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A Spectrographic Analysis of Arabic Vowels: A Cross-dialect Study

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Abstract. The frequency, intensity and bandwidth of the first five formants of six Arabic vowels, /a/, /i/, /u/, /a:/, /i:/ and /u:/, were measured. In addition, the durations of these vowels were taken. The informants were 15 native speakers representing three different Arabic dialects: Saudi, Sudanese and Egyptian. The results show that these dialects differ in vowel quality while they exhibit similar vowel quantity. The main difference in vowel quality is in the frequency of the first formant. The results of this study will be useful for further research on speech recognition, speech synthesis and dialect identification.

Introduction

It has been observed that a vowel system might be more stable in some languages but not so in other languages. In English, for example, wide variation is found among its dialects unlike that of Spanish dialects that possess almost the same vowel system.[1] The question now is what about the Arabic vowel system when spoken by people representing different Arabic dialects?

The vowel system of Modern Standard Arabic (MSA) is different from that of

(1) G.E. Peterson, "The Phonetic Value of Vowels," *Language*, 27 (1951), 541-53; J. Amastae, "The Acquisition of English Vowels," *Papers in Linguistics*, 11 (1978), 423-57; A. Mendez, "Production of American English and Spanish Vowels," *Language and Speech*, 25 (1982), 191-97.

English and Spanish in terms of the quantity and number of vowels. MSA possesses six vowels only, /a, i, u, a:, i:, u:/. Also, it is a quantitative language where sound duration is phonemic; three short vowels, /a, i, u/, and three long counterparts, /a:, i:, u:/.

Arabic is spoken in different dialects across the Arab World. Those dialects sometimes vary to the extent that illiterate speakers of different dialects might find it difficult if not impossible to communicate with each other. However, literate speakers who have different dialects but speak in MSA can understand each other with ease. At the same time, each listener might realize that the dialect of the other one is different from his/hers.

MSA is based on Classical Arabic (CA) in terms of lexicon, syntax, morphology, semantics and phonology. This was done to standardize the language of education and media throughout the Arab World, and has succeeded to some extent especially in writing. However, Arabic speakers tend to be influenced by their dialects during speaking. The influence of Arabic dialects is more salient at the phonological level. For example, an Egyptian tends to produce ج g, in a syllable such as جاء. Although the consonants are produced differently depending on the dialect of the speaker, the six vowels mentioned above can be found in almost all Arabic dialects.

This study intends to investigate whether the six vowels are the same at the phonetic level when spoken by speakers of different Arabic dialects. This means that we assume they are the same at the phonological level, but the phonetic implementation might be different.

I. Method

A. Informants

The informants consisted of 15 men: 5 Saudis, 5 Sudanese and 5 Egyptians. The means and ranges of their ages are shown in Table 1. The Saudis are from Najd and the Southern Region of Saudi Arabia. Those from the Southern Region have been living in Riyadh for more than 7 years. The Sudanese are from Khartoum and the Egyptians are from Cairo. The Sudanese and Egyptians have been working in Saudi Arabia for 1-5 years. All informants have a Bachelor's or a higher degree in various fields.

Table 1. The means and ranges of the ages of 5 informants from each dialect.

Dialect	Mean	Range
Saudi	35	29 to 42
Sudanese	36	34 to 38
Egyptian	42	36 to 48

B. Linguistic Materials

The informants read six CVC syllables where V is /a, i, u, a:, i:, u:/ and C is /s/. Syllables with long vowels are meaningful words and syllables with short vowels are nonsense. A syllable in isolation, not a carrier sentence, was selected because vowels are shorter and can be influenced easily by other sounds in the sentence. This would affect the steady-state of the vowel formants. Hence, the results will be misleading. In addition, engineers who work on speech synthesis and automatic speech recognition of Arabic sounds need data about the sounds in isolated words first before working on sounds at the sentence level. /s/ was selected because its spectrogram shows a clear representation of its sound wave. This makes it possible to measure the syllable onset and offset with more precision.

The syllables were written in al-Naskh script on 10x20cm cards. They were written in the following form: سُس، سَس، سِس، سُوس، سَاس، سِيس . Each informant read the syllables randomly three times. The informants were asked to speak normally in terms of speed and loudness.

C. Equipment*

The recordings were made with a digital audio tape recorder (Sony TCD-D10 PRO II) and a dynamic microphone (Sony ECM-23F3PR). The recorder was set at a 48 kHz sampling rate. The microphone was about 15 cm from the informants' mouths. A Computerized Speech Lab (CSL 4300B) was used for acoustic analysis of the recordings.

D. Measurements

Vowel and syllable duration was measured from high resolution spectrograms. Vowel duration was measured from the onset of the first formant to the offset of the first and second formants.(2) Syllable duration was measured from the beginning of the initial /s/ to the end of the final /s/.

The frequencies, amplitudes and bandwidths of the first five formants were extracted from linear predictive coding (LPC) spectrum tables.

Fundamental frequency contours (F_0) were taken at two points: 20 milliseconds (ms) after the onset of the vowels and 20 ms before the offset of the vowels.

