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The acoustic correlates of Arabic affricates

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Abstract:Background/Aim: The lack of studies addressing Arabic language affricate sounds spurred us to conduct this study that aimed to make a comprehensive inventory of affricate consonants either in Classical Arabic language or colloquial language among Egyptians in order to establish their extent and their analytical acoustic cues (acoustic correlates) that theoretically should be affected in different speech and language disorders.**Material and method:** The data was collected from 20 native Egyptian speakers from different areas of Egypt (Sohag and Menoufia Governorates). The average age of the participants was 37.8±7.13 years. Acoustic analysisof a list of 51 canonical words that divided into three groups: G1; 6 English words including major affricates, G2; 18 words of alleged affricates, G3 27 words of correspondingstop+fricative sequence.Silence duration, the duration of the internal vowel, frication duration, overall CC or C-C duration, the rise time of the frication part,steady+decay part duration, and amplitude rise slope were measures, tabulated and analyzed. **Results:** No statistically significant difference was detected between G1 and G2 as regard the overall duration while there were highly statistically significant differences (P<0.001) when comparing G3 with G1 and G2. Silence duration was significantly longer in final position than middle position in G1 and G2 while there were no significant differences in frication durations in initial, middle, or final positions in all groups. Both rise time and steady+decay part durations showed highly significant relation when comparing G3 with both G1 and G2. **Conclusion:**Arabic is a rich language with meanings and sounds that not found in many other languages. Arabic affricates are not only /t͡ʃ/ and /d͡ʒ/ but they includet͡s, g͡z, k͡s, q͡ʂ, k͡f, and b͡ʃ that varying in their lengths between short and long ones. Any combination of consonant stop and phonologically distinctive geminate with no vowel between them or an isolated consonant stop with no vowel and a non-geminate fricative in the same syllable can be received as affricate.
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1. Introduction:

An affricate is defined by some authors as a consonant that begins like a stop and releases as a fricative, generally with the same place of articulation (most often coronal). In the majority of casesit is difficult to decide if a stop and fricative form a single phoneme or a consonant pair[1].

Other authors defined affricate as a single segment that has a complete closure with a fricative or delayed release.Like stops, affricates consist of a closure phase followed by a release phase, but they differ from stops in that the release of affricates contains additional supralaryngeal properties. Phonological evidence based on phonotactics and sonorancy is often used to distinguish affricates from homorganic bisegmental stop + fricative sequences[2].

Affricates are transcribed in the International Phonetic Alphabet (IPA) by a combination of two letters, one for the stop element and the other for the fricative element. In order to show that these are parts of a single consonant, a tie bar above the two letters is generally used. This bar may be placed under them if it fits better there[3], thus we can write t͡ʃ, d͡ʒ or tʃ, dʒ[3].English has two affricate phonemes , /t͡ʃ/ and /d͡ʒ/, often spelled ch and j, respectively[1]. German and Italian z /ts/ and Italian z/ʒ /dz/ are typical affricates[4].

Little attention has been paid to the production characteristics of affricate consonants in the worlds' languages, though there has recently been an increasing interest in the study of these sounds in different languages as diverse as Hindi, Korean, Italian[4], and Arabic[5,6].

A number of studieswhich compared between a fricative and an affricate pointed that there are several acoustic cues used to distinguish between them, such as the duration of a noise (frication duration)[7,8,9], the

duration of a rise part of a noise (rise time)[7,10], the duration of a preceding closure (silence duration)[10,11], the duration of a preceding vowel[7,8,10], the rate of increase of the sound pressure in the rise part (rate of rise)[12], the spectral shape of a noise[7,8,10], amplitude rise slope[8,12], F2 transition[10], and frication onset centroid frequency[13].

All of these studies have been motivated by the importance of affrication as a phonological process which enhances our understanding to the phonological components of the grammar in particular and the Universal Grammar (UG) in general[14].

The lack of studies addressing Arabic language affricate sounds spurred us to conduct this study that aimed to make a comprehensive inventory of affricate consonants either in Classical Arabic language or colloquial language among Egyptians in order to establish their extent and their analytical acoustic characterization (acoustic correlates) that theoretically should be affected in different speech (dysarthria, apraxia, stuttering or may be cluttering) and language disorders (like dysphasia)Which should be studied in the near future.

