

# An Acoustic Study of Fricative-to-Vowel Coarticulation in Arabic

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## Abstract

This study examines the carryover coarticulatory effects of consonantal context upon the acoustic characteristics of vowels in Arabic. Five speakers read a list of 65 cv:c syllables containing various Initial fricatives, five long vowels, and either final voiceless or voiced alveolar stop consonants. Formant frequency analysis has shown that fricative consonants induced significant coarticulatory effects on the F2 steady state frequency of the vowels but no significant difference in F1 steady state frequency has been observed. Moreover, the F2 transitions show large amount of variation as an influence of fricative context but the degree of transition variation varies significantly as a function of fricative place of articulation. The degree of fricative-to-vowel coarticulation appears to be related to the amount of articulatory constraint on the tongue activity during the production of fricative consonant. Thus the large amount of F2 transition may reflect the antagonistic demand on the articulatory movements during the production of fricative-to-vowel sequence as in emphatic or pharyngeal fricatives and front high vowels combinations, whereas the relatively small amount of F2 transition may reflect the complementary demand on the articulatory movements as in the sequence of alveolar or palatal fricatives and front high vowels. The insignificant F2 transition variation in the sequence of labiodental or glottal fricative and vowels may be interpreted to mean neutral demand on the articulatory movements.

Introduction

Studies on the acoustic characteristics of vowels across languages have revealed that the abstract vowel phonemes have a range of phonetic variants across segmental and prosodic contexts. Vowel formant variation has been of particular interest. Vowel quality is usually described by its acoustic information of the first two formant frequencies ( see House and Fairbanks (1953), Stevens and House (1963), Lindblom (1963), Öhman (1966), Broad and Fertig (1970), Ohde and Sharf (1975), Recasens (1987).....among others)<sup>1</sup>.

One of the purposes of the present study is to find out whether the spectral characteristics of the steady state portions of vowels in the Gulf Arabic Dialect spoken in the United Arab Emirates (henceforth GAD) in monosyllabic words vary systematically as a function of the neighbouring fricative consonants. Schouten and Pols (1979)<sup>2</sup> reported that the steady state portion of Dutch vowels was found not to vary systematically with consonantal context, but the cv and, to a lesser extent, the vc transitions turned out to combine into pattern that was quite consistent over speakers and conditions.

A second purpose of the present investigation is to measure and describe, in acoustical terms, any regularities in the transitions from fricatives to vowels in the tested utterances. Transitions are usually seen as rapid shifts in the frequency position of the vowel formants where vowel and consonant join and are typically most marked for the F2 (Cooper et al, 1952)<sup>3</sup>.

Studies of natural and synthesized speech have shown that the transitions between the consonant and the steady state portion of the vowel provide important cues for the perception of vowels and consonants. Heinz and Stevens (1961)<sup>4</sup> exposed their listeners to isolated friction (constant duration of 200 ms), isolated friction plus the steady state portion of [a], and friction plus transition plus vowel. On the basis of fricative cues alone, listeners reliably sorted their response into three groups: [š] for low frequency poles, [s] for midfrequency poles, and [f-θ] for high-frequency poles. Adding the synthetic vowel to these friction portions still resulted in [f-θ] confusion. They indicated that F2 transition seemed to be a necessary cue for distinguishing between these two consonants.

Sharf and Hemeyer (1972)<sup>5</sup> used cv- and vc- stimuli from which the consonant portion had been deleted. They found that vowel formant transitions provided sufficient perceptual cues for fricative consonant identification.

Kuehn and Moll (1972)<sup>6</sup> progressively deleted portions of the consonants and transitions in syllables consisting of fricatives or nasals followed by a vowel on either side of the cv transitions. They found that listeners were able to identify most consonants and all vowels above chance level even though the steady state portions had been deleted.

Ostreicher and Sharf (1976)<sup>7</sup> presented portions of cv, vc, cvc and vcv utterances to American subjects to identify the deleted preceding or following sounds. Subjects were able to determine the tongue height and tongue advancement features of vowels from consonants.

