Gestural overlap within word medial stop-stop sequences in Moroccan Arabic

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Abstract

This paper deals with the factors behind temporal overlap differences in word medial [bd, db, bg, gb, gd, dg] clusters produced by speakers of Moroccan Arabic (MA). It is argued that certain overlap differences in these MA clusters are related to motor constraints. Specifically, these differences can be attributed to intrinsic physiological properties of the main articulator of each consonant or to constraints in coordinating adjacent consonants due to (presence or absence of) the biomechanical linkage of their articulators. The reported effects weaken the explanatory power of the previously proposed perceptual basis for the place order effect.

Keywords: EMA, gestural overlap, stop-stop clusters, gestural coordination, speech production.

1. Introduction

This paper addresses perceptual and physiological factors behind the temporal overlap differences between [bd, db, bg, gb, gd, dg] produced within Moroccan Arabic (MA) items. Our focus is on stop-stop combinations where no categorical place (nor voicing) assimilation have been previously reported.

Previous studies (e.g. Chitoran et al. 2002) have shown that the amount of intergestural overlap in the C1C2 stop-stop sequences is greater in word medial than word initial position (the so-called Word Position Effect), and when C1 has a more anterior place of articulation than C2 compared to the posterior (post)-anterior (ant) order (the so-called: Place Order Effect). These two effects are generally attributed to perceptual factors. Since word initial position is crucial for lexical access (Marslen-Wilson 1987), less overlap is expected in this position to enhance the recoverability of the stop-stop sequence. A relatively higher degree of overlap within C1C2 stop-stop sequences is expected in the ant-post than in the post-ant place order, since C1 release can still be perceived only in the first order improving its recoverability.

More recent studies have shown place order effects (POE) even between plosive/non-plosive sequences. Kühnert et al. (2006) reported more overlap in [pl, fl] and [pn, fn] compared to [kl] and [kn] respectively). According to these authors, this POE between stop-liquid and stop-nasal clusters seems to be “due to low-level motor constraints rather than considerations of perceptual recoverability”. Indeed in [pl, pn], the tongue tip is free to move during C1 without significantly influencing its articulatory and acoustic properties, while in [kl, kn], anticipation of tongue tip/blade movement for [l, n] is antagonistic with the dorsal articulation of [k]. Notice that in [kp] a low degree of overlap has been reported (Kochetov et al. 2007); this result is not predicted by Kühnert et al.’s (2006) physiological hypothesis, since in [kp] the two consonants involve non-connected articulators. Chitoran et al. (2006), also reported more overlap in ant-post [pl, pr] than in post-ant [kl, kr] respectively. This pattern suggests, according to these authors, that POE “may be a lexically specified pattern” independent of the substance of the phonological forms.

Chitoran et al. (2002) reported an articulatory regularity that they consider as an "unpredicted effect of place combination”. They observed “that combinations of labial and coronal stops are the least overlapped” compared to lab-dor and cor-dor. This regularity is also observed and discussed in our present study.

Previous physiological studies have also shown that the overlap can vary across languages. Based on acoustic data, Zsiga (2000) observed that stop-stop clusters produced across word boundary (C#C) are more often released in Russian than in English, suggesting less overlap in the former than in the latter. Recently, Gao et al. (2011) reported more coproduction within [p#k] and especially [p#t] sequences in Taiwanese than in English. These cross-linguistic articulatory differences show that languages exhibit specific coordination patterns. According to Kochetov et al. (2007), language-particular differences in “the degree of overlap may be related to the propensity of a language to assimilate in consonant clusters”. More precisely, they propose to relate the higher degree of overlap in Korean than in Russian to the presence of a place assimilation only in the former.

Existing cross-linguistic articulatory studies are not exhaustive enough to provide irrefutable evidence for potential relations between cross-linguistic asymmetrical place assimilations and some parallel spatio-temporal patterns. It is also not clear if regressive place assimilation within C1C2 sequences is due to the overlap of C1 by C2 (Browman and Goldstein, 1992; Son et al. 2007), (spatial or temporal) reduction of C1 (Jun, 1996), or a combination of the two factors. Since regressive place assimilations are more common than progressive ones (Steriade, 2001), our articulatory measurements will quantify the amount of C2 anticipation during C1 in stop-stop sequences. We examine whether a coronal C1 is more overlapped than labial and dorsal, since cross-linguistically the former tends to undergo regressive place assimilation more frequently than the latter do (Jun, 2004; Steriade, 2001). We will also check whether dorsal C2 is more anticipated than labial and coronal, since the former triggers regressive place assimilation more than the latter ones (Jun, 2004).