Most studies[4,7,9,10,11,12,13]on affricates designed to find out the acoustic cues that distinguish between affricates and fricatives. This condition is completely different from our behave in the present study as our aim was to prove that specific sounds are affricates so we tried to match acoustic cues of the pretended sounds with that established in previous studies and applied in our study when dealing with/t͡ʃ/ and /d͡ʒ/ sounds. In the same time we had to find a difference between pretended affricate sounds and stop+fricative sequence that involves internal vowel (CVC).

2. Material and Methods:

Participants:

Twenty native Egyptian speakers (10 males and 10 females) from different areas of Egypt (upper and lower Egypt) Sohag and Menoufia Governoratesparticipated in our study. The average age of the participants was 37.8 years (Min = 33, Max = 45, SD =±7.13). Participants were not randomly collected; they were chosen from highly educated population and fluent in speaking both Englishand Classical Arabic language. Some Holy Quran memorizers that are skilled in the science of Tajweed (N= 5, 25%) were involved in the study. The participants werevolunteers and were not informed about the real aim of the study as we claimed that Arabic language is in danger in front of colloquial and English accent so they did their efforts to pronounce in an ideal ways.

Speech sample:

Fifteen familialEnglish words that were as follows; 6contained majoraffricate sounds in different position and 9with stop+fricative sequence,and thirtysixClassical or colloquialArabic words that were as follows; 18containedsuspected affricate sounds and 18 with stop+fricative sequence were included in a list (Table 1) to be pronounced by the volunteers for the purpose of spectrographic analysis. The selected words matched the following criteria; the constituent parts of the studied sound distributed over one syllable with homogeneous articulatory movement of the sounds combination and the duration of each sound not exceeded the duration of the realization of other phonemes in its language.

A list of the affricates and their corresponding stop+fricative sequence was developed in canonical words and recorded from the native Egyptian speakers with good English accent. The acoustic properties of sounds are expected to be enhanced in natural canonical form.The data were examined both spectrographically and statistically in the computer software, 'Visia;CS4706-HW2'. The spectrographic analysis was carried out to examine the acoustic-phonetic characteristics of different phonemes and the statistical measurement was taken into account to find out the silence duration, internal or median vowel duration, frication duration, overall duration, the rise time duration,steady+decay part duration, and amplitude rise slope.

Procedure:

The recording of the listed words was conducted in a quiet room. The pronunciation list of all the words were duplicated and randomized within the groups for each participant. Therefore, there were a total of 102 words on the list that divided into three groups (G1 included 12 words of major English affricates, G2included 36 words of intended tested Arabic sounds, G3 included 54 words of tested English and Arabic stop+fricative sequence). Participants were given enough time before the test to familiarize themselves with the tested sample. The participants were asked to push the start button and then naturally pronounce the presented word at a normal speaking rate and after finishing they push the stop button.Recording was carries out though high fidelity pressure-sensitive microphone with 16-bit quantization and 48-kHz sampling frequency that placed 45° degrees with the subject's mouth of a constant distance 10 cm, hence the words were stored in a computer. The computer checked the recorded sample for optimal loudness. In case of improper recording the word was recorded again. The professional operator that monitored the pronunciation interfered when there was any mispronunciation or hesitant pronunciation.

This study used the following variables based on our findings in addition to previous studies reviewing; the duration of a preceding closure (silence duration of

the plosive part), the duration of the internal vowel (in affricate) or median vowel (in stop+fricative sequence), frication duration, overall CC (in affricate) or C-C duration (in stop+fricative sequence),the rise time of the frication part,steady+decay part duration, and amplitude rise slope in order to clarify the differences in the acoustic cues between established affricates (/t͡ʃ/ and /d͡ʒ/) and their corresponding stop+fricative sequence (/t-ʃ/ and /d-ʒ/) that enabled us to judge on the pretended Arabic sounds and proved their belonging to affricates (Figure 1).