Jenkins et al (1983)<sup>8</sup> and Strange et al (1983)<sup>9</sup> reported that the steady state portion of the vowel is not necessary for good vowel identification. They excised the relatively steady state portion from natural vowels spoken in cvc syllables, and obtained high degrees of accuracy when only the initial and final transitions and relative timing of these portions were left intact. Identification accuracy for these "vowel-less" syllables was equal to or greater than that for the steady state portions extracted from the syllables.

## Material and Procedure

The linguistic material consisted of 65 cv:c syllables. Arabic possesses a phonotactic constraint which limits the monosyllabic words to cv:c or cvcc structures (Swadesh, 1937; Flege, 1981)<sup>10</sup>. In order to separate the influence on the syllable nucleus that is attributable to the initial consonant from that attributable to the final consonant only various initial consonants are examined in the context of the similar final consonants. In fact, MacNeilage and DeClerk (1969)<sup>11</sup> reported that the cv unit is more cohesive than the vc unit on the basis of greater coarticulation effects of the initial consonant on the medial vowel, than of the final consonant on the medial vowel. Their results support Kozhevnikov and Chistovich (1965)<sup>12</sup> who suggested that the cv syllable is the basic unit of articulation. Similarly Recasens (1985)<sup>13</sup> has shown that the magnitude of carryover coarticulatory effects is greater than anticipatory effects in Catalan.

In each cv:c syllable the initial consonant represents one of the following GAD fricative consonants: [f, θ, ð, ð̣, s, ʃ, z, ʒ, x, ɣ, ʕ, ʕ̣, h], the vowel one of the following long vowels: [i:, e:, a:, o:, u:], and the final consonant represents either voiceless or voiced alveolar stop consonants. The test material was carefully selected to be as representative as possible of all GAD fricative-to-vowel sequences. However, by using real words it was not possible to have a uniform set of fricatives with each long vowel cluster, especially with the vowels [e:, o:]. Therefore 29 cv:c artificial syllables were used to fill the gap, but all these artificial syllables conform to the phonology of Arabic.

Five male native speakers of GAD students of the United Arab Emirates University took part in this experiment. All were in their early twenties, were linguistically and phonetically naive. Each speaker was asked to read words from individual cards presented by the experimenter. Cards were arranged in random order, all tokens were printed on the cards using normal Arabic orthography. Subjects were told to produce each token five times at a speaking rate they considered to be representative of their normal conversational speech. The speech material was recorded in a sound treated room on a professional-quality portable cassette tape recorder (Sony model TCD5M) using an electret condenser microphone positioned about six inches from the speaker's mouth. The recordings were processed at the University of Texas Speech Laboratory, they were digitized at a sampling rate of 10 KHz, after pre-emphasis and low-pass filtering. The frequencies of vowel formants were estimated using linear predictive coding (LPC) analysis on a VAX computer.

The segmentation criteria for the vowels and fricative consonants boundaries are similar to those employed by Peterson and Lehiste (1960)<sup>14</sup> and Al-Ani (1970).<sup>15</sup> The vowel portion of each cv:c syllable was divided into two segments: (1) the transition from

the initial fricative consonant to the steady state part of the vowel, (2) the steady state part of the vowel.

**Results and Discussion**

**Table (1). Means and standard deviations (in HZ) of the low vowel [a:] F1 and F2 frequencies in various Initial fricatives context.**

Token	F1 frequency				F2 frequency			
	on glide		steady state		on glide		steady state	
	m	SD	m	SD	m	SD	m	SD
fa:t	712	16	773	12	1364	20	1470	37
θa:t*	742	12	781	14	1545	18	1576	46
ða:t	710	21	758	17	1636	42	1682	23
ð̣a:t	646	9	682	15	985	39	1183	52
sa:d	636	25	712	10	1727	21	1667	24
ʃa:d	667	18	685	19	939	37	1258	20
za:d	683	11	716	13	1736	47	1636	54
ʃa:t	685	20	715	24	1652	42	1480	46
xa:t*	768	7	727	11	1324	56	1515	36
ʎta:t	786	15	740	14	1318	29	1500	19
ħa:d	758	26	712	17	1384	38	1545	45
ʕa:d	788	31	758	21	1403	44	1655	54
ha:t	697	14	716	18	1318	37	1485	48

\* artificial cv:c syllables.

