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FORMANT FREQUENCY ANALYSIS OF QURANIC ALPHABETS IN *SUKOON* PRONUNCIATION BETWEEN ADULT MALE AND FEMALE EXPERTS(*)

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ABSTRACT

The recitation of the Holy Quran is an essential activity for all Muslim around the world, where reading the Quran in its proper manner according to the Prophet Muhammad (p.b.u.h.) will be rewarded. Traditionally the learning takes place thorough face to face session where the teacher will correct the recitation of the student. The learning normally started with recognizing the alphabet and its characteristics. There is no proof that one has pronounced the alphabet correctly except by hearing and looking at the student. This resulted in the rise of the development of Quranic recitation tools based on the speech, and image recognition. In this paper, formant features were extracted from the *sukoon* (°) pronunciation of Quranic alphabets by male and female expert reciters. The Quranic alphabets pronunciation signals were grouped according to the range of the first and second formant frequencies (*F1* and *F2*), for both male and female experts. The result shows that female pronunciations gave higher values of *F1* and *F2* than male pronunciation for most of the Quranic alphabets. As for the alphabets, the pronunciation of the أَشْ (Ash) has the highest *F1* and *F2* values for both male and female. Classification of alphabets were done using linear and quadratic discriminant analysis. The features of both experts will later be used as the reference in the overall *Makhraj* learning platform.

Keywords: *Quranic alphabets, Formants, Speech Processing, Tajweed, Linear Discriminant Analysis, Quadratic Discriminant Analysis.*

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1. INTRODUCTION

The Holy Quran is the Holy book of Islam which was revealed 1400 years ago to the Prophet Muhammad (p.b.u.h) as a main guidance for all Muslim. Until now, Muslims continue to learn the Quran as it is compulsory to read the Quran regularly with the proper *Tajweed* as how the Prophet has recited before. A proper *Tajweed* means the correct way of recitation by following rules of pronunciation during the recitation of Quran, which are the correct point of articulation and the correct characteristics of the pronunciation. These rules acknowledge the differences between the normal Arabic speech and the Quranic recitation, although the Quran is written in Arabic language.[1]

Recently, speech recognition is often used in the research related to Quranic recitation due to the high level of performance of the system.[2] In most of the cases,[3] speech features were extracted as part of speech recognition process. The Fundamental frequency (F_0) and Formant frequencies are important attributes in the production of the human voice. However, the frequencies are different in male and female voice.[4] This is due to the anatomical differences of male and female vocal tracts, where the male vocal folds are usually larger than female, hence yielding a lower F_0. Typical values obtained for F_0 are 120 Hz for male and 210 Hz for female. The mean values change slightly with age. Usually for male, F_0 drops significantly during puberty. As for female, the value of F_0 maintains with age until they reach menopause, where it decreases. In addition, the vocal

[1] N. J. Ibrahim, M. Y. Zulkifli, and H. Mohd. 2011. "Improve Design for Automated Tajweed Checking Rules Engine of Quranic Verses Recitation : A Review," *J. Quranic Res.*, no. January, 39–50.

[2] M. Bezoui, A. & A. Beni-Hssane. 2017. "Feature extraction of some Quranic recitation" in *ICMCS,* 127–131.

[3] A. A. Almisreb, et al. 2016. "Acoustic analysis of Arabic phonemes based-/a:/ vowel," *CSPA 2016*, no. March, 275–279.

[4] H. Traunmüller & A. Eriksson. 1994. "The frequency range of the voice fundamental in the speech of male and female adults," *Dep. Linguist. Univ. Stock.*, vol. 97, 1905191–5.

tract of male is longer than female's,[1] thus giving a lower formant in the speech signals.[2]

This research explores the viability of Formant frequency as the features to be extracted from audio signals of Quranic alphabets pronunciation from the experts. The purpose of this research is to model the correct pronunciation of the Quranic alphabets and later will contribute to the teaching and learning of the Quran. Particularly in this study, we will compare the range of frequency based on gender to see whether there are any significant differences between the audio signals produced by both male and female experts.