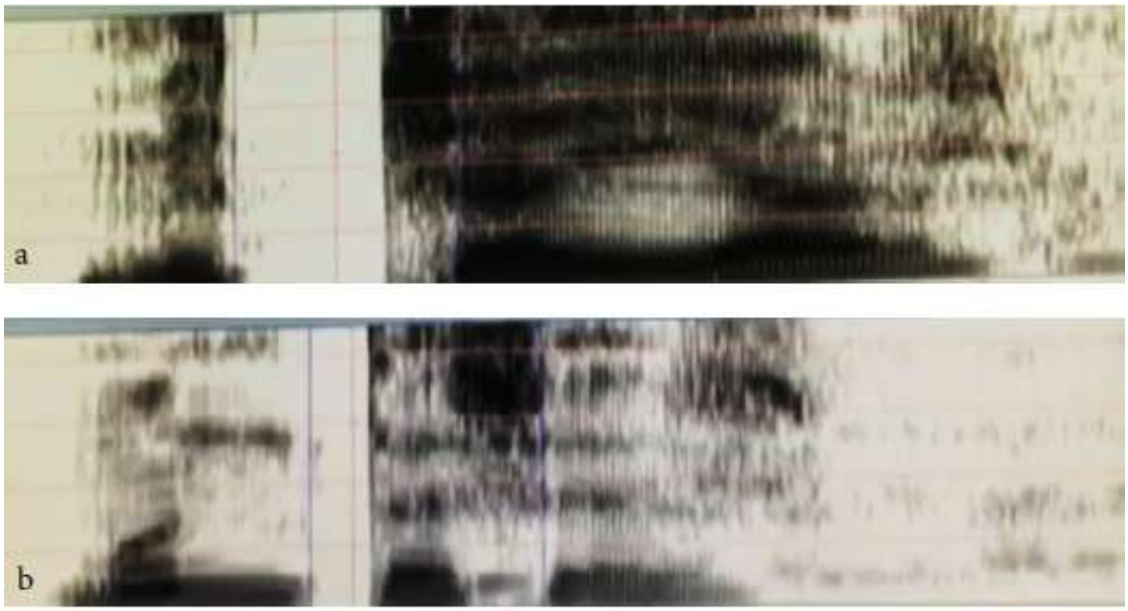


Figure 1: The images represent two tested words of a general Egyptian speaker pronounces (a) metshaier (/mit͡ʃae:r/)and (b) montasher (/mon.tæʃIr/)**.**

Each acoustic cue was measured by considering both spectrograph and waveform. We did not measure silence duration in initial position (in 4 English and 11 Arabic words) since it was difficult to measure it after silence. In cases of the occurrence of the tested items in middle or final position, the beginning of the closure was marked at the end of the preceding sound's second formant (F_2) and after the last pitch period on signal. The end of closure was determined on the waveform at the point of burst release for affricate and at the end of the vowel's F_2 for stop+fricative sequences. The beginning of frication noise in initial position was marked after the release burst for affricate and for stop+fricative sequences it was at the offset of the preceding vowel's F_2. The end of frication in initial and middle positions was marked at the fricative's onset of F_2 while in the final position, the end of frication was determined at the point where sustained frication ended on the waveform (Figure 2).

Statistical methodology:

The data collected were tabulated and analyzed by SPSS (statistical package for the social science software) statistical package version 22 on IBM compatible computer. Student t- test was done for normally distributed quantitative variables to measure mean and standard deviation and p-value < 0.05 was considered significant and < 0.001 highly significant. ANOVA test was done to compare three variables; one qualitative variable and the other two are quantitative variables of normally distributed variables and p-value < 0.05 was considered significant to detect mean and standard deviation in 95% confidence interval where post hoc tests (LSD test) was done to variables of significant difference of more than two groups of normally distributed data after ANOVA test to detect the significant difference between either groups[16].