Table (2). Means and standard deviations (in Hz) of the front vowels [i:, e:] F1 and F2 frequencies in various initial fricatives context

Token	F1 frequency				F2 frequency			
	on glide		steady state		on glide		steady state	
	m	SD	m	SD	m	SD	m	SD
fi:d	318	31	321	26	2571	46	2621	48
θi:t*	320	14	313	21	2182	28	2592	37
ði:t*	305	18	301	16	2045	44	2576	21
ɔ̄i:t	394	12	318	17	909	36	2273	41
si:t	360	6	348	11	2212	27	2576	45
ʃi:t	424	12	318	18	915	43	2379	32
zi:d	319	24	316	11	2242	24	2591	39
ʃi:d	310	9	303	11	2424	44	2652	47
xi:t*	373	17	305	15	1924	41	2576	30
χ i:t*	411	21	312	20	2167	31	2591	30
hi:d	492	13	386	10	1970	38	2561	20
ʕi:d	505	20	418	28	1955	43	2681	40
hi:t	341	17	326	24	2606	57	2636	48
fe:t*	424	8	426	5	2315	23	2424	37
θe:t*	450	12	424	10	1818	46	2409	56
ðe:t*	379	9	425	15	1924	43	2410	43
ɔ̄e:t*	576	13	485	10	955	21	2179	18
se:d	475	18	434	21	2061	13	2319	27
ʃe:d	561	5	485	12	818	10	1894	28
ze:t	515	21	500	18	2159	21	2394	23
se:t*	519	23	515	22	2091	48	2470	51
xe:t*	621	16	485	13	1864	31	2318	35
χ e:t*	515	18	481	12	1833	46	2258	50
he:t*	636	14	485	19	1803	41	2273	21
ʕe:t*	652	26	530	17	1870	27	2378	20
he:t	485	18	495	11	2212	20	2455	44

Table (3). Means and standard deviation (in Hz) of the back vowel [o:,u:] F1 and F2 frequencies in various initial fricatives context

Token	F1 frequency				F2 frequency			
	on glide		steady state		on glide		steady state	
	m	SD	m	SD	m	SD	m	SD
fo:t*	439	14	424	8	888	24	863	27
θo:t*	394	9	413	13	1121	48	898	25
ðo:t*	452	12	460	16	1197	32	879	29
ɸo:t*	495	6	410	5	561	18	742	34
so:d	394	17	439	10	1470	40	924	37
ʃo:t	486	14	441	21	673	37	773	29
zo:d	401	15	428	26	1470	13	993	26
šo:t	394	7	430	18	1380	40	894	43
xo:t*	500	24	485	20	902	15	839	30
ɣo:t*	512	11	469	26	909	28	879	18
ħo:t*	636	31	515	16	1091	27	876	46
ʕo:d	652	18	518	10	1242	18	1030	26
ho:t*	455	21	456	28	1061	26	982	35
fu:t	352	16	348	24	735	26	716	32
θu:t*	364	10	333	81	424	42	788	26
ðu:t*	361	12	336	12	1470	18	803	31
ɸu:t*	374	24	404	18	667	40	705	36
su:d	350	32	348	17	1425	36	742	18
ʃu:t*	364	19	368	14	682	31	692	45
zu:d	379	16	385	24	1712	18	864	27
šu:t	365	21	365	29	1409	31	727	40
xu:t*	376	31	380	37	768	48	712	28
ɣu:t*	382	18	379	11	778	29	727	17
ħu:d	348	27	346	20	1121	20	796	42
ʕu:d	424	19	396	16	1167	37	803	20
hu:d	394	14	395	17	788	18	742	36