1. DATABASE COLLECTION

The data acquisition process was done via audio recording session with experts in Quran, where total of 30 people including 19 adult males and 11 adult females were selected based on the recommendation by a certified expert in this field. The audio data was recorded using the portable high-quality field recorder, TASCAM DR-05, with frequency response of 40Hz to 20 kHz. The recordings were done in classrooms and labs in engineering faculty of the university to imitate a normal learning environment and with minimum unwanted noise. During the audio recording, the participants recited 28 combinations of Quranic alphabets in *Sukoon* (°) pronunciation. *Sukoon* pronunciation is the pronunciation of the combination of the alphabet أ (alif) with the phoneme /a:/ and the Quranic alphabet with *sukoon* (°) (absence of vowel after consonant)[3]. Table 1 shows the *sukoon* combination of Quranic alphabets and its pronunciation that is recited for the recording. The participants were required to recite each *sukoon* alphabets only once without repeating them. This *sukoon* combination of Quranic alphabets dataset can be used to describe the *Makhraj* (point of articulations) and *Sifaat* (characteristics) of each alphabet.

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[1] S. Poon and M. L. Ng. 2011. "Contribution of Voice Fundamental Frequency and Formants To the Identification of Speaker ' S Gender," *ICPhsXVII*, no. August, 1630–1633.

[2] A. Simpson. 2000. "Gender-specific differences in the articulatory and acoustic realization of interword vowel sequences in American English," *5th Semin. speech Prod. Model. …*, 2–5.

[3] R. Zaidi, *et al.* 2008. "Quranic Verse Recitation Recognition Module for Support in j-QAF Learning : A Review," *IJCSNS Int. J. Comput. Sci. Netw. Secur.*, vol. 8, no. August 2015, 207–216.

Table 1. The *sukoon* (°) combination of Quranic alphabets and its pronunciation.

Combination of Quranic alphabets	Pronunciation	Combination of Quranic alphabets	Pronunciation
اَءْ	aa	أَضْ	adh
أَبْ	ab	أَطْ	athd
أَتْ	at	أَظْ	azd
أَثْ	ath	أَعْ	a’
أَجْ	aj	أَغْ	agh
أَحْ	ah	أَفْ	af
أَخْ	akh	أَقْ	ak
أَدْ	ad	أَكْ	akk
أَذْ	az	أَلْ	al
أَرْ	ar	أَمْ	am
أَزْ	azz	أَنْ	an
أَسْ	as	أَهْ	ahh
أَشْ	ash	أَوْ	aww
أَصْ	asd	أَيْ	aii

The audio samples were digitized with a sampling rate of 10 kHz and edited using Audacity, an open source software for audio signal. The processing of data was started with de-identification of personal information as well as removal of the interviewer’s voice and undesirable sound. The unwanted background noise was also removed using Audacity. For the sake of simplicity, all stereo data have been converted to mono channel prior to the noise reduction step. Then the audio signal has been normalized with the amplitude in between -1 to 1. There is 28 Quranic alphabets *sukoon* pronunciation by 30 people making it in total of 840 individual audio files to be stored for analysis. Figure 1 and Figure 2 shows the setup of the recording session with male and female experts.

Figure 1. Recording session with a male expert.

Figure 2. Recording session with a female expert.

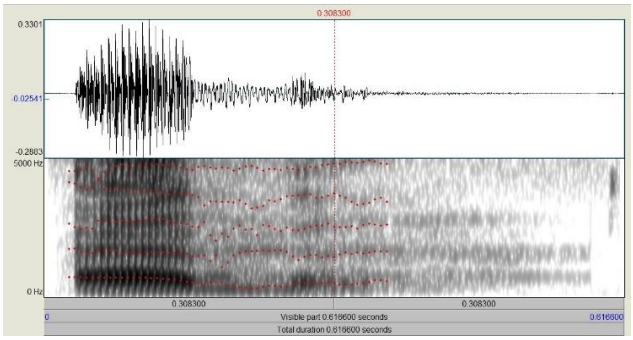
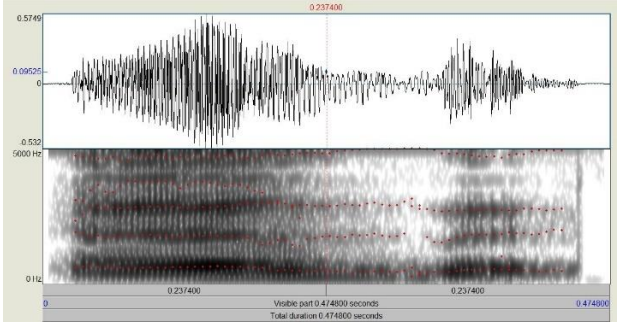
2. FORMANT FEATURES

