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Effects of Consonant on Vowel to Vowel Coarticulation in Arabic

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Abstract —The present study investigates acoustic effect of consonants /b/, / d/, / k/ in Modern Standard Arabic (MSA). To study coarticulatory effects when introducing consonant /b/, / d/, / k/ or vowel /a/, / i/ and, / u/, ten Moroccan speakers were recorded to pronounce the consonants /b/, /d/, /k/ in different contexts CV, VCV and CVCV. In VCV context, the introduction of first vowel leads to a variation in F2 onset of the consonant and an increase in the carry-over effect. In CVCV context, the introduction of /b/ or /d/ consonant leads to stronger coarticulation between the second consonant and the final or the first vowel than VCV context. Yet, the coarticulation is lower for /k/ consonant. This variation could be correlated with the tongue gestures in the production of consonants.

Keyword — F2 onset, locus equations, articulation, anticipatory effect, Standard Modern Arabic.

1. INTRODUCTION

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For more than 50 years now, researchers have been debating how the rapidly changing speech stream is mapped onto discrete categories of features. The correspondence between a physical property in the acoustic signal and phonetic feature is complicated not only due to individual variation caused by speakers' differences in social, regional origin, size, age, gender, but also due to the coarticulation effects.

The effects of coarticulation have motivated studies on segment based, articulatory, context dependent (CD) modeling techniques. Even in carefully articulated speech, the production of phoneme results from a continuous gesture of the articulators, that come from the configuration of the previous phonemes going to the configuration of the following phonemes [1]. The acoustic consequences of this gestural overlap can be captured using F2 locus equations, [2]-[3]-[4] which provide an indirect acoustic phonetic representation of the articulatory gestures dynamics involved in the production of consonant-vowel sequences.

F2 locus equations are phonetic descriptors of place of articulation [3]-[4], expressed through the linear relationship between the F2 midvowel (or vowel target) frequencies (plotted along the x-axis) and F2 vowel onset frequencies (plotted along the y-axis). F2 locus equations are therefore expressed by regression functions as: F2 vowelonset = k*F2 midvowel + c, where k represents the slope of the function and c the y-intercept. It has been established that the slopes of these regression lines vary with the place of articulation [4]- [5] , higher slope values

occur where there are high levels of covariation between the F2 onset and F2 target values of a vowel in a CV syllable, and therefore provide an index of higher degrees of articulation [3]-[4]-[6].

The present investigation is an acoustic study of coarticulation in CV, VCV and CVCV syllables produced by Arabic native speakers. The study concerns C-to-V, V-to-CV, V-to-V and C-to-VCV coarticulations. The recorded series consist of Consonant-Vowel (CV), Vowel-Consonant-Vowel (VCV) and Consonant-Vowel-Consonant-Vowel (CVCV) utterances in which the consonants range from /b/, /d/ and /k/ in three vowel contexts: /i/, /a/ and /u/. Yéou has used locus equation in standard Arabic (SA) produced by Moroccan speakers in order to study the differences between consonants having different place and mode of articulation. He showed that LE doesn't reflect the differences in places of articulation of consonants (which is aligned with the hypothesis of Fowler), moreover LE can distinguish successfully the place of articulation of pharyngeal/non pharyngeal consonants. Sussman & Modarresi studied the coarticulation of VC and CV in syllables CVC.VC, CV.CVC and VCV. They reported that higher slopes and hence greater coarticulation was found for CV relative to VC. In addition, R2 measures of the regression functions indicated significantly higher correlation between F2 midvowel frequencies and F2 onset frequencies for CVs relative to F2 midvowel frequencies and F2 offset frequencies for VCs [6].

2. METHODOLOGY

Ten male native Moroccan Arabic speakers between the ages of 24 and 30 participated in this study. They were asked to perform nine utterances for each series of "CV", "VCV" and "CVCV". The syllables consisted of one initial voiced stop consonant /b d k/, one of three vowels /a/, /i/ and /u/. Tokens were randomized and repeated four times, for a total of 108 utterances per subject.

All formant measurements were taken from a wideband spectrum display generated with PRAAT using short term LPC analysis. In addition, wideband spectrograms and FFT spectra were consulted. In order to derive locus equation scatterplots, second formant frequency (F2) was measured at the following points:

1. F2 onset: According to the voicing quality of the intervocalic stop, the frequency of F2 was measured at the first discernible pitch pulse following the release burst.
2. F2 offset: F2 offset was measured at the last pitch of the first vowel.
3. F2 midvowel: the second formant was measured at the visually determined midpoint of first and second vowels.