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* The equipment used in this study is from the Speech Science and Technology Center, Riyadh.

(2) J.E. Flege and R. Port. "Cross-language Phonetic Interference: Arabic to English," *Language and Speech*, 24 (1981), 125-46.

II. Results

The results of all measurements are shown in Tables 2-7 for Saudi dialect, 8-13 for Sudanese and 14-19 for Egyptian. The tables show the mean, standard deviation (SD), maximum (Max.), and minimum (Min). To avoid loss of information the means and SDs are presented to the nearest two decimals.

A statistical t-test was also applied to the results of the measurements. The major difference between the dialects was found to be in the frequency of the first formant. Saudi informants show higher F_1 in the production of /u/, /u:/, and /i:/ than those of the same vowels produced by Sudanese and Egyptian ($p. < 0.05$). F_1 in /i/ was lower in Sudanese than that of Saudi and Egyptian ($p. < 0.05$). Egyptian informants produced /a:/ with lower F_1 than that of Saudi and Sudanese ($p. < 0.0001$). In the case of /a/, all dialects showed different F_1 frequencies ($p. < 0.05$).

In addition to F_1, F_2 was significantly different in /i/ where Sudanese informants produced it with a higher frequency than the other two dialects ($p. < 0.0001$).

Within each dialect, the frequency of F_1 and F_2 of long vowels was different from that of the short vowels ($p. < 0.0001$) except in F_2 of the Saudi and F_1 of the Egyptian /a/ vs. /a:/.

In terms of quantity, all vowels behave similarly in all dialects, i.e., the duration of the vowels in each dialect was almost the same. The duration of the short vowels was less than half of their long counterparts (Tables 7, 13 and 19). In the case of syllable duration, Sudanese informants exaggerated the duration of the final /s/. That is why the average duration of their syllables is longer than that of the other dialects (Tables 5, 11 and 17; Fig. 2).

F_0 frequency, formant amplitude and bandwidth were similar in all three dialects, and the differences were not statistically significant.

III. Discussion

The long vowels are more than twice longer in duration than their short counterparts. The big difference here may be attributed to the fact that the syllables were spoken in isolation. It is expected that the ratio will be higher if the syllables were in a sentence. In a previous study on Arabic, it was found that the average ratio between short and long vowels was 0.51.[3] The average ratio in this study is 0.45 for Saudi, 0.41 for Sudanese and 0.40 for Egyptian. The vowel durations across the three dialects are very similar (Fig. 1).

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(3) M. Alghamdi, *Analysis, Synthesis and Perception of Voicing in Arabic* (Reading: Reading University, 1990), 94.

Although the main difference between short and long vowels is in their durations, the two categories also differ in terms of quality. The long vowels are peripheral while their short counterparts are close to the center when the frequencies of the first two formants are plotted on a formant chart (Figs. 6, 7 and 8). This is in agreement with what has been found in other languages which possess long and short vowels.[4] However, /a/ and /a:/ in the Egyptian dialect show similar F_1 frequency (Fig. 8). Similar results were previously obtained on this dialect.[5] The results of this study and the previous mentioned study violate the universality of vowel quality difference. It seems that the similarity between the two vowels is due to the low F_1 frequency of the long vowel /a:/. /a:/ in Egyptian shows much lower F_1 frequency on average than the other two dialects (Fig. 5).

Figures 4 and 5 show that the difference between vowels within a dialect is less if the vowels are short. On the other hand, the short vowels are more distinct cross the dialects. The reason that long vowels cross dialects are closer in frequency is due to duration; long vowels are longer than short vowels. Thus, it is possible to sustain almost the same formant frequency for each long vowel.

Formant amplitude and bandwidth show a similar tendency, i. e., the higher the formant frequency the higher its amplitude and longer its bandwidth. This is true in most of the results but not all, and it is in agreement with results on other languages.[6]

The results of this study and other studies on English show that low vowels tend to possess slightly lower F_0 than that of higher vowels (Tables 6, 12 and 18). This is due to the effect of lowering the tongue during the production of low vowels on the frequency of the vocal fold vibration.

The reason that F_0 measurements were taken at two places of a vowel is to see if the tone is different in the three dialects. Figure 3 shows that Egyptian informants tend to produce the vowels with falling tones, Sudanese informants produced the high vowels with rising tones. Similarly, Saudi informants produced /i/, /a:/, /u/ and /u:/ with rising tones.

On average, F_0 was found to be about 15 Hz higher than that found in American speakers.[7] This is presumably due to the difference in vocal fold length. It may well be that an average American speaker has longer vocal folds than an average Arabic speaker because of the difference in body size. Children's speech shows higher fundamental frequency than that of the adults since fundamental frequency correlates with the length of the vocal folds.

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(4) I. Lehiste, *Suprasegmentals* (Cambridge, Mass.: MIT Press), 31.

(5) K. Norlin, "Acoustic Analysis of Vowels and Diphthongs in Cairo Arabic," *Studies in African Linguistics*, 9 (1985), 238-44.