3. Results:

The silence duration of the stop part of the affricate was longer than that measured in stop part of stop+fricative sequence (in M&F) with highly statistically significance difference (P=0.001) when comparing their means in major affricates group (G1) with G3 and also between G2 and G3 while lack of significance difference detected when comparing means of G1 and those of G2 (P=0.787). The means of silence duration of G1 and G2 sounds in middle position were significantly shorter than those in final position (P= 0.01&0.02 respectively). On measuring the mean of friction duration of the fricative part, both in affricates and in stop+fricative sequences, it was

highly significantly shorter ($p<0.001$) in G2 when compared with G3 but was significantly shorter ($p<0.05$) in G1 when compared with G3. On applying LSD Post Hoc test, despite it was noted that the frication durations varies in different positions of the tested sounds in the words though there were no statistical significant differences ($P>0.05$) in frication durations in different words' positions in all groups. The mean frication durations of the voiced targeted sounds in G2 were significantly shorter than the voiceless ones in the same group.

No median vowels were detected in G1 and G2 sounds while their presence was a specific character in most of G3 studied sounds with varying durations that had no statistical significant relation to either silence or friction durations.

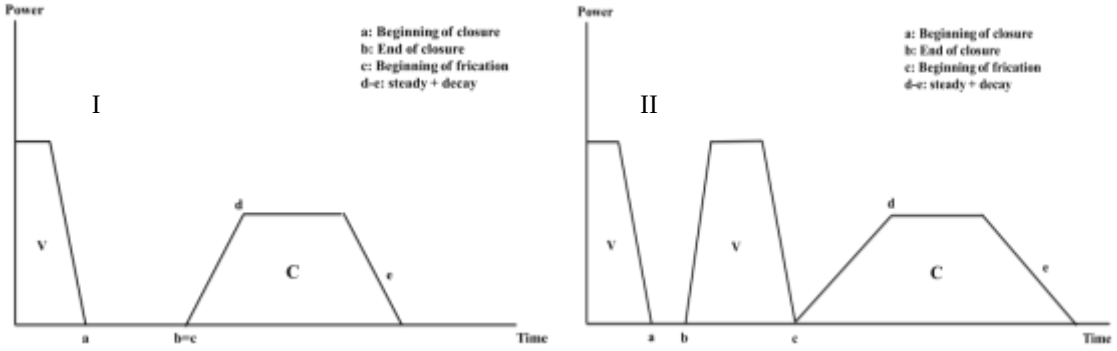
The means of overall duration (CC in G1&G2 and C-C after subtraction of median vowel duration in G3) of major affricates in G1 was 160.03±51.3 while they were 166.24±36.79 and 293.56±54.8 in G2 and G3 respectively with standard errors 26.152, 10.190, and 14.966 in the three groups in order. The small error in G2 and G3 in contrast with G1 indicated that the productions of Arabic words are well discriminated than English words. There were statistically significance differences ($P<0.05$) when comparing overall durations of the studied segments in both G1 and G2 with G3 (Table 2).

Table 1: A designed list of some canonical words involving affricates and their corresponding stop+fricative sequence in different positions.

	Word	**position**	**Meaning**
jam	/ d͡ʒæm/	initial	
adjective	/æd.d͡ʒIk.tIv/	middle	
raj	/rɑ:d͡ʒ/	final	
cartilage	/kɑr.tI.lId͡ʒ/	final	
bridge	/brId͡ʒ/	final	
channel	/t͡ʃæ.nil/	Initial	
teacher	/ti:t͡ʃəʳ/	middle	
rich	/rIt͡ʃ/	final	
tosh	/ to͡ʃ /	One syllable	
tush	/tʌʃ/	One syllable	
intelligentsia	/In.te.lI.ʒent.sIə/	middle	
pantsuit	/pæn.tɛs.u:t/	middle	
zigzag	/zIg.zæg/	middle	
next	/nɛ.kɛst/	middle	
taxi	/tæk.sI/	middle	
جدع[C] (jadaa)	/d͡ʒæ.dæʕ/	initial	Stump
مسجد[A] (masjid)	/mæs.d͡ʒɛd/	middle	Mosque
تاج[A] (taj)	/tæd͡ʒ/	Final	Crown
دجلة[A] (Degla)	/dʒ.læ/	initial	The Tigris
دجاجة[A] (dagaja)	/dæ.ʒæ.d͡ʒæ/	initial	Hen
مدجج[A] (modaggag)	/modæʒ.ʒæʒ/	middle	Topped
كاوتشوك[C] (kawitchook)	/kæ.wɛt͡ʃʃo:k/	middle	Rupper
ساندوتش[C] (sandawitch)	/sæn.dæ.wɛt͡ʃ/	final	Sandwich
متشير[C] (metshaier)	/mit͡ʃae:r/	middl	Shared
مرتشر[A] (montasher)	/mon.tæʃIr/	middle	Hospital
تشجيع[A] (tashgiee)	/tæʃ.ge: ʕ/	initial	Encouragement
اتْرابا[A] (at°raba)	/ʔt͡s.rʌbæ/	middle	At°raba
اتْبع[A] (at°bee)	/ʔt͡s.b ʕ/	middle	Follow on
كانت[A] (kanat°)	/kænæt͡s/	final	Was
تسع[A] (tiseaa)	/tɛsʕ/	initial	Nine
متسع[A] (motasae)	/mot.tæsæʕ/	middle	Ample
مجزرة[A] (magzara)	/mʌg͡z.zʌ.rʌ/	middle	Massacre
تجزئة[A] (tagzeaa)	/tæg͡z.ze. ʔæh/	middle	Fragmentation
جزيرة[A] (gazera)	/gæ.zi.ræ/	initial	Island
جزر[A] (gazer)	/gʌ.zʌr/	initial	Carrots