3. RESULTS AND DISCUSSION

Fig.1 displays formants frequencies measured at the onset of the consonant, at the onset of final vowel and at the midpoint of final vowel for CV context. For VCV context, the midpoint and the offset of the initial vowel measures are added. One notable feature of the data is the apparent differences in the value of onsets due to presence or absence of an initial vowel. Furthermore, we were able to determine which vowel is added to the consonant in VCV context whereas it was impossible in CV context. Indeed, Table (1) shows that the values of consonant onsets vary in separated domains for each vowel.

Table (1) values of consonant onsets for each first vowel in vcv context

Vowels	F2onset of consonant (Hz)		
	/b/	/d/	/k/
/a/	1300-1700	1420-1850	1420-1860
/i/	2100-2349	2090-2480	2080-2470
/u/	700-1000	1090-1480	520-870

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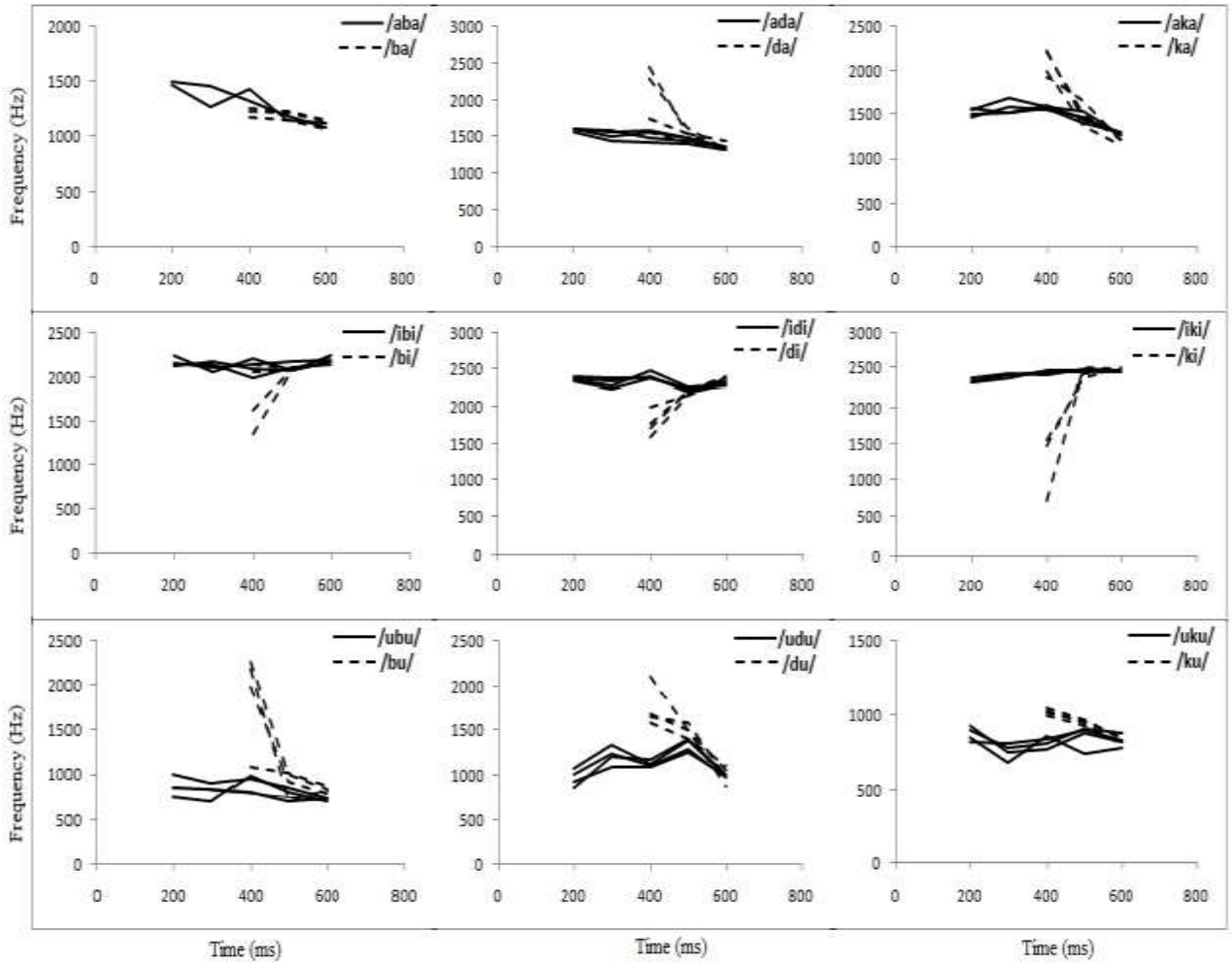

Fig. 1. Formant frequencies of F2 measured at the onset of the consonant, at the onset of the initial vowel and at the midpoint of the final vowel for CV context. For VCV context, the midpoint and the offset of the initial vowel measures are added.

