VOWEL-to-CONSONANT COARTICULATION IN MOROCCAN ARABIC

Chakir Zeroual[1,2], Phil Hoole[3], Adamantios Gafos[4]

[1]*University Mohammed First, Oujda-Morocco;* [2]*Laboratoire de Phonétique et Phonologie UMR-7018 Paris-France;* [3]*Institute of Phonetics and Speech Processing, Munich-Germany,* [4]*Universität of Potsdam, Germany*

c.zeroual@ump.ac.ma hoole@phonetik.uni-muenchen.de adamantios.gafos@uni-potsdam.de

ABSTRACT

The richness of consonant contrasts in MA offers an opportunity to test hypotheses about contextual variability of tongue positions during /C/ and /V/ in /VCV/ symmetric vowel contexts. This study focuses on V-to-C coarticulation influence and aims to better characterize for the first time the degree of such coarticulation as a function of the different primary and secondary articulations of MA consonants. Our physiological investigations confirm our main hypothesis that contextual variability of tongue positions during /C/ is greater in regions not involved in its closure or the formation of the constriction for that /C/.

Keywords: speech production, Arabic, EMA, coarticulation

1. INTRODUCTION

Moroccan Arabic (MA) is characterized by its very rich consonant system with several place and manner contrasts as well as two secondary articulations: labialisation and pharyngealisation [13, 15]. This richness of contrasts in MA therefore offers an opportunity to test hypotheses about contextual variability of tongue positions during /C/ and /V/ in the /VCV/ contexts we examine in our present study.

Our hypothesis is that contextual variability of tongue positions during /C/ is greater in tongue regions not involved in the constriction formation of the /C/ [5, 9]. This central hypothesis has been motivated on the basis of a wide range of facts, starting with the earliest observations by Öhman on the absence of V-to-V coarticulation in a /VCV/ contexts when the C is palatalized (versus its presence when the /C/ involves no tongue body gesture) and including, more recently, results concerning the higher degree of V-to-C coarticulation at the tongue dorsum for plain coronals, e.g., /n/ and non-velarized /l/ [10]. It is of course expected that lingual V-to-C coarticulation is maximal when the consonant is produced without tongue involvement. The higher degree of lingual V-to-C coarticulation during labial [10] or laryngeal /C/ [12, 14, 15] is consistent with this hypothesis.

We aim to assess this hypothesis in MA, taking advantage of the presence of contrasts and places of articulation not present in the languages or datasets that originally motivated it. Specifically, as we will see in the forthcoming, the presence of an apicality-laminality distinction in the MA coronals and the presence of a dorsal vs. post-dorsal contrast offer good testing ground for assessing and sharpening the original hypothesis. Regarding the latter contrast, physiological data from MA [14, 15] and modern Arabic dialects [8, 3, 6] show that Arabic has epiglottal and not pharyngeal consonants. Their primary articulation is at the supraglottic and/or aryepiglottic level produced with tongue root and epiglottis retraction. They are therefore more similar to the laryngeals and should thus exhibit a less resistance to V-to-C coarticulation at the anterior part of the tongue (compared to other consonants in which these regions are crucially implicated).

Overall, thus, this study focuses on V-to-C coarticulation, aiming to better characterize for the first time the degree of such coarticulation as a function of the different primary and secondary articulations of MA consonants.

2. METHOD

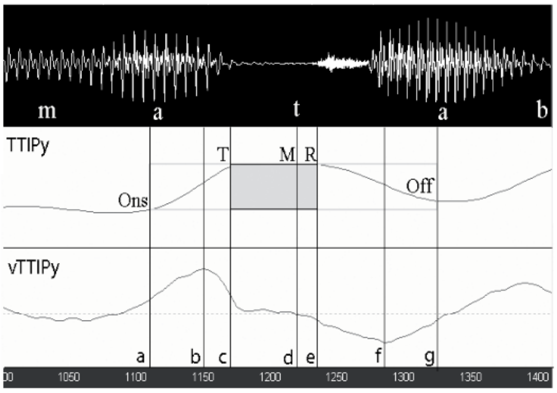
MA non-pharyngealized /b t s l k q χ ħ h/ and pharyngealised /S T/ were pronounced (8 times) by 3 native MA (male) speakers in /-aCa-/ and /-iCi-/ contexts which were parts of real words. Due to space limitations, only data from S1 are presented.