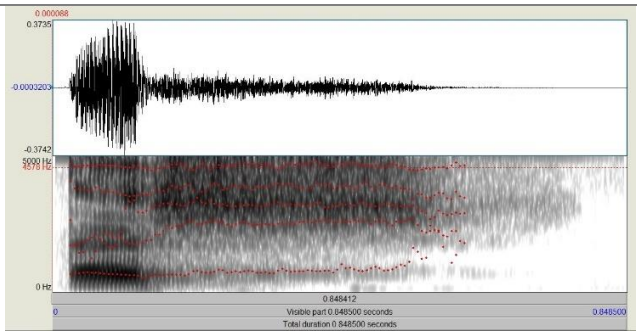
A formant frequency is a concentration of acoustic energy around a frequency in the speech signal. Each formant corresponds to a resonance in the vocal tract. They represent the frequencies that pass most of the acoustic energy from the source to the output. It is often said that the first two formants can be related to the shape and position of the tongue thus affecting the pharyngeal space of the mouth. Higher degree of the opening of the mouth will result in a higher formant frequency and vice versa.[1] Formant frequencies of the audio signal of each Quranic alphabet pronunciation were first obtained using spectrogram features

[1] L. Rabiner & B.-H. Juang. 1993. *Fundamentals of speech recognition.* Prentice-Hall International, Inc.

in PRAAT software. Table 2 shows the audio waveform and spectrogram of pronunciation of أبْ (Ab) and أشْ (Ash) by male and female experts. A series of dotted marks indicates the first to fifth formant frequencies of the signals.

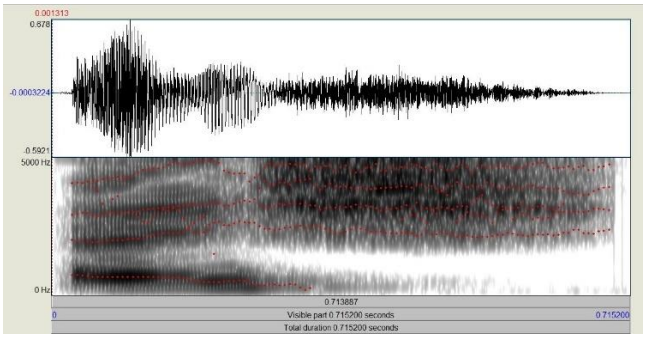
Table 2. The waveform of audio signals of some alphabet's pronunciation.

Quranic Alphabet	Waveform of Audio Signals
أبْ	 Male pronunciation of أبْ
أبْ	 Female pronunciation of أبْ
أشْ	



Male pronunciation of أشْ

أشْ



Female pronunciation of أشْ

The first and second formant frequency (*F1* and *F2*) are extracted from 840 samples, which contains of 19 male data and 11 female experts' data set of 28 alphabets. The average formant frequency was calculated, as can be seen in Table 3, where it shows the average *F1* and *F2* value of 19 male experts and 11 female experts for all Quranic alphabets in *sukoon* combinations.

Table 3. Average *F1* and *F2* value (Hz) for 11 males and 11 female samples.