Another way to see the influence of the initial vowel is the computation of locus equation in CV and VCV contexts.

In the CV context, locus equations are plotted for each consonant category by fitting regression lines to the points defined by F2 vowel-onsets and the F2 midvowel frequencies. The coefficients of the correlation R2 were very satisfactory (R2(b) = 0.973; R2(d) = 0.907; R2(k) = 0.934) indicating a good correlation between F2 vowel-onsets and F2 midvowel frequencies (Fig.2). The slopes, we obtained vary according to the place of articulation of each consonant category (slope of k (velar) = 0.90; slope of b (bilabial) = 0.81; slope of d (alveolar) = 0.48). Moreover, it can be seen from the value of the slopes that the coarticulation is strong for velar consonant and low for alveolar consonant which correspond to the results found by previous studies (see Table (2))

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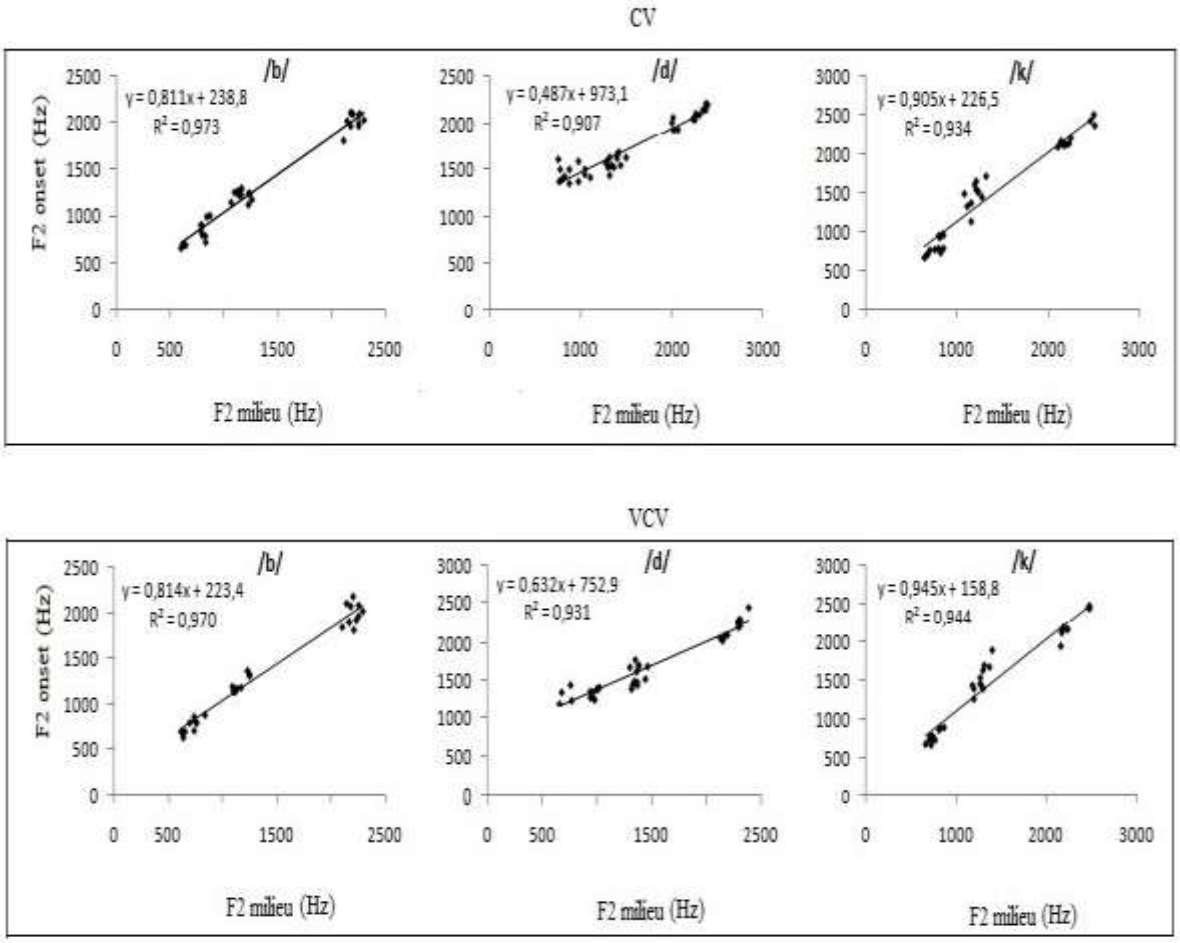

Fig. 2. Scatter plot representation of the relationship between F2 onset and F2 mid and the regression line for the consonants / b, d, k/ in the CV and VCV contexts.