(6) J. Hillenbrand, "Acoustic Characteristics of American English Vowels," *Journal of Acoustics Society of America*, 97 (1995), 3099-3111.

(7) Hillenbrand, "Acoustic Characteristics."

IV. Conclusion

Research on automatic speech recognition and synthesis of Arabic sounds has been delayed due to unavailability of data about Arabic sounds. This study is to provide data about the vowels of MSA produced by speakers of three different dialects. It was found that the phonetic implementation of the MSA vowel system differs according to dialects. This might be one acoustic cue that listeners use to identify the dialect of an Arabic speaker even when he/she speaks in MSA.

The results of this study can be utilized in automatic speech synthesis, recognition and dialect identification of Arabic speakers.

Table 2. The means, standard deviations, maximums and minimums of the five formant frequencies of the six vowels produced by Saudi speakers.

		i	i:	a	a:	u	u:
F_1	Mean	402.4	292.2	573.27	654.87	450.93	349.67
	SD	60.86	23.52	61.55	43.66	60.26	18.03
	Max	520	334	677	732	579	379
	Min.	332	236	487	595	379	317
F_2	Mean	1840.6	2285.93	1537.27	1587.33	1301.8	958.47
	SD	102.53	104.41	69.04	183.18	130.39	163.1
	Max.	2022	2499	1638	1930	1685	1202
	Min.	1696	2129	1415	1314	1107	689
F_3	Mean	2645.27	2792.8	2260.27	2660.27	2426.8	2443.4
	SD	102.05	185.23	104.19	172.91	233.68	218.83
	Max.	2791	3087	2855	2893	2745	2731
	Min.	2483	2517	2519	2313	2078	1903
F_4	Mean	3763.6	3665	3722.53	3661.93	3473.93	3415.73
	SD	177.64	149.58	149.67	285.54	176.84	202.91
	Max.	4025	3905	3983	4098	3742	3678
	Min.	3537	3375	3515	3119	3047	3078
F_5	Mean	4674.2	4658.13	4713.8	4606.47	4359.27	4290.6
	SD	261.3	545	191.54	441.63	210.74	379.71
	Max.	5166	6069	5106	5226	4750	4878
	Min.	4342	3621	4299	3879	4014	3679

Table 3. The means, standard deviations, maximums and minimums of the five formant bandwidths of the six vowels produced by Saudi speakers.

		i	i:	a	a:	u	u:
BW_1	Mean	81.4	39.2	92	94.07	134.33	109.8
	SD	27.46	19.47	32.26	50.02	83.64	89.59
	Max	142	82	143	222	381	417
	Min.	35	17	21	24	53	31
BW_2	Mean	211.67	232.27	190.53	243.47	335.13	252.13
	SD	116.28	234.31	79.26	119.79	170.75	171.37
	Max.	474	1013	376	532	714	722
	Min.	87	55	58	92	110	53
BW_3	Mean	234.67	389.8	261.7	380.53	457.73	347
	SD	129.83	172.97	110.28	233.45	162.52	181.85
	Max.	584	685	486	987	814	682
	Min.	74	96	122	151	179	88
BW_4	Mean	305.13	315.93	265.93	516.4	361.93	234.4
	SD	277.84	239.8	120.78	361.18	249.63	159.3
	Max.	1229	746	569	1429	909	571
	Min.	128	60	66	153	76	12
BW_5	Mean	624.93	640.07	517.33	565.4	564	688.93
	SD	257.28	436.3	215.74	288.69	280.92	410.93
	Max.	1054	1674	857	1213	1458	1504
	Min.	275	109	241	211	292	256

Table 4. The means, standard deviations, maximums and minimums of the five formant amplitudes of the six vowels produced by Saudi speakers.

		i	i:	a	a:	u	u:
A_1	Mean	13.87	17.27	17.93	20.4	12.87	11.93
	SD	3.07	3.52	3.08	4.41	4.16	4.2
	Max	20	25	27	30	19	19
	Min.	9	12	14	15	4	2
A_2	Mean	4.6	8.47	10.47	12.07	3.4	1.27
	SD	4.87	5.76	3.89	5.19	3.33	4.82
	Max.	12	16	19	22	8	13
	Min.	-4	-1	3	3	-1	-5
A_3	Mean	4	6.27	6.13	6.53	-3.07	-10.27
	SD	4.81	4.22	4.44	2.72	2.82	4.03
	Max.	12	12	12	10	3	-4
	Min.	-5	-2	-3	1	-8	-16
A_4	Mean	1.07	6.93	5.47	3.87	-0.13	-7.2
	SD	9.1	1.89	6.02	5.71	5.91	8.05
	Max.	15	17	14	16	11	7
	Min.	-13	-6	-9	-6	-8	-18
A_5	Mean	-6.87	-1.8	-1.53	-0.73	-6.93	-18.13
	SD	8.11	11.25	4.02	9.53	4.77	7.08
	Max	7	22	6	18	1	-4
	Min.	-19	-18	-8	-11	-20	-28

Table 5. The means, standard deviations, maximums and minimums of the durations of the vowels (VD) and syllables (SD) produced by Saudi speakers.