Using electomagnetometry (AG500 Carstens Medizinelektronik, [7]), we recorded (200Hz) the displacements of 6 articulators with sensors placed below the lower incisors (JAW), near the tongue tip (TTIT), the predorsum (TMID) the dorsum (TDOR) and the external extremity of the lower (LLIP) and upper lips (ULIP).

With a Matlab Mview program developed by M. Tiede (Haskins Laboratories), and for any given /C/'s, its articulatory gesture was automatically identified by its Onset, Peak closing velocity, Target, Maximal constriction, Release, Peak opening velocity and Offset timestamps (Fig. 1). The gestural Onset and Target positions landmarks correspond to the timepoints where the instantaneous velocity exceeds in the case of Onset, or falls below, in the case of Target a 20% threshold of its maximum value during the closing movement. The same threshold was used for identifying the Release and Offset landmarks during the opening movement for the /C/. Based on these timestamps, we calculated automatically several kinematic measurements (e.g. amplitudes and peak velocity of the closing and opening movements of the /C/'s gesture).

We also extracted automatically vertical (y-values) and horizontal (x-values) positions of the JAW, LLIP, ULIP, TTIP, TMID and TDOR articulators at the acoustic midpoint positions of the /V/ (used to quantify C-to-V coarticulation degree), and at the acoustic midpoint position of the /C/, which is the most relevant landmark for our case study, to quantify V-to-C coarticulation degree.

Figure 1: Traces of audio, tongue tip vertical movement (TTIPy) gesture, its velocity (vTTIPy), during /t/ in the MA word /matabʃ/, with spatio-temporal landmarks: Onset (a), Peak closing velocity (b), Target (c), Maximal constriction (d), Release (e), Peak opening velocity (f) and Offset (g).



In addition to the articulatory measures above, we measured: (i) the acoustic duration of /V_1/, /C/ and /V_2/; (ii) the formant values at the midpoint and offset of /V_1/ and at the onset and midpoint of /V_2/; and (iii) the VOT duration of the plosives.

Due to space, only TTIP, TMID and TDOR spatial variation is analyzed. Since V-to-C coarticulation is more substantial in the vertical than the horizontal dimension, we limit our analyses to the former dimension while taking into consideration results of JAW movements during MA consonants published in [16].

3. RESULTS AND DISCUSSIONS

We present our results graphically in Fig. 3 and numerically in Tab. 1 to have a more complete picture. Specifically, Fig. 3 provides the vertical and horizontal positions of TTIP, TMID and TDOR sensors at the acoustic midpoint of all our consonants /C/ produced in /iCi/ and /aCa/ contexts.

Three separated two-way ANOVA tests run on the data of each sensor show that the vertical position of these articulators vary with consonant type (TTIP [$F(10, 88)=267.22$, $p<0.0001$)]; TMID [$F(10, 88)= 182.74$, $p<0.0001$]; TDOR: [$F(10, 88)= 365.8$, $p<0.0001$)]) and with vowel context (TTIP [$F(1, 88)=45.43$, $p<0.0001$)]; TMID [$F(1, 88)=1443.17$, $p<0.0001$]; TDOR: [$F(1, 88)=2588.8$, $p<0.0001$)]). The interactions between these two factors are significant ($p<0.0001$). Tukey post-hoc comparisons (given in Tab. 1), for each statistical test, were used to identify in more detail the sources of the significant differences.

Figure 2: Mean differences (y-axis in mm) in TTIP, TMID and TDOR vertical positions at the acoustic midpoint of /b h t s l T S k χ q ħ/ (5 tokens) between the /iCi/ and /aCa/ context shown for each consonant C (see also M. Dif., in Tab. 1). Data are produced by one MA speaker (S1). NB. /tt ss hh x/ = /T S ħ χ/.