Table (2) Locus equation slopes and y-intercepts in cv context for previous studies

	Language	/b/	/d/	/k/
Al-Tamimi (2004)	Jordanian Arabic	0.63	0.36	0.87(g)
Sussman & al. (1993)	Egyptian Arabic	0.77	0.25	0.92(g)
Sussman & al. (1993)	Urdu	0.81	0.5	0.97(g)
Current Study	Standard Arabic	0.81	0.48	0.9

In the VCV context, the locus equation was performed for the final vowel. The slopes obtained respectively for /b/, /d/ and /k/ were 0.814, 0.632 and 0.945. These slope values are higher than that calculated in CV context. This behavior may be due to the influence of the initial vowel introduction. Otherwise, by performing locus equation for CV (F2 onset-consonant vs F2 midvowel), the slopes obtained respectively for /b/, /d/ and /k/ are 0.798, 0.766 and 1.011. This result denotes strong coarticulation between the initial vowel V and CV (V1 onto C) and then confirms the carry-over (left-to-right) effect reported in earlier studies [6]. The slopes performed from locus equation for VC (F2vowel offset vs F2 midvowel) respectively for /b/, /d/ and /k/ were 0.895, 0.704 and 1.126. The values obtained show strong coarticulation

between the consonant and the initial vowel (C onto V1) and then imply the anticipatory effect (right-to-left) reported by previous studies [6]. Looking more carefully at slope values, a consistent trend is seen that anticipatory effect exceeds carry-over with velars (1.126 vs 1.1011) and bilabials (0.895 vs 0.798) except for alveolars (0.704 vs 0.766). The same trend has been observed for open VCV syllable [6].

Looking further to investigate how well locus equation can serve to describe the influence of introducing a consonant to the VCV context, we carried out an analysis using slopes as predictor variable for place and degree of articulation. To explore this, we established locus equation for final and first vowels to examine carry-over and anticipatory effects respectively. For the first case, the slopes obtained respectively for /b/, /d/ and /k/ were 0.868, 0.656 and 0.909. For the second case, the slopes obtained respectively for /b/, /d/ and /k/ were 0.951, 0.79 and 1.048. In both cases, we realize that slope values are higher than those calculated in VCV context for /b/ and /d/ but lower for /k/. This result implies that the introduction of /b/ or /d/ consonant lead to stronger coarticulation between the second consonant and final or first vowel in CVCV than VCV context. Yet, the coarticulation is lower for /k/ consonant. These findings illustrate carry-over and anticipatory effects induced by the introduction of consonant.
One possible explanation for this difference in slope values is the fact that the place of articulation can be correlated with the tongue gestures in the production of consonants. Indeed, various studies report that the degree of coarticulation is inversely proportional to the coarticulation control of the tongue [7], [8], [9]. Since tongue is not involved in the articulation of bilabial consonant /b/, the effects of consonant-vowel coarticulation are intermediate. In contrast, the production of dental consonant /d/ requires tongue as primary articulator, allowing higher resistance of the consonant-vowel coarticulation. In the articulation of a velar consonant, the use of the back of the tongue does not allow all the precision necessary to enable the articulatory gesture consonant to resist to the effect of vowel coarticulation. Hence, the tongue gestures are more involved in producing dental than bilabial than velar consonant. This behavior may justify why the variation of slopes in the anticipatory effect is more important for /d/ than /b/ than /k/ (Table (3)).

Table (3) Coefficient of variation (std/mean) calculated for all slopes of /b/, /d/ and /k/ consonants for anticipatory effect (↗ increase in slope; ↘ decrease in slope)

Consonants	Mean	Std	Std/mean
/d/	0.747	0.086	0.11 ↗
/b/	0.923	0.056	0.06 ↗
/k/	1.087	0.078	0.071 ↘

4. Conclusion

In the present study, the results indicate that both F2 onset values and locus equations provide important information about place of articulation for /b/, /d/ and /k/ Arabic consonants. Indeed, F2 onset-consonant allow us to determine which vowel is added to the consonant in VCV context yet, it was impossible in CV context. We also found that in VCV context, anticipatory effect exceeds carry-over only for bilabial and velar consonant. The same result has been reported by Modarresi for open VCV syllable [6]. Finally, we realize that the introduction of consonant to VCV leads to an increase in coarticulation degree. Moreover, by examining anticipatory effect for different kind of consonants, the increase in slope values is higher for /d/ than /b/ than /k/. Comparing our result to those that have been reported for English, there are several findings in agreement, with some slightly different ones. Regarding slope values, the differences between the current study and previous works can be caused by the specifications relative to the nature of Arabic and English languages.

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