		i	i:	a	a:	u	u:
VD	Mean	110.8	247.6	132.8	311.4	113.73	237.33
	SD	22.46	50.43	24.31	116.16	23.96	43.88
	Max	164	332	169	621	175	302
	Min.	80	171	100	176	80	160
SD	Mean	666.2	716.13	674.4	785.73	642.13	682.87
	SD	120.37	129.86	122.1	155.54	117.15	79.84
	Max.	848	973	931	1037	835	864
	Min.	485	498	525	581	457	561

Table 6. The means, standard deviations, maximums and minimums of the fundamental frequencies at the two positions produced by Saudi speakers.

		i	i:	a	a:	u	u:
F_0 a	Mean	146.07	139.33	138.47	138.87	152.4	144.07
	SD	16.77	14.55	19.41	18.66	22.58	19.39
	Max.	174	167	186	174	188	168
	Min.	119	116	109	113	115	108
F_0 b	Mean	140	141.47	137.93	127.27	147.47	136.73
	SD	21.19	26.08	22.42	19.37	15.48	26.11
	Max.	176	190	179	161	168	176
	Min.	101	111	94	95	120	85

Table 7. The ratios of the vowel durations (VD) and syllable durations (SD) for Saudi speakers.

	i/i:	a/a:	u/u:	Mean
VD	0.45	0.43	0.48	0.45
SD	0.93	0.86	0.94	0.91

Table 8. The means, standard deviations, maximums and minimums of the five formant frequencies of the six vowels produced by Sudanese speakers.

		i	i:	a	a:	u	u:
F_1	Mean	330.73	272	524.6	634.87	353.53	318.8
	SD	28.02	19.64	47.09	70.31	48.89	46.69
	Max.	387	315	597	760	424	372
	Min.	289	230	427	510	240	227
F_2	Mean	2066.07	2255.33	1564.27	1492.4	1308.47	984.2
	SD	103.66	120.78	108.55	90.14	101.64	127.92
	Max.	2204	2449	1802	1624	1480	1185
	Min.	1926	2053	1432	1326	1130	831
F_3	Mean	2674.07	2932.73	2623.73	2467.2	2504.53	2407.93
	SD	60.3	130.06	122.5	329.12	135.71	160.3
	Max.	2781	3230	2860	2781	2709	2659
	Min.	2585	2767	2402	1401	2236	2096
F_4	Mean	3951.8	3819.87	3685.33	3760.27	3430.8	3403.27
	SD	307.68	175.61	389.41	225.04	257.81	127.54
	Max.	4736	4135	4225	4336	4018	3590
	Min.	3610	3577	2895	3496	2811	3181
F_5	Mean	5247.13	5158.27	4830.73	4735.07	4253	4169.67
	SD	357.67	275.57	340.73	257.88	369.05	256.77
	Max.	5948	5389	5534	5252	5370	4539
	Min.	4689	4463	4217	4303	3844	3692

Table 9. The means, standard deviations, maximums and minimums of the five formant bandwidths of the six vowels produced by Sudanese speakers.

		i	i:	a	a:	u	u:
BW_1	Mean	81.93	47.93	91.87	129	93.8	98.8
	SD	49.82	29.45	62.12	81.06	101.61	79.9
	Max.	228	113	274	322	358	296
	Min.	26	22	30	39	19	21
BW_2	Mean	150.73	131.4	157.2	461.53	257.13	193.47
	SD	79.94	63.24	82.47	351.37	170.54	94.07
	Max.	280	215	322	1094	690	373
	Min.	34	19	61	76	76	22
BW_3	Mean	170.87	254	229.47	324.2	283.87	296
	SD	67.6	189.78	222.18	107.28	141.91	180.61
	Max.	295	770	993	540	539	758
	Min.	64	59	92	176	98	106
BW_4	Mean	373.73	314.4	479	611.33	479.93	406
	SD	439.17	245.89	268.07	349.42	358.83	273.54
	Max.	1686	761	1277	1546	1538	943
	Min.	45	42	187	212	81	94
BW_5	Mean	662.6	463.67	671	677.87	553.8	580.13
	SD	464.27	213.27	312.4	392.03	251.22	396.61
	Max.	1698	822	1309	1797	950	1388
	Min.	94	152	311	161	191	96

Table 10. The means, standard deviations, maximums and minimums of the five formant amplitudes of the six vowels produced by Sudanese speakers.

		i	i:	a	a:	u	u:
A_1	Mean	13.4	15.47	16.53	17.47	15.6	13.93
	SD	4.24	4.37	5.71	6.29	7.61	6.88
	Max.	22	21	28	29	26	24
	Min.	7	7	8	6	2	2
A_2	Mean	8.6	8	9.87	8.53	1.73	1.87
	SD	6.98	4.5	7.79	7.93	5.93	5.53
	Max.	21	17	20	21	10	16
	Min.	-5		-8	-5	-10	-5
A_3	Mean	8	6.33	5.6	5.33	-1	-8.93
	SD	5.01	8.9	6.71	5.01	5.77	3.83
	Max.	14	18	15	17	6	-4
	Min.	-5	-10	-9	-2	-15	-15
A_4	Mean	1.53	2.6	-2.93	-1.33	-3.4	-9.2
	SD	10.95	11.1	9.63	7.03	5.54	6.34
	Max.	20	25	11	10	4	3
	Min.	-16	-9	-21	-12	-13	-18
A_5	Mean	-5.53	-3.53	-5.93	-3.53	-8.4	-12.93
	SD	9.39	6.89	8.75	7.68	4.32	9.92
	Max.	7	8	8	12	1	5
	Min.	-18	-17	-21	-13	-16	-27

