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An acoustic investigation of Arabic vowels pronounced by Malay speakers

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Abstract In Malaysia, Arabic language is spoken, and commonly used among the Malays. Malays use Arabic in their daily life, such as during performing worship. Hence, in this paper, some of the Arabic vowels attributes are investigated, analyzed and initial findings are presented based on tokens articulated by Malay speakers as we can consider the spoken Arabic by Malays as one of the Arabic dialects. It is known that in Arabic language there are 28 consonants and 6 main vowels. Firstly, the duration, variability, and overlapping attributes are highlighted based on syllables of Consonant–Vowel with each syllable representing every Arabic consonant with the corresponding vowels. Next, the dispersion of each vowel is examined to be compared with each other along with the variability among vowels that may cause overlapping between vowels in the vowel-space. Results showed that the vowel overlapping occurred between short vowels and their long counterpart vowels. Furthermore, an investigation of the Arabic vowel duration is addressed as well, and duration analysis for all the vowels is discussed, followed by the analysis for each vowel separately. In addition, a comparison between long and short vowels is presented as well as comparison between high and low vowel is carried out.

1. Variability and overlapping of Arabic vowels

While listening to vowels, it seems steady and unchanging due to the fast modification, which may happen in milliseconds in acoustic variables such as the fundamental frequency and formant frequencies. The modifications in acoustic variables may influence the uniqueness and intelligibility of the speaker's voice (Gordon, 2012). Variability in the production of vowels may include stress, context, speaking rate and formant frequencies. Three factors could influence the formant frequencies (Nicolaidis, 2003; Seung-Jae and Lindblom, 1994) namely:

(1) Duration of the vowel.
(2) Contextual environment.
(3) Articulatory effort.

There are two phonetic variables to describe the vowels specifically the quality and the quantity of the vowels. The

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vowel quality describes the vowel's articulation place, the tongue position inside the vocal tract, stricture size, the lips shape and the status of the vowel, whether nasalized or not, while the vowel quantity describes the vowel duration (Saadah, 2011). In addition, the vowel duration could be affected by the speech rate, for instance the vowel duration becomes shorter if the speech rate increases. Moreover, the speakers tend to produce scattered vowels if they spoke slowly and the vowels will be centralized in the vowel space if the subjects spoke faster (Souza and De Mora, 2014).

As stated earlier, there are six vowels in Modern Standard Arabic (MSA), and it can be divided into two categories. Firstly, are the short vowels, which include /a/, /i/ and /u/, and next are the long vowels which is comprised of /a:/, /i:/ and /u:/. Several researches have been carried out about Arabic vowels. A study by Saadah (2011) has investigated the production of Arabic vowels by English second language (L2) learners and heritage speakers of Arabic. Another study by Thesieres (2001) has addressed the vowels in Lebanese Arabic and the United Arab Emirates. Results of Lebanese Arabic vowels were compared with the results of Iraqi Arabic vowels based on a study conducted by Al-Ani (1970). Meanwhile, the experiments on Emirates Arabic vowels were compared to the Lebanese and Iraqi vowel experiments.