	Word	position	Meaning
أجزخانة [C] (agzakhana)	/ʔægzæxænæ/	middle	Pharmacy
مكسرات [C] (mekasarat)	/mɛ.kəs.sə.rət/	middle	Nuts
كسلان [A] (kaslan)	/kæs.læn/	initial	Lazy
اكسير [A] (iksier)	/ɛk͡sse:r/	middle	Elixir
مكسورة [A] (maksora)	/mak͡s.so.rʌ/	middle	Broken
مقص [A] (mequas)	/meqʌs/	middle	A pair of scissors
قصر [A] (quasr)	/qʌsr/	initial	Palace
مقصورة [A] (maqusora)	/mʌqʂ.ʂo.rʌ/	middle	Compartment
مقصلة [A] (mequsala)	/mɛqʂ.ʂə. lə/	middle	Guillotine
مكفوفين [A] (makfofien)	/mækf.fufe:n/	middle	Blind
كفتة [C] (kofta)	/kof.tæ/	initial	Kofta
أكفان [A] (akfan)	/ʔæk.fæ:n/	middle	Shrouds
مبشرة [C] (mabshara)	/mʌb͡ʃ.ʃərə/	middle	Grater
كبشرة [C] (kabsha)	/kæb͡ʃ.ʃə/	middle	Soup ladle
بشير [A] (bashier)	/bɛʃe:r/	initial	Boy's name
مبشرين [A] (mobashrien)	/mobæʃ.ʃe.rI:n/	middle	Missionaries

([A]= Arabic, [E]= English, [C]= colloquial)



V= vowel, C= consonant (fricative)

Figure 2: A diagram shows power versus time for both an affricate (I) and a fricative (II) in middle position.

Table 2: Silence duration, internal vowel duration, frication duration, and overall duration means±SDof different tested sounds.

		Silence duration (ms)		Internal vowel duration (ms)		Friction duration (ms)		Overall duration (ms)	
		mean	SD	mean	SD	mean	SD	mean	SD
Major affricates (G1)									
/t͡ʃ/ [E]	I	-	-	0.00	0.00	109.71	±18.83	-	-
	M	54.40	±6.60	0.00	0.00	88.85	±5.41	143.25	±13.75
	F	88.44	±19.5	0.00	0.00	133.16	±16.84	221.60	±24.31
/d͡ʒ/ [E]	I	-	-	0.00	0.00	54.63	±11.09	-	-
	M	50.35	±8.56	0.00	0.00	47.46	±10.00	97.81	±19.22
	F	83,22	±22.51	0.00	0.00	93,05	±15.34	176.27	±18.40
Total Overall duration		**Mean =160.03**				**SD =±51.3**			
Group 2									
/t͡ʃ/ [A]	M	59.00	±11.78	0.00	0.00	79.01	±19.06	138.01	±11.85
	F	94.77	±13.42	0.00	0.00	111.00	±12.44	205.77	±7.76
/d͡ʒ/ [A]	I	-	-	0.00	0.00	68.40	±21.16	-	-
	M	49.00	±24.56	0.00	0.00	58.57	±17.13	107.57	±23.15
	F	90.06	±13.75	0.00	0.00	98.25	±8.07	188.31	±12.77