Table 11. The means, standard deviations, maximums and minimums of the durations of the vowels (VD) and syllables (SD) produced by Sudanese speakers.

		i	i:	a	a:	u	u:
VD	Mean	116.53	275.13	128.27	294.8	116.27	304.47
	SD	28.89	112.48	31.08	109.58	38.32	164.91
	Max.	168	476	192	485	194	665
	Min.	66	116	83	149	63	131
SD	Mean	718.67	801.07	774.4	834.73	677.2	805.67
	SD	182.23	194.48	235.04	203.35	172.44	256.7
	Max.	988	1224	1186	1198	1030	1345
	Min.	477	573	502	587	511	516

Table 12. The means, standard deviations, maximums and minimums of the fundamental frequencies at the two positions produced by Sudanese speakers.

		i	i:	a	a:	u	u:
F_0 a	Mean	155.27	147.4	136.6	134.67	155.47	151.07
	SD	32.32	32.91	29	18.36	34	32.49
	Max.	219	209	223	163	221	222
	Min.	126	117	95	96	119	111
F_0 b	Mean	144.07	130.2	138.33	133.73	148.93	133.07
	SD	24.13	19.85	24.08	21.34	25.18	21.89
	Max.	198	157	194	172	197	170
	Min.	103	104	104	99	105	93

Table 13. The ratios of the vowel durations (VD) and syllable durations (SD) for Sudanese speakers.

	i/i:	a/a:	u/u:	Mean
VD	0.42	0.44	0.38	0.41
SD	0.90	0.93	0.84	0.89

Table 14. The means, standard deviations, maximums and minimums of the five formant frequencies of the six vowels produced by Egyptian speakers.

		i	i:	a	a:	u	u:
F_1	Mean	356.67	256.4	468.27	461.73	369.93	318.93
	SD	38.42	29.45	71.38	23.37	25.34	24.39
	Max.	424	324	588	501	413	351
	Min.	294	214	313	418	334	274
F_2	Mean	1748.67	2175.4	1505	1676.8	1285.27	941.6
	SD	196.44	348.56	142.57	122.95	71.93	107.55
	Max.	1996	2421	1649	1905	1454	1151
	Min.	1253	949	1254	1525	1175	768
F_3	Mean	2565.4	2773.13	2537	2628.93	2482.87	2326.13
	SD	88.9	298.43	70.2	165.76	129.13	212.89
	Max.	2671	3218	2651	3141	2728	2665
	Min.	2376	2237	2342	2404	2280	1889
F_4	Mean	3692.73	3584.47	3690.6	3734.8	3439.2	3287.33
	SD	149.04	328.75	183.39	79.2	210.94	310.9
	Max.	3914	4537	3952	4277	3817	3658
	Min.	3411	3123	3267	3375	3091	2716
F_5	Mean	4740.47	4660.73	4924	4778	4212	4208.93
	SD	467.9	512.97	233.07	378.4	324.88	228.95
	Max.	5468	5491	5511	5202	4776	4697
	Min.	3708	3715	4573	3645	3731	3915

Table 15. The means, standard deviations, maximums and minimums of the five formant bandwidths of the six vowels produced by Egyptian speakers.

		i	i:	a	a:	u	u:
BW_1	Mean	89	47.87	146.13	130.4	97.27	84.07
	SD	35.76	37	37.02	37.33	29.49	35.3
	Max.	139	168	207	196	159	193
	Min.	36	21	82	53	48	29
BW_2	Mean	305.67	225.8	144.67	132.07	219.93	331.47
	SD	147.27	211.58	47.96	49.91	89.94	238.32
	Max.	601	934	237	254	412	819
	Min.	110	89	81	71	117	44
BW_3	Mean	304.87	320.33	303.13	324.53	339.4	277.67
	SD	163.75	198.8	147.86	157.84	172.04	184.5
	Max.	758	811	555	575	766	655
	Min.	59	158	90	110	172	73
BW_4	Mean	452.33	507.2	270.2	574.73	427.33	355.2
	SD	452.47	495.35	231.26	605.76	301.66	262.12
	Max.	1672	1530	854	2577	1315	964
	Min.	48	75	54	141	104	101
BW_5	Mean	760.33	659.6	573.33	396.4	874.6	575.67
	SD	317.29	469.85	295.96	267.61	454.23	379.39
	Max.	1440	1555	1109	932	2046	1322
	Min.	147	162	199	64	432	141

