced intervocalically with a longer oral closure and longer period of alveolar contact. MA geminate consonants don't induce shortening of their preceding vowel, and are produced without larger anticipation of their gesture in the preceding vowel compared to their simple cognates. Our data show that geminate/singleton consonants are not controlled by only varying the stiffness and the virtual target of their gestures.

1 Introduction

This study tests some hypotheses assumed to explain the acoustic and articulatory differences between intervocalic simple and geminate consonants, with a main focus on Moroccan Arabic (AM) coronal plosives.

Intervocalic geminate plosives are produced in general with a very long closure [6, 13], which constitutes their major acoustic and perceptive cue [6], including in Arabic [10]. The ratio geminate/simple closure duration varies from one language to another: higher in Arabic [13] and in Japanese, but lower in Swedish [7]. The VOT duration of the geminate is in general identical to their simple cognates [6], with a tendency toward a slight reduction of the VOT of the geminates [6, 11]. Cypriot Greek seems to constitute an exception, since the VOT of its geminate plosives is much longer than for the simple ones [1].

According to the "mass spring model" [5], one source of absolute time differences is due to variations in the abstract parameter of stiffness. This model predicts that the geminates would have lower stiffness than their simple counterparts. This hypothesis has been supported by data reported on the opening movement of Italian labial consonants [3, 4], as well as on the closing movement of Japanese labial consonants [7].

Previous studies have shown that a virtual target is associated in the production of a consonant [2, 7, 8]. This idea suggests that the long consonant has a higher virtual position and greater amplitude than the short one [7]. This hypothesis predicts that the geminate would also have a higher peak velocity than the simple one, since a strong positive correlation is generally observed between amplitude and peak velocity. Data on closing movement of simple and geminate labial plosives of Japanese [7] show some evidence for the first (target differences), but not for second hypothesis (velocity differences).

The vowel shortening before a geminate consonant observed in some languages [9, 12] (e.g. Italian) and not in others [6] (ex. Japanese), has been hypothesized by Smith [12] to arise from a difference in the temporal coordination (degree of overlap) between simple and geminate consonants with the adjacent vowels. According to Smith [12], when vowel shortening before a geminate is attested, we have a constant vowel_to_vowel time interval, a constant timing for the centre of maximum constriction of /C_i/ and /C_iC_i/, and an anticipation of the geminate gesture in the preceding vowel.

2 Method and material

Two Moroccan Arabic subjects (S1 and S2: male, 25 & 27 years) participated in an EMA experiment (AG500, Carstens Medizinelektronik). Vertical and horizontal movements of the tongue (tip : TTIP, mid: TMID, dorsum: TDOR), lips, and the jaw were tracked at 200 Hz sampling rate with sensors placed on these articulators [15].

Intervocalic simple and geminate /t d tt dd/ were pronounced 8 times in three words (/ma$_1$ta$_2$bʃ/, /ma$_1$da$_2$bʃ/, /maddah/) and one pseudo-word (/ba$_1$tta$_2$h/), where /a$_2$/ is the accented vowel. In these items, the movement of the anterior part of the tongue tip (TTIP) is clearly defined. All stimuli were inserted in "galha ___hnaya": *'he told her_here'*.

Gestural Onset (Ons), Target (T), maximal position (M), Release (R) and Offset (Off) were identified automatically from the velocity of the opening and closing phases of the TTIPy signal using a 20% threshold criterion (Fig. 1).

Our statistical analyses are based on paired t-tests done separately for each subject.

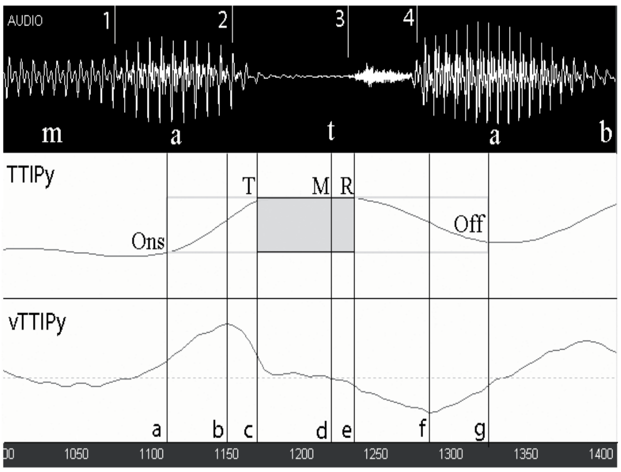

Figure 1*: Acoustic and articulatory landmarks* used to *extract duration, spatio-temporal and kinematic measurements (see also figures below). TTIPy: tongue tip vertical position signal, vTTIPy: tongue tip vertical velocity.*

3 Results and discussion

Figure 2 shows that the closure is longer during /tt dd/ than during /t d/ (/d vs. dd/ and /t vs. tt/: $p<0.001$). The duration ratio geminate/simple is 2.22 for S2, 2.01 for S1). In general, /a$_1$/ is longer before /C$_i$C$_i$/ than before /C$_i$/ (only /d vs. dd/ for S2 is not significant: $p=0.24$); this result confirms that the vowel shortening before a geminate is not a universal parameter [6]. For S1 and S2, the burst is significantly longer during /dd/ compared to /d/ (S1: $p<0.01$; S2: $p<0.02$). This difference would be bound to the voicing that spreads during the whole length of the closure of /d/, and stops before the release of /dd/. For S2, the VOT of /tt/ is significantly shorter ($p<0.01$) than of /t/ (see [6, 11]). This result can be due to the alignment of maximal glottal opening with the oral release of /t/, and before it during /tt/ [14].