No	Quranic Alphabets	Male (19)		Female (11)	
		F1 avg (Hz)	*F2* avg (Hz)	*F1* avg (Hz)	*F2* avg (Hz)
1	أءْ	709	1496	840	1718

No	Quranic Alphabets	Male (19)		Female (11)	
		F1 avg (Hz)	*F2* avg (Hz)	*F1* avg (Hz)	*F2* avg (Hz)
2	أبْ	468	1469	484	1551
3	أتْ	647	1702	671	1897
4	أثْ	671	1741	704	2090
5	أجْ	478	1791	596	2206
6	أحْ	961	1938	1093	2085
7	أخْ	791	1495	864	1394
8	أدْ	430	1636	506	1980
9	أذْ	547	1765	445	1717
10	أرْ	518	1005	585	1008
11	أزْ	541	1793	464	1853
12	أسْ	955	2151	1147	2231
13	أشْ	1436	2612	1686	2761
14	أصْ	1121	2271	1126	2067
15	أضْ	485	1188	526	1113
16	أطْ	625	1148	668	1085
17	أظْ	485	1191	527	1068
18	أعْ	831	1333	879	1422
19	أغْ	502	1180	551	1252
20	أفْ	930	1924	1149	2134
21	أقْ	667	1133	752	1170
22	أكْ	786	1825	800	1847
23	ألْ	410	1680	418	2172
24	أمْ	338	1436	343	1376
25	أنْ	341	1706	364	1429
26	أهْ	769	1675	929	1813
27	أوْ	422	932	468	978
28	أيْ	406	1946	403	2533

3. CLASSIFICATION OF SELECTED FEATURES

In this study, Linear Discrimant Analysis (LDA) and Quadratic Discriminant Analysis (QDA) were used as the classifier. The analysis is done to obtain the decision boundaries for the classification of Quranic alphabets between the pronunciation of male and female. Jackknife method was applied as the resampling method because of the small number of data sets. The method leaves one sample from the data set for testing and constructs the classification function with the remaining N-1 samples as the training data.[1]

4. RESULTS AND DISCUSSION

Based on the average values of *F1* and *F2* that were calculated for male and female reciters, it is shown that female recitation produced a higher range of *F1* and *F2* values than males. For male recitation, the highest *F1* value is 1436 Hz while for female, the highest *F1* value is 1686 Hz. The highest value of *F2* for male is 2612 Hz and 2761 Hz for female. These highest values of *F1* and *F2* were by the pronunciation of the alphabet أَشْ (Ash). The lowest *F1* values is given out by the pronunciation of أَمْ (Am), which is 338 Hz for male and 343 Hz for female. As for *F2*, the alphabet أَوْ (Aww) gave the lowest values for both male and female which are 932 Hz and 978 Hz respectively. These values are caused by the shape and position of the tongue during pronunciation or the degree of mouth opening when the alphabets are recited.

The values of *F1* and *F2* were plotted into a graph of *F2* vs. *F1* for further analysis. Figure 3 shows the plot of *F2* vs. *F1* for male recitation, and Figure 4 shows the plot for female recitation. From both graphs, the pronunciation of أَشْ (Ash) is shown to set apart from the pronunciation of the rest of the alphabets because of its high values of *F1* and *F2*. This analysis can be related to the rules of *Tajweed*, where each alphabet has its own *makhraj* (the place of articulation) and *sifaat* (the characteristics). The alphabet ش (shin) has its own unique characteristics called التَفشِّي (at-tafassyi) which means "the diffusion". It is the spreading of sound of alphabet starting from its articulation point until it collides

[1] S. Khairuddin *et al.* 2017. "Classification of the Correct Quranic Letters Pronunciation of Male and Female Reciters," in *IOP Conference Series: Materials Science and Engineering*, vol. 260, no. 1.

with the inner plates of the top teeth.[1] This characteristic only applies to the alphabet ش thus proving the different values of *F1* and *F2* for its pronunciation.

Table 4 and Table 5 shows the range of first formant (*F1*) and second formant (*F2*) for Quranic alphabets pronunciation by both male and female. The table gives a clearer view of the position or the characteristics of each alphabet by the range of formant frequencies produced. For example, male recitation of the alphabet أَظْ (Azd) and أَوْ (Aww) gives out a low value for both *F1* and *F2* while for female, only the alphabet أَوْ (Aww) gives a low value of *F1* and *F2*. The position of the alphabets in the specific range of frequencies may be because of the common *makhraj* and *sifaat* that the alphabets possessed.