Table 16. The means, standard deviations, maximums and minimums of the five formant amplitudes of the six vowels produced by Egyptian speakers.

		i	i:	a	a:	u	u:
A_1	Mean	12.73	15.33	11.87	12.07	12.8	12.47
	SD	4.46	4.08	3.44	3.43	2.96	3.5
	Max.	22	23	20	21	20	22
	Min.	6	6	7	7	8	5
A_2	Mean	1.07	4.6	10.33	11.27	2.6	-2.33
	SD	5.48	6.47	4.07	5.09	3.81	5.86
	Max.	10	11	17	19	7	9
	Min.	-8	-10	1	4	-5	-12
A_3	Mean	1.53	3.73	1.4	3.33	-2.53	-9.27
	SD	6.73	6.3	6.01	7.9	4.96	7.41
	Max.	13	16	14	15	6	2
	Min.	-10	-11	-12	-11	-10	-21
A_4	Mean	-1.73	0.13	2.6	-0.27	-3.53	-8.87
	SD	8.89	9.99	7.21	8.44	5.48	8.33
	Max.	9	19	14	14	5	8
	Min.	-19	-11	-8	-12	-12	-22
A_5	Mean	-7.33	-6	-4.87	0.4	-10	-17.6
	SD	7.17	6.09	4.39	5.71	4.29	7.11
	Max.	6	5	1	16	-5	-7
	Min.	-20	-14	-14	-8	-16	-30

Table 17. The means, standard deviations, maximums and minimums of the durations of the vowels (VD) and syllables (SD) produced by Egyptian speakers.

		i	i:	a	a:	u	u:
VD	Mean	98.4	255	122	315.53	109.53	253.4
	SD	17.58	56.47	15.84	68.88	17.03	33.07
	Max.	132	324	150	464	133	296
	Min.	73	150	95	212	74	185
SD	Mean	637.53	743	607.87	786.8	638.13	703.87
	SD	80.11	64.53	77.24	81.25	68.5	45.37
	Max.	808	836	785	933	758	801
	Min.	528	632	502	638	560	634

Table 18. The means, standard deviations, maximums and minimums of the fundamental frequencies at the two positions produced by Egyptian speakers.

		i	i:	a	a:	u	u:
F_0 a	Mean	143.33	136.6	139.53	135.6	142.53	147.27
	SD	27.43	24.37	30.65	26.63	24.87	25.86
	Max.	188	174	184	172	170	193
	Min.	107	110	107	107	115	119
F_0 b	Mean	150.07	142.33	141.87	141.33	148.4	149.53
	SD	38.79	36.43	36.92	36.85	32.58	44.16
	Max.	208	195	198	190	198	207
	Min.	100	90	86	85	105	91

Table 19. The ratios of the vowel durations (VD) and syllable durations (SD) for Egyptian speakers.

	i/i:	a/a:	u/u:	Mean
VD	0.39	0.39	0.43	0.40
SD	0.86	0.77	0.91	0.85

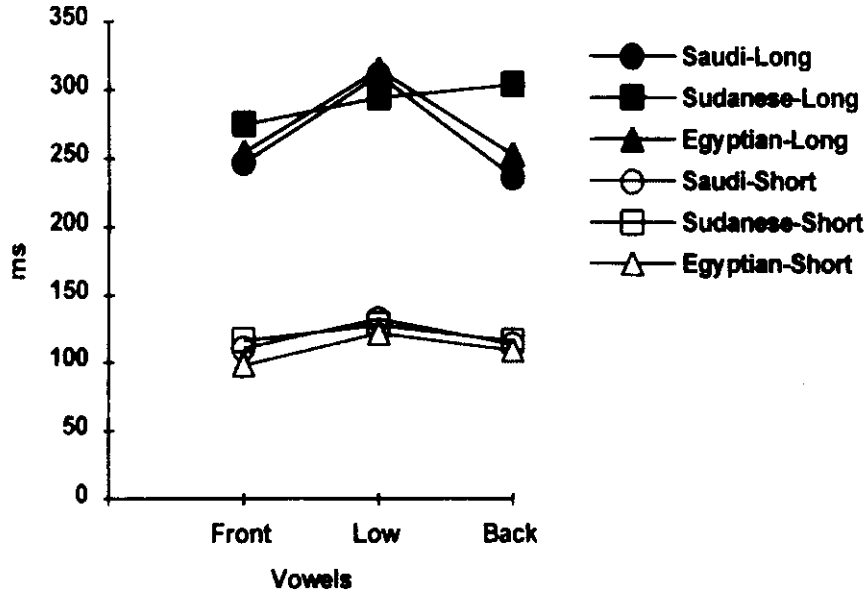

Fig. 1. Durations of the six vowels of the three dialects: /a/=short and low, /u/=short and back, /i/=short and front, /a:/=long and low, /u:/=long and back, /i:/=long and front.