/t͡s/ [A]	M	45.71	±18.71	0.00	0.00	77.21	±11.00	122.92	±21.43
	F	73.11	±23.90	0.00	0.00	87.99	±16.43	161.10	±18.66
/g͡z/ [A]	M	63.02	±19.23	0.00	0.00	102.66	±12.55	165.68	±14.00
/k͡s/ [A]	M	75.00	±12.41	0.00	0.00	109.50	±10.76	184.50	±10.11
/q͡ʂ/ [A]	M	71.13	±9.83	0.00	0.00	135.33	±7.94	206.64	±5.68
/k͡f/ [A]	M	79.00	±17.55	0.00	0.00	122.00	±11.83	201.00	±9.82
/b͡ʃ/ [A]	M	66.27	±17.43	0.00	0.00	91.82	±14.33	158.09	±16.99
Total Overall duration		**Mean = 166.24**				**SD =±36.79**			
Group 3									
/d-ʒ/ [A]	I	-	-	89.50	±6.50	136.55	±14.11	-	-
	M	46.08	±4.55	81.22	±7.19	167.18	±9.44	213.26	±14.88
/d-ʒ/ [E] (age)	F	99.78	±12.55	00.00	00.00	148.67	±10.00	248.45	±15.65
/t-ʃ/ [E]	I	-	-	76.37	±6.63	138.99	±11.78	-	-
/t-ʃ/ [A]	I	-	-	72.44	±8.77	204.12	±6.02	-	-
	M	90.00	±7.66	80.00	±5.43	183.50	±8.11	273.50	11.54±
/t-s/ [E]	M	72.85	±18.55	81.50	±9.45	259.50	±12.07	332.35	17.14±
/t-s/ [A]	I	-	-	77.15	±6.27	199.20	±6.77	-	-
	M	96.11	±6.13	89.66	±7.73	177.09	±8.07	273.20	±10.56
/g-z/ [E]	M	89.88	±8.67	50.13	±9.55	211.33	±12.54	301.21	±19.34
/g-z/ [A]	I	-	-		±		±	-	-
	M	88.87	±8.06	55.34	±7.21	172.88	±9.44	261.75	±13.62
/k-s/ [E] (x)	M	81.00	±11.90	50.05	±7.32	168.99	±16.33	249.99	±15.22
/k-s/ [A]	I	-	-	81.57	±9.44	190.00	±9,32	-	-
	M	91.07	±9.45	62.40	±6.60	185.22	±12.42	276.29	±17.19
/q-ʂ/ [A]	I	-	-	80.06	±5.07	247.42	±8.68	-	-
	M	93.02	±8.66	75.81	±9.71	270.86	±12.34	363.88	±19.33
/k-f/ [A]	I	-	-	83.50	±7.06	281.33	±14.61	-	-
	M	88.08	±10.34	39.12	±7.18	289.98	±9.95	378.06	±11.87
/b-ʃ/ [A]	I	-	-	63.99	±8.09	199.31	±11.30	-	-
	M	77.96	±6.77	84.33	±8.54	277.88	±13.33	355.84	±17.02
Total Overall duration		**Mean = 293.56**				**SD = ± 54.8**			

([A] = Arabic, [E] = English, I= initial, M= middle, F= final)

The means of rise-time and steady+decay durations of the fricative part in stop+fricative sequence were longer than those measured in affricates in G1 and targeted sounds in G2 with highly statistically significance difference (P<0.001) when comparing both G1&G2 with G3. No statistically significance differences were detected when comparing rise-time (P=0.188, F=210.439) and a steady+decay (P=0.54, F=165.545) durations' means in G1 with G2. Values of rise time were detected to be changed with the change in position of the sound in the word. They were significantly longer in final position than initial and middle position (53.51±11.37, 31.16±7.13, and 27.44±6.48 respectively in G1 and 55.15±16.09, 26.88±5.66, and 29.17±8.43 respectively in G2) while there was lack of statistical significant difference between the three positions in G3 on applying Post Hoc test. Moreover, it was noticed that means of rise time and steady+decay durations were shorter in voiced segments than voiceless ones in G1 and G2 but with no statistically significant differences (P>0.05).