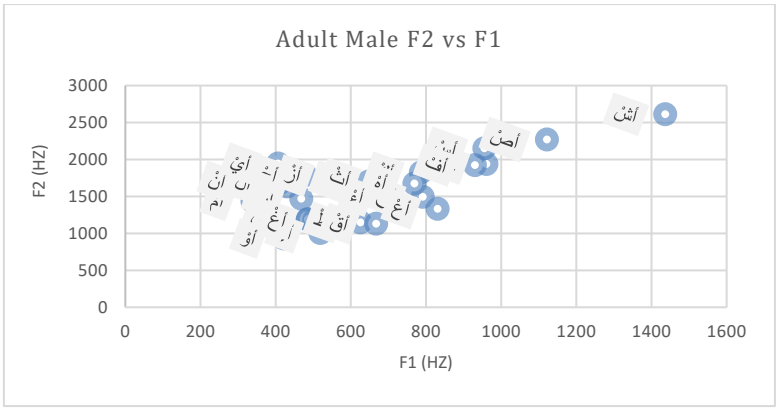


Figure 3. A graph of Adult Male's F2 vs. F1.

[1] S. Khairuddin *et al.* 2017. "Classification of the Correct Quranic Letters Pronunciation of Male and Female Reciters," in *IOP Conference Series: Materials Science and Engineering*, vol. 260, no. 1.

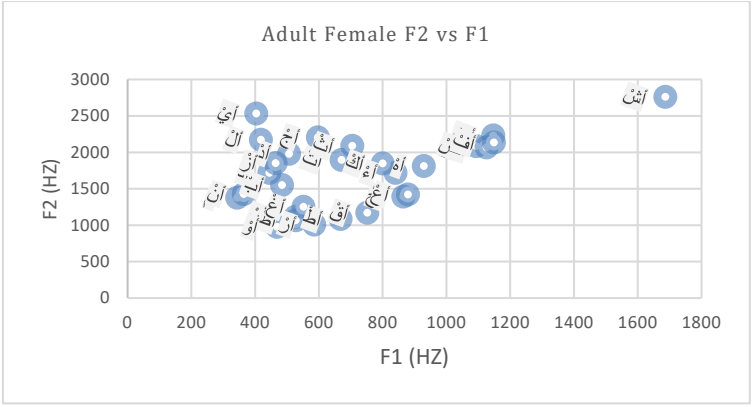


Figure 4. A graph of Adult Female's F2 vs. F1.

Table 4. Range of first formant frequencies (*F1*) of Quranic alphabets *sukoon* pronunciation.

Average F1 range	300-500 Hz	501-700 Hz	701-900 Hz	901-1100 Hz	1101-1300 Hz	1301-1500 Hz	1501-1700 Hz
Male	أبْ /أجْ / أدْ /أضْ / أظْ /ألْ / أمْ /أنْ / أوْ /أيْ	/أتْ أثْ/ /أزْ /أذْ/ /أطْ /أزْ أقْ /أغْ	/أخْ /أءْ أ غْ/ أهْ /أكْ	/أحْ أسْ/ أفْ	أصْ	أشْ	
Female	أبْ/أذْ/أزْ / ألْ /أمْ / أنْ /أوْ /أيْ	/أتْ أدْ /أجْ /أزْ /أضْ/ /أطْ/ أ غْ /أظْ	/أءْ /أثْ/ /أخْ/ /أ غْ/ أكْ /أقْ	أهْ /أحْ	/أسْ /أصْ/ أفْ		أشْ

Table 5. Range of second formant frequencies (*F2*) of Quranic alphabets *sukoon* pronunciation.

