Gestural coordination differences between intervocalic simple and geminate plosives in Moroccan Arabic: An EMA investigation

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ABSTRACT

Based on EMA data (3 speakers), we investigates the articulatory strategies responsible for the singleton/geminate plosive contrast in Moroccan Arabic. Our data showed that closing and opening phases of the geminate gesture share several articulatory properties with those of its single cognate. These results and our analyses of V-to-V and V-to-C temporal coordination are consistent with the hypothesis that MA geminate plosives can be analysed as two identical overlapped consonants.
Keywords: Geminate, EMA, Moroccan Arabic.

1. INTRODUCTION

The nature of the speech motor mechanisms responsible for temporal variations is one of the most controversial aspects of speech production field studies. Intergestural and/or intragestural articulatory strategies are often linked to the stiffness parameter to explain such variations. For the "mass spring model" [10, 18], segmental duration lengthening may be a passive consequence of stiffness lowering. Intergestural adjustments seem more involved in linguistic time variations, and intragestural strategies in paralinguistic ones [2]. This study is in the context of this debate with a focus on the single/geminate plosive contrast.

Few articulatory studies have been devoted to single/geminate plosives and generally in intervocalic position where this contrast is cross linguistically widely attested [12]. They showed that geminate stops always have longer articulator contact [3, 6, 15, 21, 22, 23]. Perceptual investigations also show that constriction duration lengthening is the primary acoustic correlate of intervocalic plosive geminate [13, 16]. This geminate/single ratio varies with languages (higher in Japanese [7] than Arabic [22] and Swedish [15]). A slight and non-significant VOT shortening is generally observed during the geminate plosives compared to their single cognates [19, 22]. In Cypriot Greek, the geminate has long VOT [1].

This study tests two main hypotheses. The first one is that the geminate is produced by intragestural reorganization of its single cognate. It predicts stiffness lowering during the geminate [15, 18]. Higher virtual target and amplitude was also suggested for geminates [15] connected with high peak velocity due to the positive correlation generally observed between these two parameters. Lengthening the articulatory constriction may also be achieved by increasing the relative deceleration phase of its closing movement and the relative acceleration phase of its opening movement [2, 9] to maintain the articulator as long as possible close to its target.

The alternative hypothesis claims that a geminate is produced as a cluster of two overlapped identical consonants, i.e. involving mainly intergestural (or coproduction) mechanisms. Hypothesis2 predicts that single and geminate consonants would have comparable spatiotemporal and kinematic properties for their closing and opening movements.

Vowel shortening before geminate has also been reported: clearly present in Italian [23], but slight or absent in Arabic [8, 11, 22]. This shortening is generally attributed to a different temporal coordination between single and geminate consonants with the preceding vowel. The substantial [i] shortening in Italian –ibba- compared to –iba context, was largely attributed by Smith [21] to the constant vowel-to-vowel time interval (i-a).

For Benus [2] the single/geminate contrast "seems to primarily involve intra-gestural characteristics". However, observation at least from [22], but limited to few speakers and plosive types, seem more in accordance with the first (intergestural) hypothesis. Using Moroccan Arabic (MA) data, we test these two articulatory hypotheses related to the single/geminate distinction. All MA consonants contrast with their geminate cognates intervocalically. Due to space limitations, we discuss the articulatory differences between single/geminate /b t k/ only (/p/ not attested in MA).