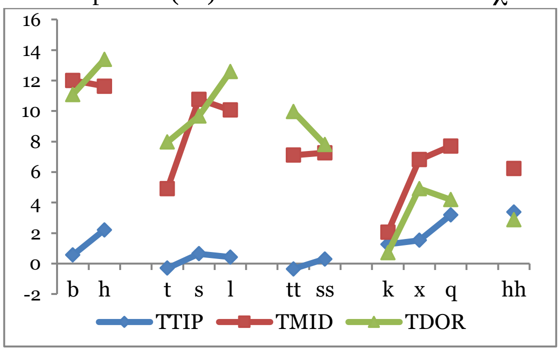


Table 1: Mean values of vertical positions (in mm) of the tongue tip (TTIP), tongue midpoint (TMID) and tongue dorsum (TDOR) at the acoustic midpoint of /b h t s l T S k χ q ħ/ (5 tokens) produced in /aCa/ and /iCi/ contexts by (S1), along with their mean differences (M. Dif) between these two contexts. ***: p < 0.001; **: p < 0.01; *: p < 0.5; ns = not significant.

/C/	TTIP			TMID			TDOR		
	iCi	aCa	M. Dif	iCi	aCa	M. Dif	iCi	aCa	M. Dif
/b/	-0.9	-1.5	0.6^{ns}	11.6	-0.3	12.0***	9.3	-1.8	11.1***
/h/	-2.1	-4.4	2.2*	13.0	1.3	11.6***	12.5	-0.9	13.4***
/t/	6.2	6.5	-0.3^{ns}	14.1	9.2	4.9***	11.5	3.5	8.0***
/s/	3.4	2.8	0.7^{ns}	7.6	-3.2	10.8***	10.8	1.2	9.7***
/l/	5.5	5.1	0.4^{ns}	13.7	3.7	10.1***	12.2	-0.4	12.6***
/T/	4.3	4.7	-0.4^{ns}	4.6	-2.5	7.1***	8.0	-2.0	10.0***
/S/	2.7	2.4	0.3^{ns}	1.1	-6.2	7.3***	8.3	0.4	7.8***
/k/	-3.1	-4.3	1.3^{ns}	14.8	12.8	2.1^{ns}	17.6	16.8	0.7^{ns}
/χ/	-5.9	-7.4	1.5^{ns}	9.2	2.4	6.8***	13.3	9.1	4.2***
/q/	-4.9	-8.1	3.2***	10.2	2.5	7.7***	14.7	9.8	4.9***
/ħ/	-0.3	-3.7	3.4***	10.9	4.7	6.2***	1.6	-1.3	2.9***

In order to quantify the degree of V-to-C coarticulation, we calculated, for each articulator, its vertical position difference at the acoustic midpoint of the consonant between the /iCi/ and /aCa/ contexts. Mean values of these differences are summarized in Fig. 2 and Tab. 1 for each consonant and articulator. For each consonant, these differences serve as an index of its coarticulatory resistance. We then carried out three separate one-way ANOVA tests (one for each articulator) with vertical position differences as the dependent variable and consonant type as the independent variable. ANOVA tests show that the articulator height difference at the acoustic midpoint of a /C/ between /iCi/ and /aCa/ varies significantly with the type of this consonant: TTIP [$F(10, 55)=4.32$, $p<0.0001$)]; TMID [$F(10, 55)=24.01$, $p<0.0001$]; TDOR: [$F(10, 55)=80.65$, $p<0.0001$)]. Tukey post-hoc analyses are used to compare degrees of these height differences between the different consonants, which in turn allow us to evaluate our hypotheses.

During /b h,/ TMID ($p<0.001$) and TDOR ($p<0.001$) are substantially higher in /iCi/ than in /aCa/ (Fig. 3). In /iCi/ context, TMID during /b/ is as high as during /h/, while TDOR is higher during the latter compared to the former ($p < 0.001$). Fig. 2 and Tukey post-hoc analyses indicate that the mean difference between TMID and TDOR height positions during /b/ and /h/ in /iCi/ and their versions in /aCa/ (Tab. 1) are also substantial (Tab. 1). /b h/ have a similar TMID height difference between /iCi/ and /aCa/, but this mean difference is slightly ($p < 0.05$) higher for /h/ compared to /b/.

