AN ACOUSTIC STUDY OF COARTICULATION IN MODERN STANDARD ARABIC AND DIALECTAL ARABIC: PHARYNGEALIZED *vs* NON-PHARYNGEALIZED ARTICULATION

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ABSTRACT

The present study carries out an acoustic investigation of coarticulation in the context of pharyngealized /tˤ dˤ sˤ ðˤ/ *vs* non- pharyngealized consonants /t d s ð/ both in MSA and in four Arabic dialects (Yemeni, Kuwaiti, Jordanian and Moroccan). The speech material, produced by four males per country, consisted of 24 words in symmetrical VCV contexts [iCi, uCu, aCa] where C is either pharyngealized or non-pharyngealizd, in both MSA and Dialectal Arabic.
The results from 4608 CV sequences showed a substantial regularity in coarticulation. Comparison of the two contexts – pharyngealized *vs* non-pharyngealized – indicated quite different acoustic cues. Speakers presented comparable cues, allowing an effective classification by geographical area. Intraspeaker variation showed that the transition from MSA to the native dialect was realized by different strategies of programming and production.

Keywords: Arabic, coarticulation, locus equation, resistance, pharyngealization.

1. INTRODUCTION

The classification of Arabic dialects into distinct geographical areas is an eminently linguistic problem. The division into five big dialectal zones (Arabian, Mesopotamian, Levantine, Egyptian and Maghrebi) [25] seems to be accepted by a majority of researchers. There has been a lot of research on the typology of Arabic dialects both from the phonetic-phonological point of view and the prosodic point of view. However, attentive evaluation of utilized features shows that such classification derives its legitimacy and relevance from extralinguistic criteria (historical, social, ethnic, geographical and demographic) rather than purely linguistic criteria. On the one hand, certain consonants or vowels that are representative of this dialectal classification do not highly discriminate neither horizontally between these five areas, nor vertically between sociological varieties (city *vs* sedentary Bedouin *vs* nomad Bedouin [9]). On the other hand, the geo-sociological classification of Arabic dialects needs additional features and cues to be adequate.

2. PHARYNGEALIZED CONSONANTS

Arabic dialects have some phonological traits that unquestionably account for their unity. Apart from the uncrowded vowel space, pharyngealization, which is traditionally referred to as emphasis, is a unifying factor in these dialects. Without considering their diachronic development nor their realisation in the different forms of Arabic (ranging from proto-Arabic, Old Arabic, Classical Arabic, Middle Arabic, to Modern/Ancient Dialectal Arabic) [5, 20], pharyngealized consonants /tˤ dˤ sˤ ðˤ/ and their non-pharyngealized cognates /t d s ð/ exist both in Modern Standard Arabic (MSA) and Dialectal Arabic, notwithstanding some regional or local variations.
Interest in studying pharyngealization has been very early in Arabic linguistic research. As early as the 8th century, we can find the pharyngealization contrast among the 17 phonological oppositions established by Sibawayh in his *Al Kitab* (the Book), even if the terms used are different ("itbaq" *vs* "infitah", literally: closing and opening). The review of literature [2] shows that contrast between the two groups of consonants is achieved through a

set of articulatory adjustments and acoustic cues. Pharyngealization affects dental and alveolar consonants rather than labial or velar consonants. Research has not yet addressed this special feature and it has not looked into its sensorimotor or audio-perceptual motivation. Variability of articulatory and acoustic adjustments according to regional classification has also not been investigated.

3. CV COARTICULATION

It is well known that speech consists of a chain of articulatory gestures which are not discrete but rather interrelated and context-dependent. Such gestures overlap in time, i.e. they are coarticulated. Coarticulation refers to a process whereby properties of a segment are altered, through an articulatory adjustment of either the two contiguous segments, in which case the transition between them is reduced, or just one segment whose traces are found on the other segment [3]. Coarticulation, which can be both phonetic and phonological, cannot be limited to simple contamination as it is a product of mental representation [7, 13]. Coarticulation depends on phonetic and phonological constraints proper to each langue [17]. Such constraints are linked to the size of the consonant and vowel inventory of the language.