2. METHOD

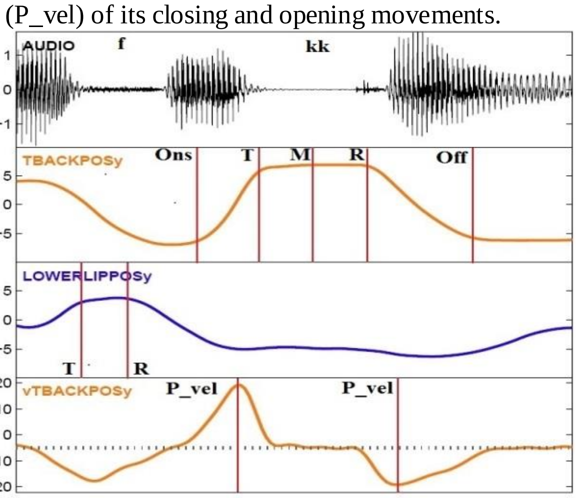
During a 3-dimensional EMA study (AG500 Carstens Medizinelektronik, 200Hz), 3 native speakers (S1-S2-S3) of MA have pronounced (8 times) words and a few pseudo-words with /b t k bb tt kk/ in $C_1a_1C_2(C_2)a_2$ items (see Tab. 1). These stimuli were designed to investigate single/geminate spatiotemporal differences. Items with b/bb in ab(b)i and ab(b)u were also pronounced by these 3 subjects (8 times) to test the single/geminate consonant effect on V_1-to-V_2 temporal intervals. Each item, with a lexical accent on the first syllable, was embedded in the carrier sentence /ʒibi _ hnaja/ (‘bring _ here’).

2.1 C/CC articulatory differences in $C_1a_1C_2(C_2)a_2$

The articulator movements were tracked with sensors placed on tongue tip (TTIP), tongue blade (TBLD), tongue dorsum (TDOR) and lower lip (LLIP) and displayed with Mview (a program developed by M. Tiedie of *Haskins Laboratories*). For each consonant, we automatically identify its Onset, Peak closing velocity, Target, Maximal constriction, Release, Peak opening velocity and Offset positions (Fig. 1) based on the tangential velocity trace (20% threshold) of its opening and closing vertical movements. The label cursor at the Maximal constriction was shifted manually to the plateau midpoint position (M), which is a more relevant landmark for our case study.

From these temporal landmarks, we calculated the closing (T-Ons), plateau (R-T) and opening (Off-R) phase duration of $C_2(C_2)$’s gesture (Fig. 1).

Figure 1: Audio signal, vertical position (mm) traces of TDOR and ULIP, and velocity trace (cm/s) of TDORy during [fa_1kka_2]. With Onset (ons), Target (T), Medial (M), Release (R) and Offset (off) gesture positions and peak velocity (P_vel) of its closing and opening movements.



The amplitudes, peak velocity and the y-values at Onset, Target, Midpoint, Release, and Offset were extracted automatically. The amplitudes are the Euclidian distance from Ons to T and R to Off for the closing and opening movements respectively.

For the degree of overlap between $C_2(C_2)$ and a_1 in $C_1a_1C_2(C_2)a_2$, we measured two temporal intervals: from C_1 Release to $C_2(C_2)$ Onset (Fig. 1=[kk]Onset–[f]Release) and C_1 Release to $C_2(C_2)$ Target (Fig.1=[kk]Target–[f]release). The C_1 gesture is captured by TTIPy in $da_1b(b)a_2$ and TDORy in ba_1ka_2 and fa_1kka_2. In $ħa_1t(t)a_2$, [ħ] shows substantial jaw lowering which reaches its maximal low position during [ħ]. Substantial jaw lowering during [ħ] was also reported by several previous studies [4, 5, 14], and considered by Elgendy [4] as an active gesture. Based on these observations, JAWy lowering is taken in our study as [ħ] gesture.

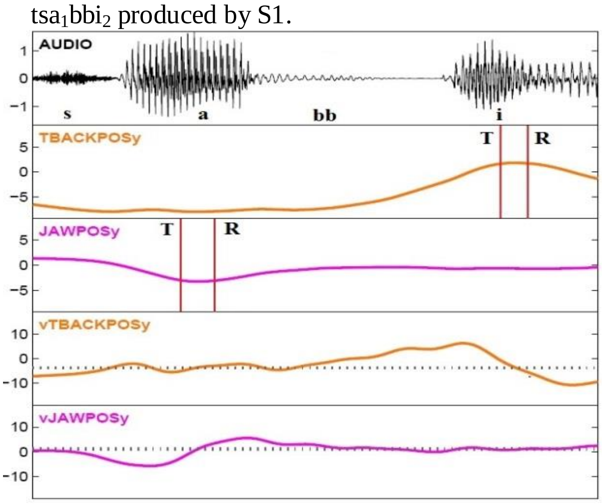
Table 1: Stimuli used in our EMA experiment.