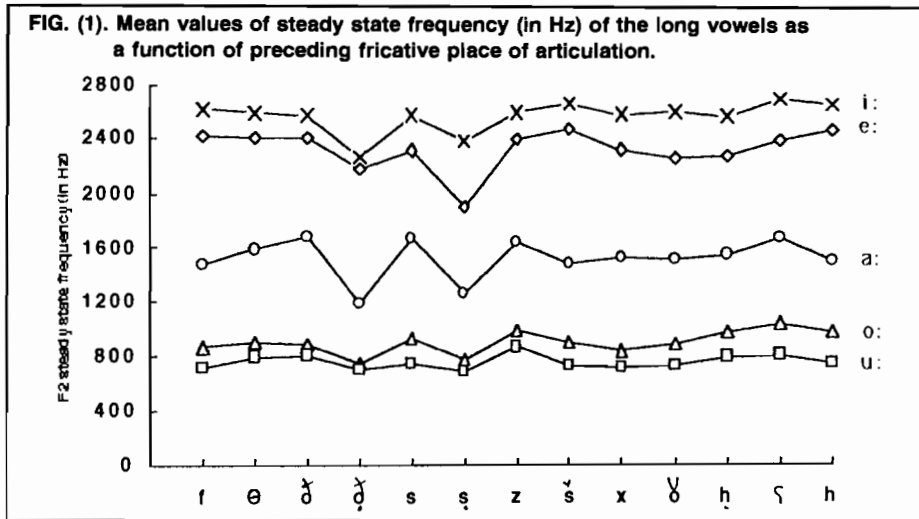
Tables (1), (2) and (3) show the carryover coarticulatory effects of initial fricative consonants on the steady state and formant transitions of the following long vowels in GAD. It is assumed that the average means of the vowel formant frequencies in various fricative contexts will capture at best the one-to-one mapping relationship between the underlying phonemic representations and their corresponding articulatory gestures. Therefore, it is hoped that, the comparison of average means with the mean of individual fricative will provide us better insight to the magnitude of consonantal effects on the target formant frequencies of vowels. The average means of the vowels steady state F1 and F2 frequencies as a function of various fricatives context is as follows: for the vowel [i:] the average mean of F1 is 330 Hz (SD 35), F2 2562 Hz (SD 112); for the vowel [e:] the average mean of F1 is 472 Hz (SD 35), F2 2322 Hz (SD 154); for the vowel [a:] the average mean of F1 is 729 Hz (SD 31), F2 1512 Hz (SD 150); for the vowel [o:] the average mean of F1 is 453 Hz (SD 36), F2 898 Hz (SD 84); and for the vowel [i:] the average F1 is 368 Hz (SD 24), F2 755 Hz (SD 50).

On the one hand, comparing the average mean of F1 steady state of the vowel [i:] with the individual fricative context mean, it appears that no systematic variation has been induced on F1 (the range does not exceed 50 Hz) as a function of fricative place of articulation. The pharyngeal fricatives show consistent increase in F1 frequency within the range of 100 Hz. Similarly, the F1 steady state of the vowel [e:] shows no significant variation as a function of fricative place of articulation. Only the voiced pharyngeal fricative [ʕ] shows consistent increase in F1 within the range of 75 Hz. The vowels [a:, o:, u:] also show no significant variation in their F1 steady state frequency in the vicinity of fricative consonants, but once again the pharyngeal fricatives induced systematic increase in the vowel [o:] F1 frequency within the range of 70 Hz.