Based on these comparisons, we can deduce that, as expected by our main hypothesis, TMID and TDOR positions are not crucially controlled by the consonants /b/ and /h/, and that these two consonants seem to be the least resistant consonants as far as lingual V-to-C coarticulation is concerned.The minimal differences across the two vocalic contexts seen for the TTIP during /b/ (Fig. 2) are likely related to the elevated jaw position [16] implicated in the production of the labials, which thereby constrains the range of motion of the TTIP.

Fig. 2 shows that for /t T s S l/ in /iCi/ compared to their occurrences in /aCa/, the TTIP maintains a stable position. This latter result can be partly attributed to jaw position which is in its highest positions at the acoustic midpoint of /t T s S/ [16].

Within the coronal group, /l/ is produced with TMID and TDOR in a maximally high vertical position ($p<0.001$) in /iCi/ compared to /aCa/ (Fig. 3). We note that mean height differences for TMID and TDOR between /iCi/ and /aCa/ are statistically similar across /l/ and /h/ (Fig. 2 and Tab. 1). Based on these observations, we can deduce that /l/ has also weak resistance to V-to-C coarticulation at the level of TMID and TDOR articulators.

Compared to their non-pharyngealised version /s t/, /S/ and mainly /T/ are produced with a strong TMID depression which is more pronounced in /aCa/ than in /iCi/ context. This predorsum depression has been reported by previous studies [6, 15, 1]. However, it is not clear if this depression is a passive consequence of the backward movement of the tongue root for pharyngealisation, or an active gesture to enhance the large F2 drop induced by these consonants during adjacent vowels (see [15]).

In /aCa/, compared to /t/, TMID is very low during /s S T l/ ($p<0.0001$) and moderately low during /l/ ($p<0.001$). This is expected given that /t/ is laminal and /s S T/ apical in MA. Specifically for the stops of this class of coronals, this apicality-laminality distinction can be linked to established differences in VOT; the laminal has a long VOT whereas the VOT of /T/ is rather short [14]. The longer narrow channel of the laminal delays achievement of the transglottal pressure difference required for voicing, thus elongating the VOT.

TMID height differences between /iCi/ and /aCa/ are statistically lower ($p<0.001$) during /t/ than /h b s l/ (Fig. 2 and Tab. 1). However, we cannot deduce that /t/ is resistant to V-to-C coarticulation, since in the /iCi/, /t/ is produced while TMID and TDOR vertical positions are as higher as for /h /.

Compared to all the other consonants, /k/ is produced in /iCi/ and /aCa/ with TMID and TDOR in their highest positions (Fig. 2, Tab. 1). /k/ has the same vertical (and even horizontal) positions for TTIP, TMID and TDOR (Fig. 2) in /iCi/ than in as in /aCa/ (not significant for all paired comparisons). This relative invariance of TDOR height during /k/ is due to the fact that this is the sensor corresponding to the major articulator for this consonant.

Contrary to what we observe during /k/, /q χ/ are produced with TMID and TDOR in higher vertical position in /iCi/ compared to their equivalent (Fig. 2) in /aCa/ context ($p<0.001$ for all paired comparisons). Notice that the fleshpoints making contact for the closure of the uvular are likely posterior to the TDOR sensor. Within the /iCi/ as well as the /aCa/ context, /q/ and /χ/ have the same vertical (statistically not different) position for TMID and TDOR which are significantly lower ($p<0.001$) than during /k/. Mean height differences for TMID and TDOR between /iCi/ and /aCa/ are more substantial for the TMID than for the TDOR (Fig. 2 and Tab. 1). Therefore, these results show that during /q χ/, TMID is relatively more free to coarticulate with adjacent vowels than the dorsum. TMID, as well as TDOR, are less constrained during

/q χ/ than during /k/ since the uvular involves raising at the post-dorsal region of the tongue. This again confirms our main hypothesis using a contrast that has so far not figured prominently in past studies assessing that hypothesis.

The TMID and TDOR postures during /k/ are also due to the fact that in MA /a/ is always [æ] before a non-pharyngealised consonant (e.g. /k/). These special TMID and TDOR configurations during /k/ also seem to be an articulatory strategy to enhance its acoustic contrast with /q/. Indeed, before /a/ and /i/, Arabic /k/ usually has a long VOT duration and a main peak close to F3 [14], while /q/ has a short VOT and a main peak burst close to F2.