Average F2 range	900-1200 Hz	1201-1500 Hz	1501-1800 Hz	1801-2100 Hz	2101-2400 Hz	2401-2700 Hz	2701-3000 Hz
Male	/أرْ /أضْ	/أءْ /أبْ	/أتْ /أثْ	/أحْ /أفْ	/أسْ أصْ	أشْ	

	/أطْ /أظْ /أغْ أوْ /أقْ	/أخْ أمْ /أعْ	/أجْ /أذْ /أدْ /أزْ /ألْ أهْ /أنْ	/أكْ أيْ			
Female	/أزْ /أضْ /أطْ /أظْ أوْ /أقْ	/أخْ /أعْ /أغْ أنْ /أمْ	/أءْ /أبْ أذْ	/أتْ /أثْ /أحْ /أزْ /أذْ /أصْ أهْ /أكْ	/أجْ /أسْ /أفْ ألْ	أيْ	أشْ

Formant features that have been extracted from the audio signals undergoes classification process using LDA and QDA. The result for classification of all alphabets to male and female using both linear and quadratic classifier are shown in Table 6. Figure 5 shows the plot of linear and quadratic classification of the data. The red straight line indicates the linear classification line, and the black line is the quadratic classification. The data are further being classified into male and female group by each alphabet. Table 7 shows the percentage of correct classification of each alphabet's pronunciation by male and female using LDA as the classifier. Likewise, Table 8 displays the result of the classification using QDA.

Table 6. Linear and Quadratic classification of Quranic alphabet

Classification	Linear	Quadratic
All (%)	62.5	67.9
Male (%)	71.4	82.1
Female (%)	53.6	53.6

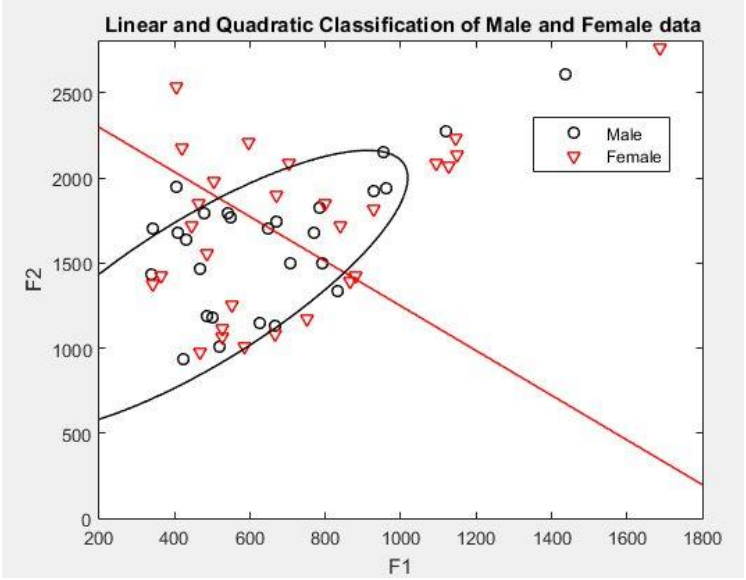


Figure 5. Linear and Quadratic Classification of Male and Female data.

Table 7. Percentage of correct classification of each Quranic alphabet using LDA.

Quranic Alphabets	أءْ	أبْ	أتْ	أثْ	أجْ	أحْ	أخْ	أدْ	أذْ
All (%)	86.7	60.0	76.7	80.0	73.3	73.3	56.7	70.0	46.7
Male (%)	78.9	57.9	78.9	84.2	73.7	73.7	52.6	68.4	42.1
Female (%)	100.0	63.6	72.7	72.7	72.7	72.7	63.6	72.7	54.5

Quranic Alphabets	أرْ	أزْ	أسْ	أشْ	أصْ	أضْ	أطْ	أظْ	أعْ
All (%)	66.7	60.0	60.0	53.3	60.0	46.7	56.7	50.0	60.0
Male (%)	68.4	52.6	68.4	52.6	57.9	42.1	57.9	47.4	63.2
Female (%)	63.6	72.7	45.5	54.5	63.6	54.5	54.5	54.5	54.5

Quranic Alphabets	أغْ	أفْ	أقْ	أكْ	ألْ	أمْ	أنْ	أهْ	أوْ	أيْ
All (%)	53.3	53.3	60.0	36.7	83.3	30.0	63.3	70.0	60.0	70.0
Male (%)	57.9	68.4	68.4	47.4	84.2	36.8	68.4	73.7	73.7	63.2
Female (%)	45.5	27.3	45.5	18.2	81.8	18.2	54.5	63.6	36.4	81.8

Table 8. Percentage of correct classification of each Quranic alphabet using QDA.