For S1 and S2, the total TTIPy gesture duration is shorter during /t/ and /d/ than /tt/ and /dd/ (/t vs tt/ and /d vs dd/: $p<0.001$) (Fig. 3). Fig. 3ii shows that Ons_M time interval (between TTIPy onset and its maximal position) and M_Off (between TTIPy maximal position and its offset) during /t/ and /d/ are statistically shorter than /tt/ and /dd/ ($p<0.01$). These results are in accord with data on the opening movement of Italian labial geminates in the normal rate [4]. The time intervals Ons_T (Onset to Target) and R_Off (Release to Offset) of /t/ and /d/ are statistically similar to those of /tt/ and /dd/ (Fig. 3i); but T_R (plateau) is largely shorter during /t/ and /d/ than during /tt/ and /dd/ ($p<0.001$). Fig. 3 clearly shows that geminate is mainly characterized by the lengthening of the plateau phase of its TTIPy gesture.

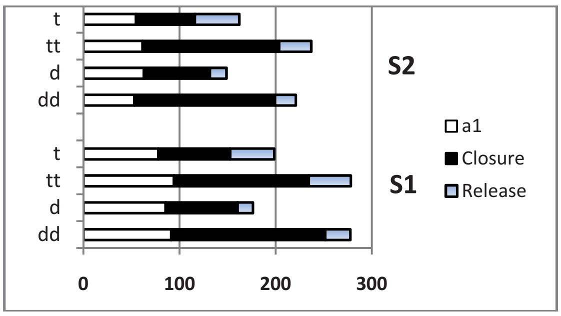

Figure 2 *: Durations (msec) of /a$_1$/ (2-1, Fig. 1), closure (3-2, Fig. 1) and noise release (4-3, Fig. 1) of /t d tt dd/ in /a$_1$__a$_2$/ context produced by subjects S1 and S2.*

Only for S1, the vertical position at the target (T), maximal (M), and release (R) of TTIP gesture are significantly higher during /t/ than /d/ ($p<0.001$) and /tt/ than /dd/ ($p<0.001$) (Fig. 4). These differences would be to enhance the voiced vs. voiceless contrast. S1 & S2 seem to have different strategies to increase the volume of the supralaryngeal cavity to have long voicing during the closure of /d, dd/. Notice that, for S1, vertical position differences for TTIPy (at T, M, R) are not neutralized by its contact with the palate. For S1 & S2, the height of TTIP (at T, M and R) during /t/ and /d/ are statistically identical compared to /tt/ and /dd/, respectively. These observations suggest that singleton and geminate consonants of our speakers have identical virtual targets.

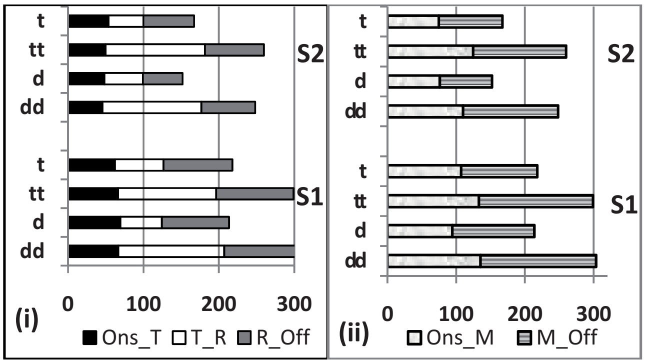

Figure 3: *(i) Duration (msec) from the onset to the target (Ons_T = c-a, see Fig. 1), the target to the release (T_R =e-c), and the release to the offset (R_Off = g-e) of the TTIPy gesture during /t d tt dd/ in /a_1__a_2/ produced by S1 and S2.* (ii) *Duration from the onset to the maximal position (Ons_M = d-a) and from the maximal position to the offset (M_Off = g-d) of TTIPy gesture.*

The peak velocity of the closing gesture during /t/ vs. /tt/ (S1: p=0.49; S2: p=0.96) and /d/ vs. /dd/ (S1: p=0.58; S2: p=0.87) is statistically similar (Fig. 5). This result is related to the fact that the amplitude and the duration of this movement (Onset to Target) are also statistically identical during /t/ vs. /tt/ and /d/ vs. /dd/. For S1 & S2, the peak velocity of the opening gesture is higher for /dd/ than for /d/ (the difference is not significant) and especially during /tt/ compared to /t/ (S2: p<0.001). The opening gesture amplitude (Release to Offset) is higher for /dd/ than for /d/ (S1 & S2: p<0.01) and during /tt/ than /t/ (S1: p<0.03; S2: p<0.001). These amplitude differences are due to the lower TTIPy offset position during /a_2/ (Fig. 4) in $a_1C_iC_ia_2$ followed by /h/ which is produced without tongue-jaw rising, but higher during /a_2/ in $a_1C_ia_2$ followed by /bʃ/ produced with tongue-jaw rising.