In /iCi/ (Fig. 2, Tab. 1), [ħ] has higher TTIP, TMID and TDOR positions than in /aCa/ ($p<0.001$ for all paired comparisons). Compared to /h/ in /aCa/, /ħ/ has similar TTIP and TDOR vertical positions, while TMID is significantly higher ($p<0.001$). These results are slightly in accord with the raising of the anterior part of the tongue, during /ħ/, reported by [6, 3, 2]. It is unclear whether this raising is a passive or an active gesture. It may be passive since Arabic /a/ is generally realized [æ] near non-pharyngealized consonants. However, it may also be active to enhance the lowering of F3 induced by the pharyngeal constriction (see [13]).

Compared to /h/ in /iCi/, /ħ/ has similar TTIP and TMID vertical positions, while TDOR is significantly lower ($p<0.001$). During /ħ/, mean height differences between /iCi/ and /aCa/ are more important for TMID than for TDOR (Fig. 1 and Tab. 1). These mean differences are significantly lower for TDOR during /ħ/ compared to all the consonants ($p<0.001$) except for /k q x/, and are significantly lower for TMID during /ħ/ compared to /b h s/ ($p<0.001$) and /l/ ($p<0.01$) consonants. These results indicate that, during /ħ/, the tongue back is more resistant to V-to-C coarticulation and seems more crucial for its production than its anterior part.

4. CONCLUSION

Overall, our results support the main hypothesis on coarticulatory resistance and provide further instantiations of its predictions in the cases of contrasts that are present in MA but not in the languages used to motivate that hypothesis.

We have seen that in /VCV/, /h b/ are the least resistant consonants to lingual V-to-C coarticulation confirming that consonants without tongue involvement undergo more V-to-C influence.

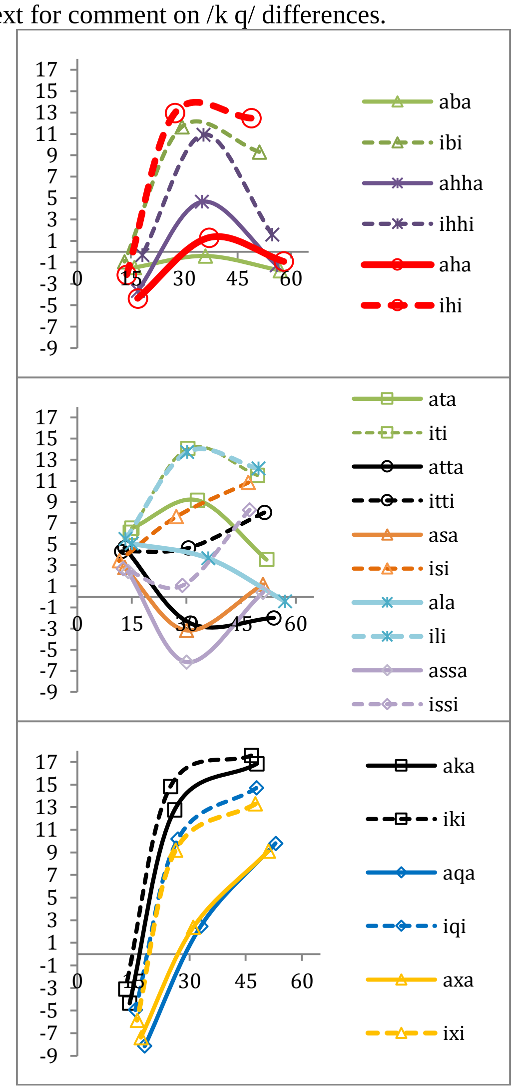
MA /k/ is produced in /iCi/ and /aCa/, while the tongue tip, midpoint and dorsum stay in the same position. MA /k/ seems to have less contextual variability as expected also by our main hypothesis.

MA /t/ and mainly /l/ are particularly sensitive to lingual V-to-C coarticulation at TMID and TDOR regions, while TTIP maintains a stable position.