The same findings were detected on studying the amplitude rise slope of the three groups where it was significantly lower in fricative part of stop+fricative sequence in G3 comparing with that of frication part in G1 and G2. Also it was affected by the position of the tested items in the words as it was significantly lower (P<0.05) in finial position than initial and middle positions in G1 and G2while there was no statistical significant differences in it between the three positions in G3. In general affricates had a steep rise slope in the time fricatives have nearly a linear slope.

Results of means and standard deviations of the rise time duration, a steady+decay duration and amplitude rise slope for different tested items of different groups are presented in (Table 3).

Table 3: Rise time, steady+decay duration, and amplitude rise slope means of different tested sounds.

	Rise time (ms)		Steady+decay duration (ms)		Amplitude rise slope (dB/ms)	
	mean	**SD**	**mean**	**SD**	**mean**	**SD**
Group 1	38.05	±17.88	63.60	±20.89	0.33	±0.07
Group 2	35.07	±12.13	59.25	±33.42	0.30	±0.09
Group 3	80.11	±10.65	123.00	±28.10	0.15	±0.10

4. Discussion:

Several acoustic parameters can be available on spectrographic analysis of affricates but a number of them can be vital as specific cues for distinguishing affricates from fricatives in isolated words. Dependable acoustic cues are silence duration, frication duration, rise time, and amplitude rise slope[8,11,14]. In the current study the overall duration of affricate also could be a specific distinguishing cue. As affricate sound is a consonant that begins as a stop and releases as a fricative, we tried to make a comparison between it and its components isolated form. So we actually compared affricate's stop part with stops and its fricative part with fricatives.

Lack of statistical significance between affricates in G 1 and stop -fricative sounds in G2 in silence duration, frication duration, overall duration, rise time duration, steady+decay duration, and amplitude rise slope indicated that the later sounds had the specific acoustic cues for affricates; hence they are proved statistically to be affricate sounds that are characterized by longer silence duration than that of isolated stops in G3 words, shorter frication duration than that of isolated fricatives in G3 words, absence of median vowel, and shorter overall duration. These results were completely in agreement with Berns[17] and Mahmoodzade and Bijankhan[15] who concluded that the mean frication duration of affricates is clearly shorter than that for fricatives but in general the later study focused more on sound position in the word and its refection on the rest of the variables.

An interesting point is that Recasens and Espinosa[4] proved statistically that affricates differed in overall length between peoples from different countries speaking the same language (e.g they were longer in Majorcan than in Valencian) and according to their nature (voiceless affricates were longer than voiced affricates) or place of articulation (alveolar affricates were longer than the alveolopalatal affricates). They also concluded that overall affricate duration decreased in the progression /t͡s/ > /d͡z/ > /t͡ʃ/ >/d͡ʒ /.In the present study the mean of overall Arabic affricates durations was 166.24±36.79 compared with 160.03±51.3 for major English affricates regardless the nature, the place of articulation, or the position in the word. These numbers rose to 293.56±54.8 upon summing the durations of the components isolated form (stop+fricative in CVC) mainly on expense of fricative part. While it was average 150 ms for affricate in final position compared with average 256 ms for stop+fricative each in isolated word, final position[17].

Moreover, there was a direct proportion between frication duration and silence duration in G1 and G2 sounds. Reppet al[11] had stated that as frication duration increases, more silence is needed for the perception of an affricate.

From our observations two types of affricates (according to their overall duration) occur; long and short. Long affricate occurs when phonologically distinctive geminate is preceded by consonant stop with no vowel between them (e.g /mak͡s.so.rʌ/) while short affricate occurs when an isolated consonant stop with no vowel is followed by a non -geminate fricative in the same syllable (e.g /kæb͡ʃə/). Non-geminate affricates may be longer in some positions (final) and in some languages depending on phonological character of the words.