The slope of the regression line between the amplitude and peak velocity of the TTIP movements has been used as an estimate of stiffness [5, 7]. For S1 and S2 (Table 1), the slope of the closing movement remains very similar during /t d/ compared to /tt dd/, suggesting a similar degree of stiffness for simple and geminate consonants. A similar result has been provided for simple and geminate labials produced by one Japanese speaker [7]. For S2, the opening movement slope is higher for simple than for geminate consonants, suggesting a lower stiffness for geminates in accord with the "mass spring model" prediction. Unexpected higher stiffness for the opening movement of geminates is observed for S1. These inconsistent stiffness results for the opening movements are perhaps also related to variability introduced by the different consonants following /a_2/.

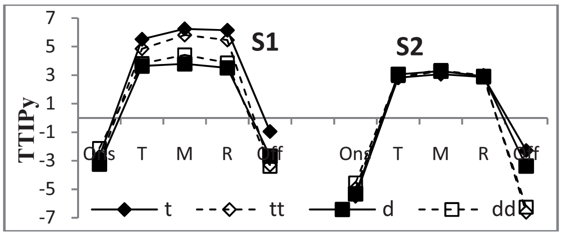

Figure 4: *The height (mm) of TTIP gesture at its onset (Ons), target (T), maximal (M), release (R) and offset (Off) positions during /t d tt dd/ produced by subjects (S1, S2) in /a_1_a_2/ (see also Fig. 1).*

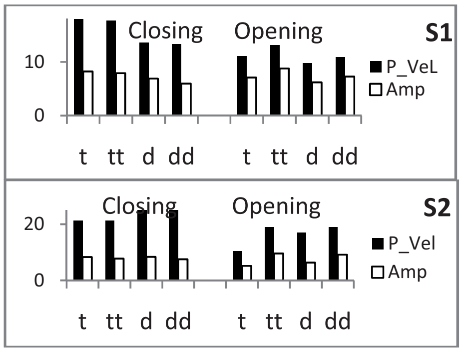

Figure 5: *P_Vel (cm/s): Peak velocity of the closing and opening movements of TTIPy during /t d tt dd/ in /a_1__a_2/. Amp (mm): Displacement from the onset to the target and from the release to the offset of TTIPy (see Fig. 1).*

Table 1. *Slope of the regression lines between the amplitude (Amp:* see Fig. 5*) and peak velocity of closing and opening movements of /t d/ and /tt dd/.*

	Consonants	S1	S2
Closing	/t d/	1.792	1.38
	/tt dd/	1.821	1.553
Opening	/t d/	0.949	2.273
	/tt dd/	1.717	1.538

To provide some temporal coordination properties of MA geminate consonants, and since we used a symmetrical vocalic context, our timing landmarks are different than those of Smith [12]. We measure two time intervals (Fig. 6): (i) between the acoustic onset of /a_1/ and the onset of TTIP closing movement, (ii) and between the onset of /a_1/ and the target of TTIPy closing movement. Except for /d vs. dd/ of S2 ($p<0.01$), the simple and its geminate cognate have a same degree of anticipation of the TTIP gesture onset and target (or closure) (Fig. 6). These observations seem to be in accord with Smith's prediction according to which a larger anticipation of the geminate gesture in the preceding vowel is observed only when we have vowel shortening before it (this shortening is not observed in our data).

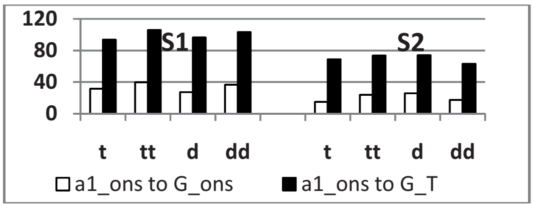

Figure *6. Durations (msec) from the acoustic onset of /a_1/ to the onset of TTIPy closing movement (a_1_ons to G_Ons), and to its target (a_1_ons to G_T) (see also Fig. 1).*

4 Conclusion

Moroccan Arabic geminate (coronal) plosives are produced by our two subjects with a longer period of tongue tip contact, and a long acoustic oral closure.

This oral closure lengthening is not controlled by changing the position of the virtual target as has been suggested for the geminates of other languages [7]. Only one subject produces the geminate with a lower stiffness, and only for the opening movement.

The vowel shortening before geminate consonants is not observed in our data. It can be due to the fact that these geminate consonants are produced without larger anticipation of their gesture in the preceding vowel compared to their simple cognates.

Duration variations are also attributed to the differences between the velocity profiles of the movements of short and long segments [13]. This hypothesis will be tested in our future investigations.

5 References

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