On the other hand, fricative consonants induced systematic large coarticulatory effects on the F2 steady state frequencies of the following vowels. Figure (1) shows the mean values of F2 steady state frequency as a function of preceding fricative place of articulation. In this figure the vowels are shown to differ in their amount of F2 steady state variation. The difference between the highest and the lowest mean values of F2 steady state for each vowel is as follows: [i:] 408 Hz, [e:] 576 Hz, [a:] 499 Hz, [o:] 288 Hz, and [u:] 172 Hz. However, the carryover coarticulatory effects did not produce a progressive increase or decrease in F2 steady state frequency of the vowel as the place of fricative articulation moves from anterior to non-anterior position in the oral cavity. Nevertheless the following tendencies emerge:

- (1) F2 steady state frequencies of the vowels are lowered considerably in the vicinity of the emphatic fricatives compared to the values in non-emphatic counterpart fricatives. The amount of F2 steady state lowering induced by the emphatic dental fricative [ð] increases in the progression [u:] < [o:] < [e:] < [i:] < [a:], and by the emphatic alveolar fricative [s] increases in the progression [u:] < [o:] < [i:] < [a:] < [e:]. The present result is in agreement with the findings reported by Fant (1960)<sup>(16)</sup> that F2 frequency is inversely related to the degree of tongue backing. The production of emphatic fricatives [ð] and [s] involves a primary articulation accompanied by a narrow constriction between the tip of the tongue and the upper front teeth for the former, and the blade of the tongue and the alveolar ridge for the latter. A secondary articulation involves tongue retraction towards the pharyngeal cavity (Ali and Daniloff, 1972; Al-Ghazali, 1979).<sup>(17)</sup>The insignificant amount of F2

steady state lowering of the vowel [u:] reflects that this vowel is intrinsically back and probably resists further backing of the tongue.



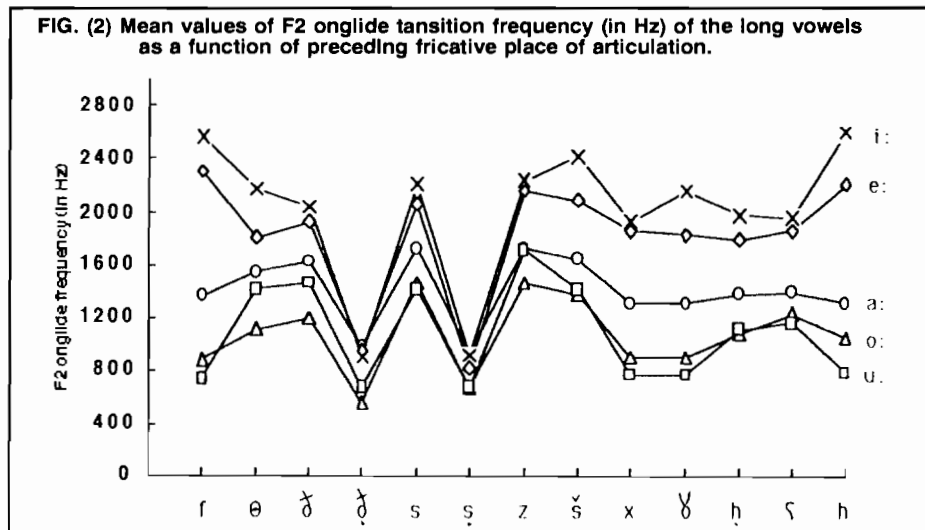
- (2) The degree of lowering in the pharyngeal fricatives construction has also systematically influenced the F2 steady state frequencies of the following vowels. Pharyngeal fricatives in Arabic language are produced by retracting and lowering the root of the tongue and making a low narrow constriction with the back wall of the pharynx in the laryngopharyngeal cavity (Delattre,1971; Ali and Daniloff,1972; Al-Ghazali,1979).<sup>18</sup> The constriction for the voiceless pharyngeal [ħ] is lower and narrower than for the voiced pharyngeal [ʁ]. In the present data the lowering of [ħ] constriction caused the F2 steady state frequencies of the vowels to decrease as follows: [i:] 120 Hz, [a:] 110 Hz, [e:] 105 Hz, [o:] 54 Hz, and [u:] 7 Hz; compared to their mean values preceding the voiced counterpart. The F2 lowering is associated with the size of the oral cavity: the wider the oral cavity, the lower the F2 frequency (Fant,1966)<sup>19</sup>. Once again the relatively small amount of the F2 steady state lowering of the vowel [u:] shows that back vowels are less sensitive to backing coarticulation effects.