These results showed that silence duration, frication duration, and overall affricate duration are potential acoustic cues (acoustic correlates) to distinguish affricates in Arabic language. Absence of internal vowel couldn't be considered as a correlate to affricate sounds as we noticed its absence in /k-s/ [E] (spelled x) and /d-ʒ/ [E] (spelled *age*) that did not match affricate cues.

A regard rise-time which is the time between frication onset and maximum amplitude in frication part of affricate, it was evident statistically that it is highly significant shorter in affricates in G1 and G2 when compared with that of fricatives in G3 which coincided with Howell and Rosen[7], Mitani[8], Mahmoodzade and Bijankhan[15], andKluender and Walsh[18] results. Howell and Rosen[7] demonstrated that 30 to 50ms rise time makes affricates to be perceived as more natural. The mean duration of rise time of their voiceless affricates in isolated words was 49ms and for voiceless fricatives was 123ms. While the mean rise time of Persian voiceless fricatives in Mahmoodzade and Bijankhan[15] study was 78.69ms in contrast with the rise time duration measured for an affricate that was close to 40ms. In the current study it

was 38.05±17.88ms in G1 and 35.07±12.13ms in G2 which is nearly coincided with that measured for Persian and Japanese affricates. Being the major part of frication duration, the steady+decay durations of affricates in both G1 and G2 and fricatives G3 were directly proportionated with frication duration and behaved like it in different positions in the words so either of the cues could be considered during affricates correlation but frication duration is more ideal.

There was an interaction between rise time and the amplitude rise slope as the later became steeper as the rise time decreased. There was a negative proportion between the frication duration and the rate of amplitude steepness. The relative importance of the slope cue was maximal at frication duration of 150 ms or less[8]. It is also reported that there is a positive relation between frication duration and rise time in Serbian affricates[19] which is the same as we noticed in G1 and G2 in our study.

These results revealed that variation in steady+decay duration alone was not sufficient to signal the difference between affricate and fricative especially in voiceless form and in final position as their frication durations were longer than those for voiced forms and in middle position the cue which were not proved statistically in our study but reported in Kluender and Walsh[18] while variation in frication duration alone was sufficient. In the same time, amplitude rise-time had been shown to be a good distinguishing cue for affricate/fricative differentiation.

In present study, lack of statistical significance relation in some parameters (e.g frication duration, rise time duration, a steady+decay duration and amplitude rise slope) for G3 as regard the position in the word is related to absence of isolated fricative in initial position as the tested words' design based on stop+fricative sequence or it may be attributed to unbalanced position design of the words in the list.

The indication for testing English /ks/ sound is that it is written as one letter (x) similar to (j) that represents English affricate /d͡ʒ/ but we did not find it matched with acoustic cues for affricates, so it is not necessary for affricate sounds to be written as one letter as English /t͡ʃ/ affricate sound written as two letters (ch). On the other hand in Arabic language we noticed that affricates like /t͡s/ and /d͡ʒ/ are written as single letter written(ث ْ) and (ج) respectively while other affricates sounds are written as two successive letters with no acoustic cues differences in between them. Now the question is; are the affricate sounds (especially those written as one letter) can be considered as a sort of phonological processes (we mean insertion) or it is just a matter of coincidence with no rules.

Conclusion:

Arabic is a rich language with meanings and sounds that not found in many other languages. Arabic affricates are not only /t͡ʃ/ and /d͡ʒ/ but they include t͡s , g͡z, k͡s, q͡ş, k͡f, and b͡ʃ that varying in their lengths between short and long ones. The reported sounds are not only Arabic affricates as any combination of consonant stop and phonologically distinctive geminate with no vowel between them or an isolated consonant stop with no vowel and a non-geminate fricative in the same syllable with short transition time can be received as affricate. Silence duration, frication duration, overall affricate duration, and rise time duration are potential acoustic cues (acoustic correlates) to distinguish affricates in Arabic language.

Ethical consideration:

The persons sharing in this study consented for participation.

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Conflicts of interest:

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