In a recent articulatory study on MA, Gafos et al. (2010) find that heterorganic stop-stop sequences of MA are almost always produced with open-transition or released C1, suggesting less overlap. This characteristic may be related to the absence of categorical place (or voicing) assimilation between radical intervocalic consonants in MA.

In this paper, the main focus is on the potential effect of low-level motor constraints on temporal coordinations. For this reason, we focus our discussions on MA [bd, db, bg, gb, dg, gb], produced word medially where a relatively great overlap and no categorical place (nor voicing) assimilation are expected. If some gestural overlap differences are physiologically based, they should still be present between these MA sequences.

2. Method

2.1. Subjects and stimuli

The stimuli of this study are selected from two large corpora recorded separately, with the 3-dimensional EMA technique (AG500 Carstens Medizinelektronik, Hoole et al. 2010), to test several hypotheses. Only items with intervocalic [bd, db, bg, gb, gd, dg] (table 1) pronounced 5 times by 2 speakers (S4, S5) in [galha ___hnaja] ('he told her (it) _ here') from a first recording and [bd, db, bg, gb, gd] pronounced 8 times by 3 other speakers (S1, S2, S3) in /ʒibi _ hnaja/ ('bring _ here') from a second are analyzed here. Our talkers are MA native speakers aged between 29 and 40 years and with no known history of speech or hearing disorders.
The items have the same morphological form /CaCC+a/ where the radical is the active participle and /+a/ 3prs fem sg object suffix. The lexical accent is on the first vowel. We chose aCCa where the movements of lingual and labial gestures are clearly identified and coarticulate relatively weakly with the vowels.

Table 1: *List of stimuli pronounced buy our 5 speakers during two EMA recordings. All the items are the same except [kadba] pronounced in the first recording by S4 and S5 (5 tokens) instead of [nadba] in the second by S1, S2 and S3 (8 tokens).*

Stimuli + glosses	[CC]		Stimuli + glosses
[ʒabda] 'to pull'	[bd]	[db]	[kadba] 'to lie' [nadba] 'to whine'
[sabga] 'to be ahead'	[bg]	[gb]	[ragba] 'to appear'
[fadga] 'to crack'	[dg]	[dg]	[ragda] 'to sleep'

2.2. Analysis

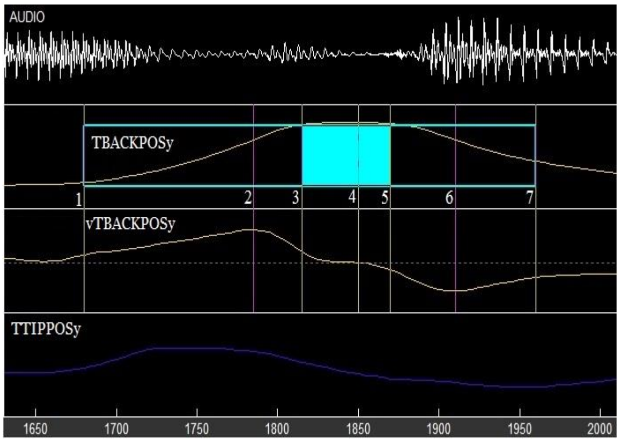

Figure 1: *Traces of audio, tongue-back vertical movement (TBACKPOSy), its velocity (vTBACKPOSy), and tongue tip vertical movement (TTIPPOSy) during [-adga-]; with spatio-temporal positions at TBACKy Onset (1), Peak velocity of closing movement (2), Target (3), Maximal constriction (4), Release (5), Peak velocity of opening movement (6) and Offset (7).*