As mentioned earlier a number of studies have shown that the formant transitions between the consonants and the steady state part of the vowel provide important acoustic cues for the perception of vowels and consonants. In the present study formant transition was examined to find out any regularities in the upward or downward shift in the values of formant transition as a function of preceding fricative place of articulation. The results showed no significant carryover coarticulatory effects on the F1 onglide transition for the vowels [i:, e:, o:] in the vicinity of fricative with anterior place of articulation (i.e. dentals, alveolars and palatals). The amount of F1 transition variation did not exceed 50 Hz. More importantly, repetition of tokens proved that the variation was inconsistent. Similar results were reported by Delattre et al (1955)<sup>20</sup> who found that

the locus of the F1 is identical for [b, d, g], and suggested that the F1 locus has nothing to do with consonant place of articulation. However, fricatives articulated in the non - anterior place of articulation (i.e. uvulars, pharyngeals) and emphatic fricatives show systematic upward shift in the F1 transition of these vowels. Although the amount of the F1 transition for the low vowel [a:] did not exceed 50 Hz range, it showed consistent upward shift after fricatives with non-anterior place of articulation and downward shift after fricatives with interior place of articulation. The vowel [u:] showed hardly any movement in the F1 transition as a function of fricative place of articulation. However in Jordanian Arabic, as reported by El-Halees (1985),<sup>21</sup> the F1 transition plays a major role in the distinction between uvular and pharyngeal place of articulation.

Figure (2) shows the mean values of the F2 onglide transition of the vowels as a function of preceding fricative place of articulation. This figure shows a large amount of variation in the F2 onglide transition but the degree of variation differs according to fricatives places of articulation. To get better understanding of such coarticulatory constraint, let us examine in more details the behaviour of the F2 onglide transition before individual fricative:

- 1- The labio-dental voiceless fricative [f] showed downward shift in the F2 transition of the front and low vowels. The F2 transition mean values decreased as follows: [i:] 50 Hz, [a:] 106 Hz, and [e:] 109 Hz, compared to their steady state means in similar environments. The back vowels showed upward shift in the F2 transition: [u:] 19 Hz, and [ɑ:] 25 Hz.
- 2- The dental voiceless fricative [θ] showed downward shift in the F2 transition of the vowels: [a:] 31 Hz, [i:] 410 Hz, and [e:] 591 Hz. The back vowels showed upward shift in the F2 transition: [o:] 223 Hz and [u:] 636 Hz.
- 3- The dental voiced fricative [ð] showed downward shift in the F2 transition of the vowels: [a:] 46 Hz, [e:] 486 Hz and [i:] 531 Hz. The back vowels showed upward shift in the F2 transition: [o:] 318 Hz and [u:] 667 Hz.