Lindblom's [16] locus equation concept has been utilized to indicate the degree of coarticulation in CV syllables (e.g. [11, 14, 1521, 22, 23]). Locus equations are linear regression functions derived by relating onsets of F2 transitions (*F2onset*) of different vowels to their F2 steady states (*F2mid*) plotted along the y-axis – *F2onset* =k**F2mid*+c (where *k* et *c* are slope and intercept, respectively). Locus equations were shown to be indicators of the amount of coarticulation at the consonant vowel boundary. A relatively flat slope indicates minimal vowel coarticulatory effects, in which case *F2onset* is not sensitive to the nature of the following vowel (i.e. maximal coarticulatory resistance of the consonant articulation to vowel effects). On the other hand, a relatively steep slope indicates maximal coarticulation of the consonant with the vowel as *F2onset* and *F2mid* tend to have the same frequency (minimal coarticulatory resistance of the consonant articulation). Sussman & *al.* ([21, 23]) argued that the locus equation metric can be an important descriptor of consonantal place as the equation slope varied according to place of articulation: /g/ > /b/ > /d/. Y-intercept values were also found to differ by place, but with /d/ > /g/ > /b/. The validity of the locus equation concept has been confirmed in many languages: Thai, Urdu, Egyptian Arabic [22]; French, American English and Swedish [18] ; American English and Persian [19]; Australian English, Yanyuwa and Yindjibarndi, which are two aboriginal related languages [24]. Findings from the above studies indicate a clear distinction between two groups: dental and alveolar consonants on one hand, and labial and velar consonants, on the other hand.

4. COARTICULATION OF PHARYNGEALIZED CONSONANTS

In Modern Standard Arabic (MSA), pharyngealized consonants differ from their non-pharyngealized cognates at the articulatory, acoustic and perceptual levels [1, 4, 8, 10, 12, 26]. Sussman *& al.* [23] reported that locus equation parameters for non-pharyngealized /d/ *vs* pharyngealized /dˤ/ in Egyptian Arabic were different, the pharyngealized consonant having a flatter slope and a lower intercept. The findings on MSA [10, 26] showed that locus equations were capable of distinguishing non-pharyngealized [t], [d], [s] and [ð] from pharyngealized consonants [tˤ], [dˤ], [sˤ] and [ðˤ]. The latter emerged as a totally distinct class having the flattest slopes and resisting to coarticulation from adjacent vowels.
Pharyngealized consonants have been traditionally described as exerting a strong coarticulatory influence on nearby vowels. They are produced with a primary articulation at the dental/alveolar region and a secondary articulation consisting of a dorsal backing towards the pharyngeal wall [1, 4].
Pharyngealized consonants influence the articulation of not only the closed vowels (/i/, /iː/, /u/, /uː/) but also the open vowels (/a/ and /aː/) by means of a modification of their first formants, F1 and F2 [12, 26]. In view of its non-native aspect, MSA shows coarticulatory indices that are closely dependent on native dialect patterns, considering that coarticulation develops with the emergence of first words around the end of the first year of life [22]. The hypothesis that needs to be tested in this paper is that Arabic speakers from different

dialectal areas would exhibit variability in locus equation parameters for pharyngealized *vs* non-pharyngealized consonants. Such variability would be dependent on both dialectal origin and language variety (MSA *vs* Dialectal Arabic). The objective of the present paper is threefold: 1) to see if pharyngealized consonants /tˤ dˤ sˤ ðˤ/ produce the same coarticulatory effects and have the same acoustic cues, compared with the corresponding non-pharyngealized consonants /t d s ð/ ; 2) to investigate if such cues are successful in clustering Arabic dialects; and 3) to see if speakers produce the same acoustic cues regardless of language variety.