This 3-dimensional EMA technique enabled us to track movements of the tongue tip (TTIP), blade (TB), dorsum (TBACK), upper and lower lips (LLIP), and the jaw with sensors placed on these articulators (sample rate 200Hz). The Mview program (developed initially by M. Tiede from Haskins Laboratories) permits to display the spatio-temporal coordinates of the vertical and horizontal movements of each articulator, as well as the evolution of its velocity and acceleration. For each gesture, several landmarks have been identified automatically from the velocity trace (20% threshold) of its opening and closing movements (Fig. 1).
Several spatio-temporal and kinematic measurements were extracted automatically on TTIPy, TBACKy and LLIPy traces (Fig. 1): (i) Temporal and spatial coordinates at onset, target, maximal constriction, release and offset positions. (ii) The peak velocity and the amplitude of the closing and the opening vertical movements of C1 and C2 gestures.
Based on these parameters, we calculate the degree of gestural overlap within our consonant sequences using the formula given in Fig. 2.

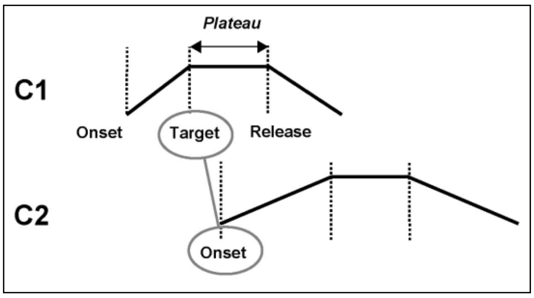

Figure 2: Temporal gestural overlap within C1C2 cluster. Overlap = 1 - (Onset C2 - Target C1)/(Plateau C1). Overlap > 1, C2 Onset occurs before C1 Target; between 0 and 1, C2 Onset occurs during C1 plateau; Overlap = 0, C2 Onset occurs at same time as C1 Release; Overlap < 0, C2 Onset occurs after C1 Release.

3. Results and discussion

Single factor ANOVA tests run on the data of each subject, show that the degree of overlap varies significantly with the cluster type (table 2). Post-hoc analyses (table 3, Fig. 3) will be used for more detailed comparisons. Additional statistical analyses will also be presented below to quantify the potential contribution of some other factors, especially physiological ones, to these overlap differences.

Table 2. *Mean values (and standard deviations) of gestural overlap within MA voiced stop-stop.*

		[bd]	[db]	[bg]	[gb]	[dg]	[gd]
S1	[F(5, 42)=30.83, p < 0.0001]	0.85 0.43	0.97 0.55	2.58 0.61	0.66 0.15	2.81 0.90	0.33 0.23
S2	[F(5 , 35=82.10, p < 0.0001]	0.57 0.29	0.07 0.11	2.46 0.57	0.19 0.20	2.40 0.48	-0.09 0.18
S3	[F(5 , 39=9.56, p < 0.0001]	0.44 0.23	0.08 0.15	1.12 0.71	0.39 0.16	0.99 0.24	0.75 0.31
S4	[F(5 , 24=9.17, p < 0.0001]	1.15 0.29	0.52 0.96	1.44 0.29	0.40 0.60	2.66 0.8	0.61 0.53
S5	[F(5 , 27=8.13, p < 0.0001]	0.81 0.45	0.20 0.50	1.48 0.95	1.29 0.26	2.02 0.45	0.87 0.12

3.1. Place order and place combination effects

A two-way ANOVA over all subjects in a repeated measure model shows that the degree of overlap varies significantly with place order (ant-post, post-ant: [df=1, F=20.44, p=0.0106]) and place combinations (lab-cor, cor-dor, lab-dor; [df=18.89, p<0.0001]), with a significant interaction [df=2, F=4.80, p=0.04].