- 4- The dental voiced emphatic fricative [ð] showed downward shift in the F2 transition of all vowels: [u:] 38 Hz, [o:] 181 Hz, [a:] 198 Hz, [e:] 1224 Hz and [i:] 1364 Hz.
- 5- The alveolar voiceless fricative [s] showed downward shift in the F2 transition of the front vowels: [e:] 258 Hz and [i:] 364 Hz. The low and back vowels showed upward shift in the F2 transition: [a:] 60 Hz, [o:] 546 Hz and [u:] 683 Hz.
- 6- The alveolar voiced emphatic fricative [ʒ] showed downward shift in the F2 transition of all vowels: [u:] 10 Hz, [o:] 100 Hz, [a:] 319 Hz, [e:] 1076 Hz and [i:] 1464 Hz.
- 7- The alveolar voiced fricative [z] showed downward shift in the F2 transition of the front vowels: [e:] 235 Hz and [i:] 349 Hz. The low and back vowels showed upward shift in the F2 transition: [a:] 100 Hz, [o:] 477 Hz and [u:] 848 Hz.
- 8- The palato-alveolar voiceless fricative [ʃ] showed downward shift in the F2 frequency of the front vowels: [i:] 228 Hz and [e:] 379 Hz. The low and back vowels showed upward shift in the F2 transition: [a:] 172 Hz, [o:] 486 Hz and [u:] 682 Hz.
- 9- The uvular voiceless fricative [x] showed downward shift in the F2 transition of the vowels: [a:] 191 Hz, [e:] 454 Hz and [i:] 652 Hz. The back vowels showed upward shift in the F2 transition: [u:] 56 Hz and [o:] 63 Hz.
- 10- The uvular voiceless fricative [χ] showed downward shift in the F2 transition of the vowels: [a:] 182 Hz, [i:] 424 Hz and [e:] 425 Hz. The back vowels showed upward shift in the F2 transition: [o:] 30 Hz and [u:] 51 Hz.
- 11- The pharyngeal voiceless fricative [ħ] showed downward shift in the F2 transition of the vowels: [a:] 161 Hz, [e:] 470 Hz and [i:] 591 Hz. The back vowels showed upward shift in the F2 transition: [o:] 115 Hz and [u:] 325 Hz.
- 12- The pharyngeal voiced fricative [ʕ] showed downward shift in the F2 transitions of the vowels [a:] 252 Hz, [e:] 508 Hz and [i:] 726 Hz. The back vowels showed upward shift in the F2 transition: [o:] 212 Hz and [u:] 364 Hz.
- 13- The glottal voiceless fricative [h] showed downward shift in the F2 transition of the vowels: [i:] 30 Hz, [a:] 167 Hz and [e:] 243 Hz. The back vowels showed upward shift in the F2 transition: [u:] 46 Hz and [o:] 79 Hz.

The following tendencies emerge from the carryover coarticulatory effects of the fricative consonants on the F2 onglide transition:

- (1) All fricatives influenced the front vowels by lowering their F2 onglide frequencies compared to their steady state values in similar context. The F2 lowering for the vowel [i:] decreased in the progression  $h < f < \check{s} < z < s < \emptyset < \gamma < \delta < \chi < x < \rho < \delta < \varsigma$ . As for the vowel [e:] the F2 lowering decreased in the progression  $f < z < h < s < \check{s} < \gamma < x < \chi < \delta < \rho < \emptyset < \varsigma < \delta$ . The back vowels showed raising F2 onglide transition before all fricatives except for the emphatic fricative which showed F2 lowering effects. The F2 onglide raising of the vowel [o:] increased in the progression  $f < \gamma < x < h < \chi < \rho < \emptyset < \delta < z < \check{s} < s$ . As for the vowel [u:] the F2 raising increased in the progression  $f < h < \gamma < x < \chi < \rho < \emptyset < \delta < \check{s} < s < z$ . The low vowel [a:] showed lowering F2 onglide transition before all fricatives except alveolar and palato-alveolar fricatives which showed F2 raising effects. The lowering



of F2 onglide decreased in the progression  $\text{ə} < \delta < \text{f} < \text{ħ} < \text{h} < \text{ɣ} < \text{x} < \delta < \text{ʔ} < \text{s}$ , and the raising of F2 onglide increased in the progression  $\text{s} < \text{z} < \text{ʃ}$ .