5. METHODOLOGY

Sixteen male speakers aged between 20 to 40 years were selected. They were recruited following their geographical origin (four speakers from each of the following countries: Yemen, Kuwait, Jordan and Morocco). Since dialects inside each of these countries are not homogeneous, the speakers' local variety was not controlled in this study. All the speakers were born and grew up in their country of origin and master both their native dialect and MSA. Yemeni speakers are students from Sanaa University, Yemen; while the rest of the speakers are postgraduate students either from Franche-Comté University at Besançon or Paul-Valery University at Montpellier. The speech material consisted of 24 real words from MSA and 24 words from Dialectal Arabic (DA). The words had a symmetrical VCV context [iCi, uCu, aCa] where C was either pharyngealized /tˤ dˤ sˤ ðˤ/ or non-pharyngealized /t d s ð/. The test words were inserted in a carrier sentence: [qul … ljawm] (say …. today). The same recording procedure was followed with all speakers. The sentences were presented individually to speakers in written format and they were asked to take their time to get familiarized with the speech material prior to recording. Each speaker repeated the sentences three times and the speech samples were recorded directly into the computer. A total of 1152 tokens or CV sequences per language variety (MSA and DA) were segmented and labelled with PRAAT [8 consonants x 3 vowels x 3 repetitions x 16 speakers = 1152]. For each sequence, measurement of the frequency of the second formant (F2) was taken from two points: at the vowel onset (henceforth, *onset*) and at the vowel midpoint (henceforth, *mid*) which was identified as steady state. Determination of measurement points were done manually and it was typically difficult at vowel onset, in which case comparison of different views with various scales was necessary. Spectral slices computed in PRAAT were systematically utilized. A total of 4608 formant measurements were carried out [1152 vowels x 2 language varieties x 2 vowel points = 4608].

6. RESULTS

6.1. General results

Although slope values were relatively higher than those reported in Yeou [26], locus equation data from MSA in this study fit with the general tendency, namely that pharyngealized consonants have flatter slopes (*cf.* Table 1)

Table 1: mean values of y intercepts (int-y), slopes and regression coefficients (R^2) in MSA for 16 speakers.

MSA	NON-PHARYNGEALISED				PHARYNGEALISED			
	t	d	s	ð	tˤ	dˤ	sˤ	ðˤ
Int-y	423	515	335	385	473	434	262	420
slope	**.773**	**.712**	**.813**	**.765**	**.545**	**.573**	**.766**	**.555**
R^2	.910	.823	.908	.925	.763	.774	.846	.792

An ANOVA was performed on *F2onset* of V2 (the vowel following the test consonant) as the dependent variable and *F2mid* of the same vowel as the predictor variable. The effect was highly significant in both consonantal contexts: pharyngealized [$F(1, 582)=10.58$; $p<.001$] and non-pharyngealized [$F(1, 590)=14.60$; $p<.001$]. Comparison of the same site, *F2onset* or *F2mid*, according to pharyngealization also reveals a highly significant effect (for *F2onset* [$F(1, 579)=1.34$; $p<.05$], for *F2mid* [$F(1, 580)=1.55$; $p<.001$]). With the exception of [sˤ], the slopes of the other three pharyngealized consonants are flatter than those of their non-pharyngealized cognates, and of all consonants, pharyngealized [tˤ] has the flattest slope (0.54). One way ANOVAs, however, do not show a significant effect neither for values of *F2onset* [$F(1, 122)=1.62$, $p>.05$], nor for *F2mid* [$F(1, 122)=1.95$, $p>.05$]. [ð] and [ðˤ] have clearly distinct slopes, with values 0.76 and 0.55, respectively. In the context of these two consonants, differences in values of *F2onset* are significant [$F(1, 124)=3.59$, $p<.01$], but not for *F2mid* [$F(1, 124)=1.57$, $p>.05$]. Likewise, the slope of the alveolar fricatives [s] and [sˤ] are quite similar, 0.81 and 0.76, respectively. The effect was significant for *F2onset* [$F(1, 123)=271$; $p < .01$] but not significant for *F2mid* [$F(1, 123)=1.96$; $p > .05$]. The two consonants [d] and [dˤ] have distinct slopes (0.71 and 0.57, respectively), but the difference was significant only for *F2mid* values [$F(1, 126)=3.32$; $p < .01$].