Spea.	Item	Gloss	Item	Gloss
(S_1 S_2 S_3)	[daba]	Now	[dabba]	Beast
	*[ħata]	Non-word	[ħatta]	To fall out
	*[baka]	Non-word	[fakka]	To separate
S_1	[nsabi]	My siblings-in-law	[tsabbi]	You quarrel
S_2 S_3	[nsabu]	His siblings-in-law	[tsabbu]	They quarrel

2.2 V_1-to-V_2 temporal differences in $V_1b(b)V_2$ contexts

The V_1-to-V_2 interval was measured in $a_1b(b)i_2$ and $ab(b)u_2$ produced by S1 and S2-S3 respectively where the articulatory gestures were relatively clearly defined. In $a_1b(b)i_2$, a_1 and i_2 gestural landmarks were identified on JAWy (lowering and raising movements) and TDORy (raising and lowering movements) traces respectively (Fig. 2). a_1-to-i_2 was measured from JAWy Release to TDORy Target (Fig. 2). In $a_1b(b)u_2$, u_2 articulatory landmarks were located on TDORx (backward and forward movements) trace. a_1-to-u_2 corresponds to the time between JAWy Release and TDORx Target. We also quantify the interval duration from JAWy Release to LLIPy Target, Midpoint and Release.

Figure 2: Audio, vertical positions (mm) and velocity (cm/s) traces of TDORy and JAWy in tsa_1bbi_2 produced by S1.



2.3. Acoustic measures

Duration of the closure and burst of $C_2(C_2)$ plosives, as well as a_1 were measured in all our items.

3. RESULTS AND DISCUSSION

Table 2: Mean values (ms) and mean ratio of a_1 and C(C) duration in $a_1C(C)a_2$ pronounced (8 times) by S1-S2-S3 speakers (ns. No=significant, ***: <0.0001).

.	a_1			C(C)		
$a_1C(C)a_2$	S1	S2	S3	S1	S2	S3
a_1ba_2	109	90	93	89	62	79
a_1bba_2	98	74	84	161	116	122
a_1ka_2	102	61	70	127	96	91
a_1kka_2	81	44	69	180	137	127
a_1ta_2	98	80	82	129	102	98
a_1tta_2	77	59	73	178	134	131
p bb/b	ns 0.90	*** 0.83	ns 0.91	*** 1.81	*** 1.87	*** 1.55
p tt/t	*** 0.80	*** 0.71	ns 0.98	*** 1.41	*** 1.43	*** 1.39
p kk/k	*** 0.78	*** 0.74	ns 0.88	*** 1.38	*** 1.31	*** 1.33

3.1 Acoustic durations in a_1C_2 $(C_2)a_2$ contexts

A two-way ANOVA show that consonant duration (closure+VOT) in $a_1C(C)a_2$ varies with single/geminate [df=1, F=343.17, p<0.0001] and speaker [df=2, F=88.14, p<0.0001] factors; their interaction [df=2, F=8.22, p=0.0004] is significant. Scheffé post hoc analyses of three separate one-way ANOVAs (Tab. 2) also indicate that all the geminate/single differences are significant (p<0.0001) and exceed 20% which is generally taken as the JND [20] for acoustic duration.

Two-way ANOVA shows that a_1 duration varies significantly with single/geminate [df=1, F=53.20, p<0.0001] and speaker [df=2, F=66.21, p<0.0001] with slight interaction between these two factors [df=2, F=4.31, p=0.015]. Post hoc analyses of three separate one-way ANOVAs revealed, for S2, a more pronounced a_1 shortening before all the geminates (p<0.0001) which reaches 20% only before /tt kk/. For S3, a_1 shortening before the geminate compared to the single cognate is also observed but is always non-significant, while for S1, this shortening is significant only before /tt kk/ but not /t k/.