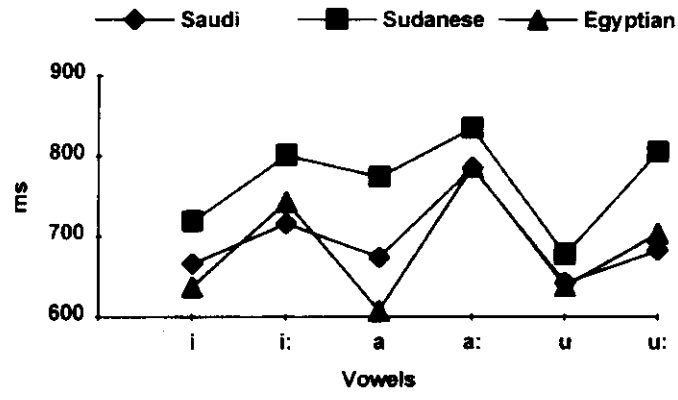

Fig. 2. Syllable durations carrying the six vowels of the three dialects.

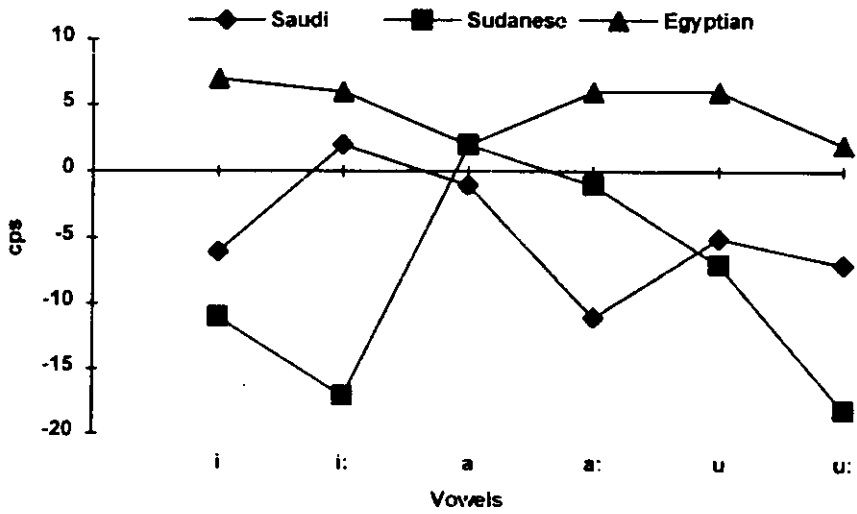

Fig. 3. The difference between the first and second fundamental frequencies (FOa-FOb).

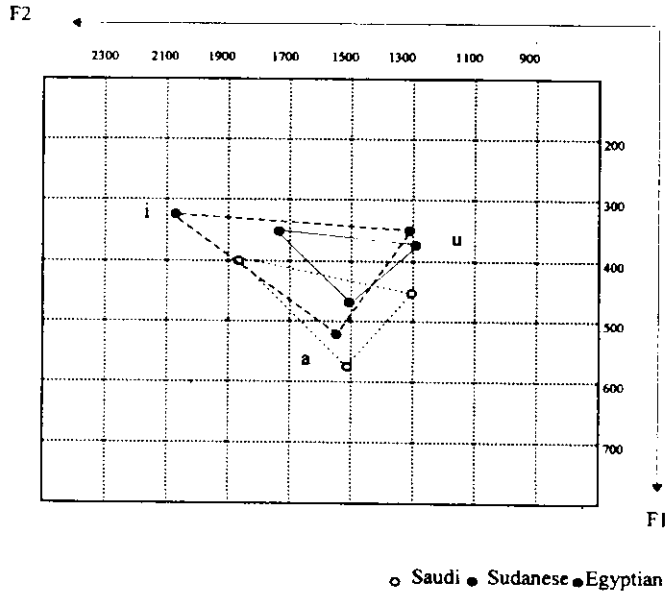

Fig. 4. A format chart showing the first and second formants of the short vowels of the three dialects.

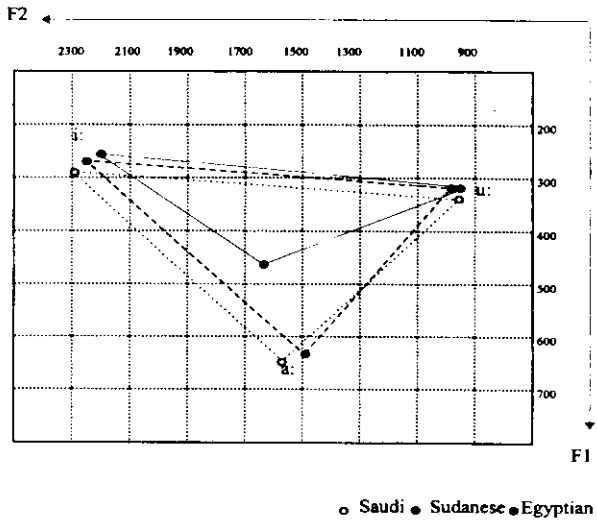

Fig. 5. A formant chart showing the first and second formants of the long vowels of the three dialects.