Table 2: mean values of y intercepts (int-y), slopes and regression coefficients (R^2) in Dialectal Arabic (DA) for 8 speakers.

DA	NON-PHARYNGEALISED				PHARYNGEALISED			
	t	d	s	ð	tˤ	dˤ	sˤ	ðˤ
Int-y	754	719	396	559	445	587	450	452
slope	**.592**	**.618**	**.796**	**.667**	**.595**	**.479**	**.662**	**.516**
R^2	.777	.782	.891	.864	.829	.653	.684	.722

ANOVAs were performed on *F2onset* of V2 as the dependent variable and *F2mid* of the same vowels as the predictor variable. The effect was highly significant in both consonantal contexts: pharyngealized [$F(1, 306)=9.33$; $p <.001$] and non-pharyngealized [$F(1, 310)=4.10$; $p <.001$]. However, comparison of the two vowel measurement points, *F2onset* and *F2mid*, according to pharyngealization shows that the effect is not significant (for *F2onset* [$F(1, 293)=0.92$; $p >.05$], and for *F2mid* [$F(1, 294)=0.625$; $p >.001$]). In comparison with results on MSA, three features emerge here: 1) slope values corresponding to the same consonant are different across language variety (MSA and DA); 2) the order of both groups of consonants is also different (MSA /tˤ<ðˤ<dˤ<sˤ/ *vs* /d<t<ð<s/; DA= /dˤ<ðˤ<tˤ<sˤ/ *vs* /t<d<ð<s/) with fricative [sˤ] and [s] having invariably the steepest slope; 3) differences in locus equations between pharyngealized consonants and non-pharyngealized cognates are more reduced in DA.

These three features indicate, on the one hand, that different strategies of programming and production are used by speakers across language varieties (MSA *vs* DA) for CV sequences. On the other hand, the degree of CV coarticulation, signalled by locus equations, shows that the coarticulatory resistance of a consonant varies between MSA and DA. With the exception of [tˤ] whose slope goes from 0.54 to 0.59, all the other consonants have a flatter slope in DA, compared with MSA: the slope for [ðˤ] goes from 0.55 to 0.51, [dˤ] from 0.57 to 0.47 and [sˤ] from 0.76 to 0.66. The same flattening of slope values is found with non-pharyngealized consonants: [d] goes from 0.71 to 0.61, [t] from 0.77 to 0.59, [ð] from 0.76 to 0.66 and [s] from 0.81 to 0.79. It seems that non-pharyngealized consonants resist vowel coarticulatory effects in MSA more than in DA. Paradoxically, *F2onset* of pharyngealized consonants is less sensitive to the articulation of the vowel in DA than in MSA. CV coarticulation in pharyngealized *vs* non-pharynealized contexts across the two Arabic varieties is characterized by an increasing resistance to vowel effects as shown in the following order: [ðˤ] (DA) < [ðˤ] (MSA) < [ð] (DA) < [ð] (MSA), [dˤ] (DA) < [dˤ] (MSA) < [d] (DA) < [d] (MSA) et [sˤ] (DA) < [sˤ] (MSA) < [s] (DA) < [s] (MSA).

6.2. Index of regional classification

The findings of this paper indicate that locus equation values vary both according to language variety (MSA *vs* DA) and to geographical origin.

6.2.1. Production data in MSA

Slope values for pharyngealized /tˤ dˤ sˤ ðˤ/ allow for a classification into two large geographical areas: Western *vs* Eastern. In the three Eastern varieties, the slopes are relatively flatter with an average value of 0.55: Yemeni (0.42, 0.54, 0.75, 0.49); Jordanian (0.46, 0.54, 0.66, 0.55); and Kuwaiti (0.51, 0.47, 0.78, 0.44). In the Western variety (Moroccan), the slopes are rather steep (0.67, 0.64, 0.79, 0.61) with an average value of 0.68. However, the slope for pharyngealized [sˤ] which has the highest value is quite comparable across Arabic dialects.