Table 3. *Gestural overlap (mean differences) comparisons between place combinations done on the data of each speaker*: ****=p<0.001; **=p<0.01; *=p< 0.5; ns=not significant*).

	bd/db	bg/gb	dg/gd	bd/bg	db/dg	gb/gd
S1	-0.12 ns	1.91 ***	2.47 ***	-1.72 ***	-1.84 ***	0.33 ns
S2	0.50 **	2.26 ***	2.49 ***	-1.89 ***	-2.33 ***	0.29 ns
S3	0.36 *	0.73 ***	0.24 Ns	-0.67 ***	-0.91 ***	-0.37 *
S4	0.63 ns	1.04 *	2.05 ***	-0.29 ns	-2.13 ***	-0.21 ns
S5	0.61 ns	0.19 ns	1.15 **	-0.67 *	-1.82 ***	0.42 ns

Post-hoc analyses of the separate two-way ANOVA tests on the data of each speaker show significantly more overlap in ant-post than post-ant sequences for all subjects (table 4). This result is consistent with previous studies (see introduction). Based on the comparisons between place combinations presented in table 3 and Fig. 3, we observe that, for all our speakers, mean overlap differences between [bd vs db], [bg vs. gb] and [dg vs gd] are positive, with a smaller mean difference between [bd] vs [db]. Indeed, [bd vs db] is significant only for two speakers, while [bg vs. gb] and [dg vs gd] are significant for 4 speakers (table 3). Within word medial MA stop-stop sequences, the place order effect seems to be only partly involved in overlap differences (see Gafos et al., 2010 for details on how the effect plays out in initial, medial and final positions).

Table 4. *Gestural overlap (mean) differences between voiced stop-stop clusters classified by place order (data of each speaker). ***=p<0.001; **=p<0.01; *=p< 0.5; ns=not significant*).

Subjects	Ant-post vs post-ant	Post-hoc comparisons
S1	1.43	< 0.0001
S2	1.61	< 0.0001
S3	0.42	0.0003
S4	1.24	< 0.0001
S5	0.72	0.0006

Post-hoc analyses of the separate two-way ANOVA also show that cor-lab exhibits a significantly less degree of overlap than lab-dor and dor-cor combinations (table 5). As mentioned earlier, Chitoran et al. (2002) also reported less degree of overlap within cor-lab sequences. Chitoran et al. (2002) associated this result to the fact that “cross-linguistically, double articulations of labials and coronals are not attested”. Notice that Ladefoged and Maddieson (1996) did not report such segments, while for Sagey (1986) /pt/ is attested in Margi as a “complex segment”. We believe that the relationship between the degree of overlap within a cluster and the tendency to have cross-linguistically a corresponding “complex segment” is not straightforward. Indeed, labial-velar /gb/ is attested in many West-African languages and is produced by two gestures that are almost synchronous (Ladefoged and Maddieson, 1996). However, our data show that MA /gb/ generally develops less overlap (table 2).

Notice that Gao et al. (2011) reported that, in Taiwanese, /pt/ exhibits greater overlap than /pk/ which seems not in accord with the place combination effect that we have observed in MA and also reported by Chitoran et al. (2002) for Georgian. To explain this gestural pattern during Taiwanese /pt/, and since it is widely admitted that the jaw is involved to achieve /p/ and /t/ constrictions (Keating, et al. 1994, Goldstein, 1994, Mooshammer, et al. 2006), Gao et al. (2011) suggest that “a possible explanation is that it is more natural and more ‘economic’ to articulate [p] and [t] in a near-synchronous manner”. We think that this physiological hypothesis may also predict lower degree of overlap within cor-lab or lab-cor sequences. Indeed, within these stop-stop sequences, the raised jaw position during C1 may permit the lower lip (in cor-lab) or tongue tip/blade (in lab-cor) to start rising from a relatively high position and to travel a relatively short distance before reaching C2 target; as a consequence, the main articulator for the C2 gesture may start later in lab-cor and cor-lab than in lab-dor and dor-cor sequences.

Table 5. *Gestural overlap (mean differences) comparisons between voiced stop-stop clusters classified by place combinations (data of each speaker): ***=p<0.001; **=p<0.01; *=p< 0.5; ns=not significant*).