Quranic Alphabets	أءْ	أبْ	أتْ	أثْ	أجْ	أحْ	أخْ	أدْ	أذْ
All (%)	83.3	40.0	70.0	76.7	63.3	73.3	53.3	63.3	50.0
Male (%)	78.9	21.1	68.4	84.2	73.7	73.7	42.1	63.2	31.6
Female (%)	90.9	72.7	72.7	63.6	45.5	72.7	72.7	63.6	81.8

Quranic Alphabets	أرْ	أزْ	أسْ	أشْ	أصْ	أضْ	أطْ	أظْ	أعْ
All (%)	70.0	43.3	63.3	66.7	60.0	53.3	46.7	50.0	56.7
Male (%)	73.7	21.1	84.2	68.4	68.4	36.8	47.4	31.6	57.9
Female (%)	63.6	81.8	27.3	63.6	45.5	81.8	45.5	81.8	54.5

Quranic Alphabets	أغْ	أفْ	أقْ	أكْ	ألْ	أمْ	أنْ	أهْ	أوْ	أيْ
All (%)	56.7	63.3	60.0	50.0	73.3	33.3	66.7	76.7	50.0	73.3
Male (%)	52.6	84.2	63.2	42.1	68.4	26.3	68.4	68.4	68.4	68.4
Female (%)	63.6	27.3	54.5	63.6	81.8	45.5	63.6	90.9	18.2	81.8

Overall, quadratic classification gives a higher percentage accuracy which is 67.9% where the male data have the higher percentage classification with 82.1%. Based on the observation of the results of individual alphabets, it is shown that the pronunciation of أءْ (Aa) gives the highest percentage accuracy for all subjects combined, with LDA and QDA as the classification method. Using LDA as the

classifier, the male pronunciation of أثْ (Ath) and ألْ (Al) have the highest percentage accuracy, which is 84.2%. However, the classification of other alphabet's pronunciation for male subjects shows a low percentage accuracy. This is the same with female pronunciation results, where only the pronunciation of أءْ (Aa) gives a 100% accuracy and the pronunciation of ألْ (Al) and أيْ (Ayy) shows a good result with 81.8%. Other than that, it seems like LDA is not a suitable classifier to correctly classify all the alphabets into its own class, with formant frequency as the features. In the classification using QDA, the results exhibit a similar behaviour as the classification result of LDA. It is shown that the feature *F1* and *F2* with QDA can correctly classify the pronunciation of أثْ (Ath) and أسْ (As) for male subjects as it gives a high accuracy of 84.2%. Meanwhile, for female pronunciation, the highest percentage accuracy is for the pronunciation of أءْ (Aa) and أهْ (Ahh) with 90.9%.

Classification process should be done to group the Quranic alphabets into the same class of *makhraj* and *sifaat*. However, it is difficult to determine the exact *makhraj* and *sifaat* of each alphabet based on only Formant feature because each alphabet may have several different characteristics. Therefore, other features should be considered, and various classification methods can be used to determine the *makhraj* and *sifaat* of the Quranic alphabets.

5. CONCLUSION

Overall, based on the results, the formant frequencies of female expert in pronunciation are higher than the frequencies of the male expert. These findings will be used for developing a different reference model for Quranic recitation for male and female. Furthermore, different alphabet will give out different values of *F1* and *F2*, because each of them are produced from different place of articulation and have several different characteristics. The classification of the pronunciation of Quranic alphabet using linear and quadratic linear analysis shows that a few alphabets can correctly be represented by using *F1* and *F2* as the features. The range of values for formant frequencies of each alphabet may be helpful for further research on Quranic recitation specifically on the *makhraj* and *sifaat* of the Quranic alphabets. This feature is a good start in the study of Quranic alphabets, however, more features should be extracted, and different method should be considered in classifying the Quranic alphabets into its group.

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