Slope values for non-pharyngealized consonants, compared to pharyngealized ones, do not allow for classification by geographical area. The mean value is around 0.75 for Kuwaitis, Moroccans and Yemenis and around 0.81 for Jordanians. Nevertheless, we can see that Yemenis exhibit homogeneous slope values around 0.77, and CV coarticulatory patterns for Moroccans are insensitive to context type (pharyngealized *vs* non-pharyngealized).

Table 3: mean values of y intercepts (int-y), slopes and regression coefficients (R^2) in MSA as a function of country (J= Jordanian, K= Kuwaiti, M= Moroccan, Y= Yemeni).

MSA		NON-PHARYNGEALISED				PHARYNGEALISED			
		t	**d**	**s**	**ð**	**tˤ**	**dˤ**	**sˤ**	**ðˤ**
J	Int-y	296	401	430	202	549	503	361	411
	slope	**.847**	**.751**	**.772**	**.851**	**.460**	**.540**	**.664**	**.552**
	R^2	.964	.931	.873	.960	.759	.781	.885	.897
K	Int-y	643	659	299	447	493	528	224	543
	slope	**.666**	**.653**	**.840**	**.739**	**.515**	**.471**	**.788**	**.442**
	R^2	.862	.748	.916	.949	.883	.796	.871	.833
M	Int-y	373	569	278	393	402	427	286	412
	slope	**.787**	**.685**	**.822**	**.756**	**.670**	**.646**	**.792**	**.610**
	R^2	.969	.867	.919	.912	.831	.806	.840	.782
Y	Int-y	388	449	409	477	571	420	257	450
	slope	**.795**	**.745**	**.772**	**.722**	**.426**	**.541**	**.751**	**.490**
	R^2	.860	.778	.914	.907	.781	.881	.832	.827

6.2.2. Production data in Dialectal Arabic

Slope values for pharyngealized /tˤ dˤ sˤ ðˤ/ are relatively flatter in Eastern varieties: Yemeni (0.44, 0.38, 0.42, 0.54; mean=0.45); Jordanian (0.52, 0.38, 0.58, 0.40; mean= 0.47); and Kuwaiti (0.51, 0.47, 0.78, 0.44; mean= 0.51). In the Western variety (Moroccan), the slopes are rather steep (0.69, 0.59, 0.93, 0.64) with an average value of 0.71.

Table 4: mean values of y intercepts (int-y), slopes and regression coefficients (R^2) in Dialectal Arabic as a function of local dialect (J= Jordanian, K= Kuwaiti, M= Moroccan, Y= Yemeni).

DA		NON-PHARYNGEALISED				PHARYNGEALISED			
		t	**d**	**s**	**ð**	**tˤ**	**dˤ**	**sˤ**	**ðˤ**
J	Int-y	676	479	614	519	509	668	485	622
	slope	**.628**	**.773**	**.662**	**.661**	**.526**	**.389**	**.589**	**.406**
	R^2	.952	.959	.919	.881	.873	.814	.915	.895
K	Int-y	665	764	513	595	425	624	661	557
	slope	**.657**	**.614**	**.726**	**.650**	**.600**	**.431**	**.513**	**.506**
	R^2	.682	.639	.705	.724	.804	.527	.388	.808
M	Int-y	817	1010	185	660	370	542	75	407
	slope	**.555**	**.451**	**.926**	**.628**	**.691**	**.593**	**.937**	**.648**
	R^2	.776	.763	.975	.890	.867	.763	.896	.891
Y	Int-y	874	758	322	473	566	647	797	524
	slope	**.515**	**.591**	**.833**	**.720**	**.448**	**.389**	**.423**	**.547**
	R^2	.816	.866	.945	.931	.823	.634	.239	.409

As in MSA, the slope values for non-pharyngealized consonants (mean value around 0.66) in the four Arabic dialects do not allow for classification by geographical area.