Ant-post	S1	S2	S3	S4	S5
lab-cor vs. lab-dor	-0.71 ***	-1.00 ***	-0.47 ***	-0.08 ns	-0.92 ***
lab-cor vs. dor-cor	-0.66 ***	-0.54 ***	-0.60 ***	-0.80 **	-1.02 ***
lab-dor vs. dor-cor	0.05 ns	0.46 ***	-0.13 ns	-0.72 *	-0.10 ns

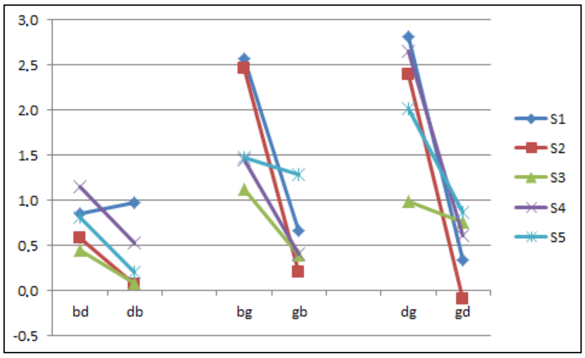

Figure 3: *Degree of overlap differences between ant-post [bd, db, bg] sequences and their post-ant [gb, dg, gd] correspondent pronounced by 5 MA speakers.*

3.2. C1 and C2 place effects

Table 6. *Mean values of the degree of overlap within C1C2 stop-stop sequences pronounced by 5 MA speakers and classified by the place of articulation of C1 and C2. Statistical comparisons are also given.*

		[d]	[b]	[g]	b vs d	g vs b	g vs d
C1	S1	1.90	1.71	0.50	ns	***	***
	S2	0.96	1.39	0.03	ns	***	***
	S3	0.47	0.75	0.57	ns	ns	ns
	S4	1.59	1.30	0.50	ns	0.55	*
	S5	1.11	1.17	1.10	ns	ns	ns
C2	S1	0.60	0.94	2.67	ns	***	***
	S2	0.24	0.12	2.43	ns	***	***
	S3	0.60	0.23	1.06	**	***	**
	S4	0.88	0.46	2.05	ns	***	**
	S5	0.83	0.70	1.75	ns	***	**

Separate ANOVA tests, show that the overlap varies significantly with C1 place of articulation for three speakers (S1: [F(2, 45)=10,95, p=0.0001; S2 [F(2,38)=7.78, p=0,0015, and S4: [F(2, 27)=4.03, p=0.03). Post-hoc analyses (Table 6) confirm that for these subjects the overlap of C1 by C2 is significantly greater when C1 is a labial or coronal ([b vs d] not significant) than when it is a velar ([g vs b] and [g vs d] significant). Table 3 also shows that, for almost all our subjects, while [bd] vs [bg] and [db] vs [dg] overlap differences are negative and significant, [gb] vs [gd] are not significant. These results are parallel to cross-linguistic asymmetrical patterns of regressive place assimilations (velar less prone to undergo place assimilation), suggesting that these assimilation patterns and the degree of overlap differences may be connected.

Separate ANOVA tests confirm that for all speakers the degree of overlap within C1C2 stop-stop sequences also relies on the C2 place of articulation ($p<0.001$). Post-hoc analyses (table 6) show that the anticipation of C2 during C1 is more substantial when the former is a velar consonant ([g vs b] and [g vs d] highly different for all subjects) and lower when it is coronal or labial ([b vs. d] non-significant for four subjects). These results also agree with patterns of asymmetrical place assimilations (velar more prone to trigger place assimilation). Notice that Gao et al. (2011) also reported that [pk] has in English a greater overlap than [pt] suggesting more anticipation of C2 in [pk] sequence than [pt].

4. Conclusion

Moroccan Arabic shows, within its word medial [bd, db, dg, bg, gb, gd], overlap differences that are in the same direction as the asymmetrical patterns of regressive place assimilations observed cross-linguistically even though this language does not exhibit categorical place assimilation in this context. This result supports the hypothesis that phonological assimilation has a basis in temporal overlap patterns (Ohala, 1990). To our knowledge, evidence for this correlation between cross-linguistic assimilation patterns and overlap patterns is documented here for the first time in a language with open transitions in clusters.

Our present study shows that several overlap pattern variations within MA stop-stop clusters are related to motor constraints (biomechanical constraints). These physiological explanations seem to weaken the explanatory power of the previously proposed perceptual basis for the place order effect.

More articulatory, acoustic and perceptual research is needed to establish a complete picture of the full interactions between physiological, perceptual and grammatical factors potentially responsible for the spatio-temporal coordination differences.

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