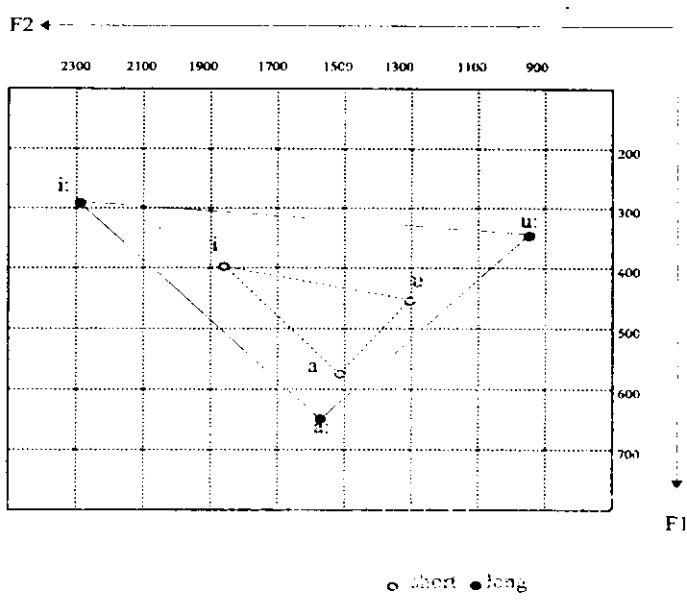

Fig. 6. A formant chart showing the first and second formants of all vowels produced by Saudi speakers.

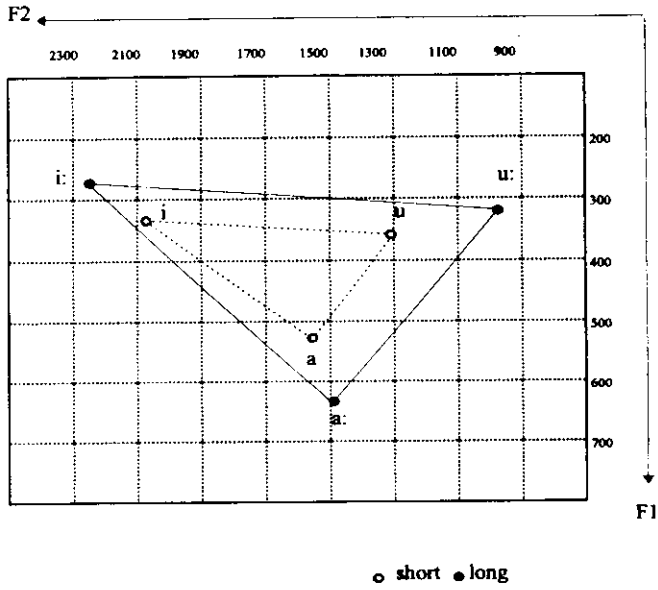

Fig.7. A formant chart showing the first and second formants of all vowels produced by Sudanese speakers.

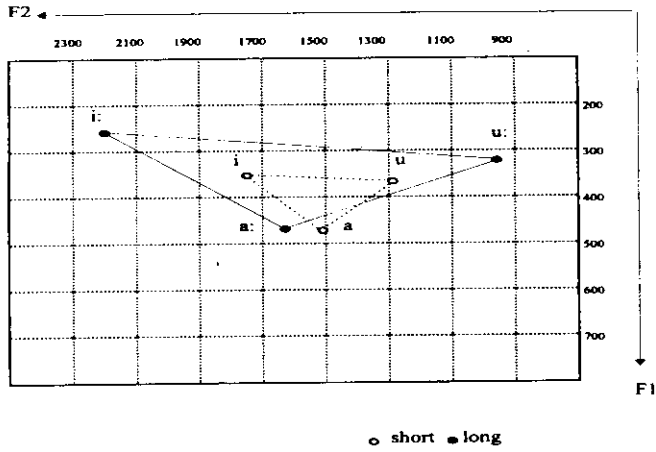

Fig. 8. A formant chart showing the first and second formants of all vowels produced by Egyptian speakers.

تحليل طيفي لصوائت العربية: دراسة عبر اللهجات

منصور محمد الغامدي

أستاذ مساعد، قسم العلوم الإنسانية، كلية الملك خالد العسكرية،

الرياض، المملكة العربية السعودية

ملخص البحث. تم في هذه الدراسة قياس النطق الخمسة الرنينية الاولى للصوائت العربية / ـَـ/، ـِـ/، / ـُـ/، / ـًـ/ ، / ـٍـ/، / ـٌـ/ وذلك من حيث ترددها وشدتها وطول موجتها. ويتكون المتحدثون من: خمسة سعوديين، وخمسة سودانيين، وخمسة مصريين. ولقد أظهرت النتائج أن للهجات المتحدثين دورا في تمييز نوعية الصوائت، بينما تحتفظ بمدد زمنية ثابتة. وكان الفارق الرئيس في نوعية الصوائت يتمثل في تردد النطاق الرنيني الأول بينما نتائج القياسات الأخرى أظهرت تقاربا بين اللهجات المذكورة. هذه النتائج لها أهميتها في بحوث تتعلق بالإدراك الآلي للأصوات وتوليفها والتعرف على لهجة المتحدث.