6.2.3.Inter-variety comparison

Locus equations are clearly successful in indicating two contrasts: 1) between pharyngealized and non-pharyngealized consonants, with the former having the flattest slopes (*cf.* figure 1 *vs* 2, and 3 *vs* 4) ; 2) between the Arabic varieties (MSA *vs* Dialectal Arabic) (*cf.* figures 1 & 2 *vs* 3 & 4). However, they only enable classification by geographical area to a certain degree. On the one hand, the slope values for pharyngealized consonants are quite lower in the Eastern area than the Western area. On the other hand, the slope values for non-pharyngealized consonants are comparable, and regional classification is thus not possible. Although the scope of locus equations is limited to encoding place distinctions, it proves to be an index of classification of Arabic dialects by geographical area. As shown by Hammarberg [13], coarticulation cannot be viewed as a simple effect of contamination from adjacent segments. If this were the case, the same CV sequence would have the same locus equation in the two language varieties. The findings of this paper indicate, in fact, that when speakers switch from MSA to the native dialect locus equation slope values get lower for pharyngealized rather than for non-pharyngealized consonants. Thus, the same CV sequence is characterized by acoustic cues that vary according to language variety probably reflecting a set of articulatory adjustments that are specific to each variety and that are not transferable. It is reasonable to hypothesize that such articulatory adjustments come from mental representations that differ between MSA and Dialectal Arabic.

7. CONCLUSION

The present paper shows that locus equations allow us to capture the degree of coarticulation between the consonant and the adjacent vowel in CV syllables. Locus equations enable distinction of two consonant groups (pharyngealized *vs* non-pharyngealized) and two language varieties (MSA *vs* Dialectal Arabic). Apart from enabling a partial classification of Arabic varieties into two large zones (Easten *vs* Western), the locus equation metric points to some aspects that have not been much studied in Arabic linguistics and Arabic dialectology: 1) the representation of pharyngealized *vs* non-pharyngealized features and of vowel allophones; 2) coarticulation and the degree of coarticulatory resistance of the same consonant across two language varieties (MSA *vs* Dialectal Arabic); 3) Relating acoustic data to classical linguistic and dialectal descriptions.

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Figure 1: locus equation of pharyngealized /dˤ/ in MSA
(F2onset = 447,72 + 0,566* F2mid)

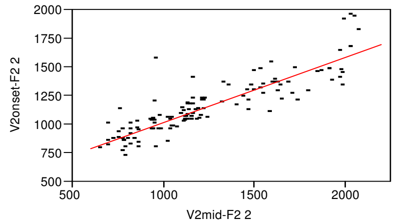

Figure 2: locus equation of non-pharyngealized /d/ in MSA
(F2onset = 508,33 + 0,713* F2mid)

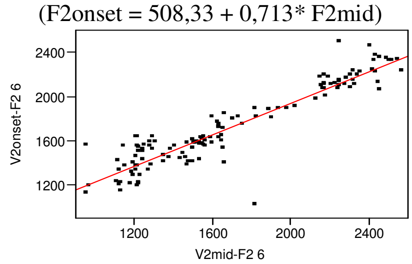

Figure 3: locus equation of pharyngealized /dˤ/ in DA
(F2onset = 587,98 + 0,479* F2mid)

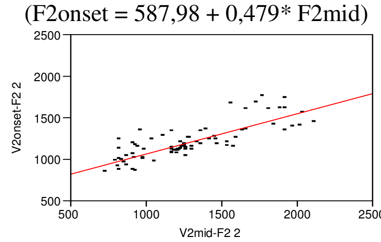

Figure 4: locus equation of non-pharyngealized /d/ in DA
(F2onset = 719,83 + 0,618* F2mid)