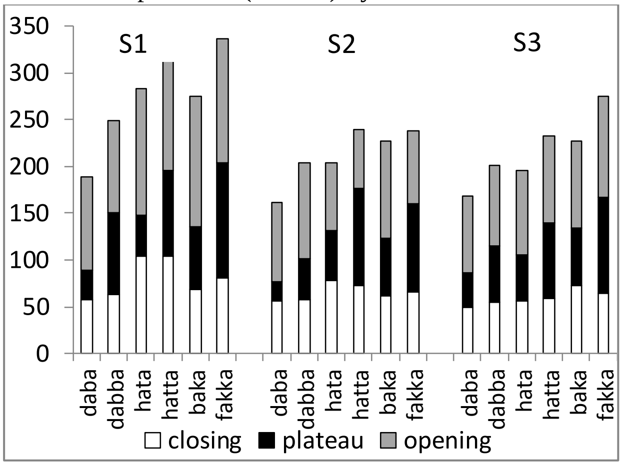
3.2 Articulatory measurements in $a_1C(C)a_2$ contexts

Geminate plateau duration also varies significantly with subjects [df=2, F=4.96, p=0.0083] and single/geminate [df=2, F=157,9, p<0.0001] factors. Their interaction [df=2, F=5,05, p=0.008] is also significant. Scheffé post-hoc analyses of 3 separate one-way ANOVAs (Tab. 3, Fig.3) revealed that for S1-S2-S3, /bb tt kk/ plateau durations are substantially higher (p<0.0001) than their single cognates

Table 3: Geminate/single ratio duration comparison of plateau $C_2(C_2)$ gesture produced (8 times) in $a_1C(C)a_2$ by S1-S2-S3 speakers (***: <0.0001)

Duration ratio	Geminate/single plateau duration		
	S1	S2	S3
bb/b	2.78 (***)	2.29 (***)	1.60 (***)
tt/t	1.83 (***)	1.97 (***)	1.61 (***)
kk/k	2.10 (***)	1.52 (***)	1.63 (***)

Figure 3: Closing, plateau and opening phase durations (ms) of C(C) gestures in $a_1C(C)a_2$ contexts produced (8 times) by S1-S2-S3.



Two other two-way ANOVAs show that closing (i) and opening movement (ii) duration vary significantly with subject [(i): df=2, F=25.28, p<0.0001; (ii): df=2, F=51.08, p<0.0001] but not with single/geminate [(i): df=1, F=0.65, p=0.42. (i): df=1, F=0.23, p=0.63] factors. Their interaction is also non-significant [(i): df=2, F=1.72, p=0.35. (i): df=2, F=1.70, p=0.19]. Post-hoc analyses of three separate one-way ANOVAs revealed that all geminate/single comparisons are non-significant except for closing phase of /kk vs k/ produced by S1. Based on two separate two-way ANOVAs we observe that the temporal interval from C1_Release to C2_Onset (i) and from C1_Release to C2_Target (ii) vary significantly with subject [(i) df=1, F=343.17, p<0.0001); (ii) df=1, F=343.17, p<0.0001)] but not with single/geminate factors [(i) df=1, F=343.17, p<0.0001); (ii) df=1, F=343.17, p<0.0001)]. Interactions between these two factors were not significant. For the two gestural intervals, post hoc analyses of separate one-way ANOVAs show that except for C1_Release to C2_Onset during [kk k] produced by S1, all the geminate/single comparisons are not significant (Tab. 4). These two patterns with the same closing movement duration reported during CC/C, suggest that single and geminates cognate have similar degree of overlap with a_1. Acoustic a_1 shortening before geminate for S1-S2 seems a consequence of laryngeal and/or aerodynamic adjustments.

Table 4: Geminate/single comparisons between [C1_Release to $C_2(C_2)$_Onset] and [C1_Release to $C_2(C_2)$_Target] interval durations in $C_1a_1C_2(C_2)a_2$ pronounced (8 times) by S1-S2-S3. Ns= non-significant.