TMID and TDOR are less constrained during /q χ/ than /k/ since the formers involve the post-dorsal region of the tongue. /ħ/ is also produced while tongue back exhibits more resistance to V-to-C coarticulation, compared to its anterior part. These observations on /t l k q χ ħ/ also confirm the view that contextual variability of tongue positions during /C/ is greater in regions not involved in its closure or the formation of the constriction for that /C/.

Figure 3 : Vertical (y-axis) and horizontal (x-axis) positions (in mm) of the tongue tip (TTIP), tongue midpoint (TMID) and tongue dorsum (TDOR) at the acoustic midpoint of /C/ (5 tokens) produced in /aCa/ and /iCi/ by a MA speaker (S1). (a) Labial, laryngeal, pharyngeal /C/ = /b h ħ/. (b) Coronal /C/ = /t T s S l/. (c) Dorsal /C/ = /k χ q/. NB. /tt ss hh x/ = /T S ħ χ/. See text for comment on /k q/ differences.

(a)
(b)
(c)



5. REFERENCES

[1] Bin-Muqbil, M. S. 2006. *Phonetic and phonological aspects of Arabic emphatic gutturals*. Ph.D. dissertation, University of Wisconsin-Madison.

[2] Butcher, A. and Ahmad, K. 1987. Some acoustic and aerodynamic characteristics of pharyngeal consonants in Iraqi Arabic. *Phonetica 44*, 156-172.

[3] Delattre, P. 1971. Pharyngeal features in the consonants of Arabic, German, Spanish, French, and American English. *Phonetica 23*, 129-155.

[4] El-Halees, Y. 1985. The role of F1 in the place-of-articulation distinction in Arabic. *Phonetica, 13*, 287 298.

[5] Gay, T. 1977. Cinefluorographic and electromyographic studies of articulatory organization. In M. Sawashima and F. S. Cooper (eds). *Dynamic Aspects of Speech Production*. Univ. of Tokyo, Tokyo, pp. 85–102.

[6] Ghazeli, S. 1977. *Back consonants and backing coarticulation in Arabic*. Ph.D. dissertation, University of Texas at Austin.

[7] Hoole, P. and Zierdt, A. 2010. Five-dimensional articulography. In: *Speech Motor Control: New developments in basic and applied research*, Editors: Ben Maassen, Pascal H.H.M. van Lieshout.

[8] Laufer, A., and Condax, I. D. 1979. The epiglottis as an articulator. *UCLA Working Papers in Phonetics 45*, 60-83.

[9] Öhman, S. 1966. Coarticulation in VCV Utterances: Spectrographic Measurements. *Journal of the Acoustical Society of America 39*, 151-168.

[10] Recasens, D. & Espinosa, A. 2009. An articulatory investigation of lingual coarticulatory resistance and aggressiveness for consonants and vowels in Catalan, *Journal of the Acoustical Society of America*, 125, 2288-2298.

[11] Recasens, D. 2002. An EMA study of VCV coarticulatory direction, *Journal of the Acoustical Society of America, 111*, 2828-2841.

[12] Steriade, D. 1987. Locality condition and feature geometry. In: *Proceeding of NELS 17*, pp. 595 618.

[13] Zeroual, C. & N. Clements. N. 2015. Pharyngeal. In A. Rialland, and R. Ridouane (eds.). *Features in Phonology and Phonetics, Posthumous Writings by Nick Clements and Coauthors*. (pp. 247-276). Berlin: De Gruyter Mouton.

[14] Zeroual, C. 2000. *Propos controversés sur la phonétique et la phonologie de l'arabe marocain*. Thèse de Doctorat (Phd), Université de Paris 8.

[15] Zeroual, C., Esling, J.H., and Hoole, P. 2011. EMA, endoscopic, ultrasound and acoustic study of two secondary articulations in Moroccan Arabic. In Z. M. Hassan and B. Heselwood (eds.), *Instrumental Studies in Arabic Phonetics*, pp. 277-297. Amsterdam: John Benjamins.

[16] Zeroual, C., P Hoole, and A. Gafos. 2016. Etude par EMA des mouvements de la mâchoire inférieure durant les consonnes de l'arabe marocain. In: *Proceedings of the 2016 JEP*, pp. 319-327.