- (2) The decrease in the F2 onglide frequencies of the high and mid front vowels reflects some tongue lowering induced by the preceding fricatives. According to Fant (1960)<sup>22</sup> F2 frequency correlates with front cavity size and therefore with the degree of tongue raising towards the palate. Wood (1982)<sup>23</sup> found that an increase in the distance between the tongue and the palate at the place of primary constriction for front vowels causes significant decrease in the F2 frequency. The large amount of F2 onglide lowering for the high front vowels in the emphatic context is then understandable since the front cavity size is enhanced by the tongue lowering and retracting for the articulation of the emphatic fricatives. The relatively small amount of the F2 onglide lowering before dental, alveolar and palatal fricatives reflects less demand on the tongue movement during the articulation of these fricatives and the front vowels.
- (3) The increase in the F2 onglide frequencies of the back vowels reflects some tongue raising induced by the preceding fricatives. The friction constriction for dental, alveolar and palatal fricatives involves tongue fronting and raising towards the palatal region of the oral cavity which causes some reduction in the front cavity size, thus yielding acoustically to an increase in the F2 onglide frequency. Wood (1982)<sup>24</sup> reported that advancing the dorsal constriction for [u] from the back or mid soft palate to the front soft palate or to even more anterior region causes a large F2 increase. Similar results were obtained by Maeda (1990)<sup>25</sup> for the vowel [o]. The emphatic fricatives influenced the back vowels by lowering their F2 onglide transition which reflects that the tongue is somewhat further retracted during the production of the sequence emphatic fricatives plus back vowels. However, the vowel [u:] showed insignificant amount of F2 onglide lowering (less than 50 Hz) which indicates that this vowel resists further backing. The carryover coarticulatory effects of the pharyngeal fricatives on the back vowels probably reflects some reduction in the back cavity size, and the small amount of F2 onglide raising before uvular fricatives may reflect that the tongue movement is minimum during the articulation of the sequence uvular fricatives plus back vowels.
- (4) The increase in the F2 onglide frequencies of the low vowel [a:] in the vicinity of the alveolar and palatal fricatives reflects some tongue raising towards the palatal region of the oral cavity during the formation of these fricative constrictions. Carney and Moll (1971)<sup>26</sup> found that the x-ray data showing more tongue dorsum raising for [a] when it is adjacent to [s] in the sequence [hisa] than when it is adjacent to [v] in the sequence [hiva]. The decrease in the F2 onglide frequency reflects some tongue backing and lowering induced by the preceding emphatic uvular and pharyngeal fricatives.
- (5) All vowels showed small amount of carryover coarticulatory effects in the vicinity of the glottal fricative and the labio-dental fricative which reflects the neutral demand on the tongue movement during the articulation of these consonants and the following vowels. The production of [h] involves tongue readiness for the articulation of the following vowel, and the production of [f] requires no tongue movements.

carryover coarticulatory effects on the following vowels in the cv:c syllables in GAD. The second formant frequency of the vowels showed significant variation as a function of the preceding fricative place of articulation. In general, it appears that the amount of c-to-v coarticulation is inversely related to the degree of fricative articulators involvement in the production of the following vowel. Thus, on the one hand, the large decrease in the F2 frequency of the front high vowel in the vicinity of emphatic and pharyngeal fricatives reflects the antagonistic demand on the articulatory movements during the production of such sequences; whereas, the emphatic and pharyngeal fricatives involve lowering and retracting the tongue, the front high vowel requires tongue fronting and raising towards the palatal region of the oral cavity. On other hand, the relatively small decrease in the F2 frequency of the front high vowel in the vicinity of alveolar and palatal fricatives reflects the complementary demand on the tongue movement during the production of such sequences, whereas the articulation of both the consonant and the following vowel involves tongue fronting and raising towards the palatal region.

However, it should be noted that the fricative carryover coarticulatory effects on the vowels can be explained more accurately by means of electropalatography study which provides detailed information on the articulators movement and position during the production of fricative-to-vowel sequence. A point which can be considered for future investigation of Arabic fricative consonants. Another point which needs further study is whether a native speaker of Arabic language can detect formant transitions in the vowel space as belonging to specific fricative consonants, without those fricative consonants being actually present in speech signal.

## NOTES

- (1) For a detailed acoustic analysis of vowels coarticulation across languages see:
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