	S1		S2		S3	
$a_1C(C)a_2$	C_1_R C_2_O	C_1_R C_2_T	C_1_R C_2_O	C_1_R C_2_T	C_1_R C_2_O	C_1_R C_2_T
bb/b	ns	ns	ns	ns	ns	ns
tt/t	ns	ns	ns	ns	ns	ns
kk/k	=0.009	ns	ns	ns	ns	ns

Separate two-way ANOVAs were conducted with single/geminate and subjects as independent variables and velocity and amplitude of closing and opening movements as dependent variables. For the closing movement, geminate velocity (df=1, F=1.03, p=0.31) and amplitude (df=1, F=0.84, p=0.36) are not significantly different compared to their single cognates. The factor of subject is significant only for velocity (df=2, F=49.47, p<0.0001). For velocity and amplitude, the two factor interactions are not significant. For opening movement, amplitude (df=1, F=5.25, p=0.02) and especially velocity (df=1, F=9.22, p=0.003) during the geminate are significantly higher than during the single cognate; subject factor and its interaction with single/geminate are not significant.
Combining these kinematic results with the temporal ones we can deduce that closing and opening phases of the geminate gesture share several properties with those of its single cognate.

3.3 V_1-to-V_2 temporal differences in $a_1b(b)i_2$ / $a_1b(b)u_2$

Separate one factor ANOVAs on the data for each speaker show substantially longer plateau duration but similar closing movement duration during /bb vs b/ pronounced by S1 in $a_1b(b)i_2$ and S2-S3 in $ab(b)u_2$ (Tab. 5). /bb vs b/ opening duration is significantly different only for S3. These temporal patterns are generally parallel to those observed in $C_1a_1C_2(C_2)a_2$.
Compared to single context, V1_Release to C_Target interval in geminate context, produced by S1, stays constant but reduces significantly for S2-S3 (p<0.05). For S1-S2-S3, our measures revealed longer V_1-to-V_2 duration in the geminate than in single context. Additional data also show that the duration from a_1 release to $C_2(C_2)$ release is significantly longer in geminate than single context.
These results are not in accordance with Öhman [17] which proposes that the vowels and consonants are programmed separately and predicts a constant V_1-to-V_2 duration in geminate and single context. These observations, combined with those reported in section 3.2, seem more in accord with the hypothesis that a geminate is a sequence of two identical consonants. Its first half is temporally coordinated with both the preceding vowel and its second half.

Table 5: Mean duration (ms) of closing, plateau and opening $C_2(C_2)$ phases pronounced (8 times) by S1 in $a_1b(b)i_2$ and by S2-S3 in $a_1b(b)u_2$ with temporal intervals from a_1_release to V_2_target, $C_2(C_2)$_target and to $C_2(C_2)$_Release.

		Clo.	Plat.	Open	V_1-to-V_2	V_1-to C_2_T	V_1-to C_2_R
S1	abi	55.0	35.0	98.1	168.8	53	88
	abbi	56.9	88.8	102.2	236.3	51	139
	p	ns	***	ns	***	Ns	***
S2	abu	47.5	20.0	77.5	95.6	44	64
	abbu	51.9	42.9	61.9	125.0	35	79
	P	ns	***	ns	***	=0.02	0.003
S3	Abu	50.0	43.8	91.3	134.4	51	95
	abbu	50.0	63.1	48.1	177.5	44	108
	p	ns	***	***	***	=0.01	0.003

4. CONCLUSION

Data from three Moroccan Arabic speakers revealed that /bb tt kk/ have substantially longer acoustic and articulatory constriction than their single counterparts. Vowel shortening before a geminate consonant was also observed but only for 2 speakers. The opening and mainly particularly the closing movements of /bb tt kk/ gestures have similar temporal (duration) and kinematic (velocity and amplitude) properties compared to /b t k/.
These observations combined with our analyses of V-to-V and V-to-C temporal coordination are consistent with the hypothesis that the geminates examined here can be analysed as sequences of two identical overlapped consonants. It seems that MA geminate realisation is dependent mainly on intergestural articulatory adjustments.
Further kinematic (velocity profile, stiffness) and spatial measurements (articulator height position) are needed to test the potential contribution of the intragestural strategies, in addition to the intergestural ones, to the production of the single/geminate contrast in MA.

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