An investigation on the acoustic attributes of the Palestinian Arabic vowels was done by Saadah (2011). This research was based on tokens that have been articulated by six native Palestinian Arabic speakers with a total number of vowel tokens as 1368. His experimental results showed that F1 for short /i/ and short /u/ has a higher frequency than its counterpart vowel, and this refers to the high long vowels, which were produced with higher tongue position. However, the short low vowel /a/ has a lower F1 frequency compared to its long counterpart vowel. Meanwhile, for F2 frequencies, the speakers were more likely to articulate the short /i/ with a lower value than the long /i/ in contrast with the short /u/. The Palestinian vowels have lower F1 and F2 values compared to Iraqi vowels (Al-Ani, 1970) and Tunisian vowels (Belkaid, 1984). Another research on vowels in the Palestinian Arabic was conducted by Adam (2014) which aimed to study the variation in the vowel durations in two cases: normal speakers and speakers with Broca's aphasia. The study claimed that the vowel durations were longer for the speakers with Broca's aphasia compared to normal speakers. Researchers have also focused to study the vowels in other Arabic dialects. For example, Saudi, Sudanese and Egyptian Arabic vowels have been addressed by Alghamdi (1998) and its aim is to decide whether vowels in MSA are realized in the same way if spoken by individuals related to different dialects. The researcher found that the short vowels were likely to be centralized more than the long vowels. Another research on vowels in eight Arabic dialects is conducted by Haidar (1994). The dialects include Lebanese, Syrian, Qatari, Tunisian, Emirati, Jordanian, Saudi, and Sudanese. The researcher used monosyllabic words in her experiments. This study has shown a significant difference in the formant values among all eight dialects. Another study of the vowels in the Libyan Arabic is addressed by Ahmed (2008). The aim of this study is to provide acoustic and auditory descriptions about vowels in Libyan Arabic in order to compare it with vowel's attributes of other Arabic dialects. The use of monosyllabic words was recorded among 20 native Libyan Arabic native speakers. His results showed that the long and short vowels were significantly varied in both quantity and quality. In case of the short vowels, it was likely to be more centralized compared to other results reported by other studies. Formant based analysis of spoken Arabic vowels is also studied by Alotaibi and Husain (2009). The first two formants were considered in this study, in addition to the differences and similarities between vowels. All the carrier words were formed using Consonant–Vowel–Consonant style (CVC).

In addition, an analysis study of the formant frequencies of the Arabic vowels is achieved by Newman and Verhoeven (2002). This research was based on Quranic recitation tokens, which consists of 30 min of Qur'an recitation. The recorded token contains 400 vocalic observations, which cover all the Arabic vowels. Moreover, along with the Quranic recitation tokens, the researchers acoustically analyzed the same vowels depending on recorded tokens taken from colloquial Egyptian Arabic.

2. Duration of Arabic vowels

Every speech sound has its physical and perceptual properties. The perceptual values of any speech sound can be linked to the physical value measured. Duration can be defined as the physical property that represents the measured duration of a speech sound from the articulatory and acoustic points perspective (Hassan, 1981). From another point of view, the duration of a speech sound can also be in the representation of time dimension of an acoustical signal (Lehiste, 1970). On the other hand, length is defined as the perceptual attribute that leads to the perception of a speech sound. Several researches have done in depth investigation on the durational and articulatory parameters in vowel articulation. Some significant information based on the findings include the vowel duration, such as the ability of the listener to perceive vowels and the production mechanism of the vowel or even demonstrate the articulatory movements degree that are required for producing a particular vowel (House, 1961). Moreover, the acoustic studies have claimed that the vowel duration was beneficial for vowel identification and the intelligibility of speech (Ferguson and Kewley-port, 2007; Mok, 2011). The acoustic investigations have reported that the low vowels are longer than the high vowels, while vowels produced within closed syllables are shorter than vowels produced within opened syllables. In addition, vowels followed by voiced consonant phonemes were found to be longer compared with vowels followed by voiceless consonant phonemes. Alternatively, vowels before stop consonant phonemes are shorter than vowels followed by fricative consonant phonemes (Ladefoged, 2006) and because vowels in Arabic are a concern, a study on Arabic vowels was carried out by Alghamdi (1998). The vowels were pronounced by speakers representing three Arabic dialects: Saudi, Sudanese and Egyptian. The experimental results have shown that the main difference between the three dialects was in the first formant frequencies, but in terms of duration, the vowels did not show any significant difference from one another. In addition, it was found that the behavior of the short vowels was less than half of the long vowels. Another study on vowels in Arabic dialects has been addressed by Khattab and Al-tamimi (2007) for Lebanese Arabic. This study reported that there is no significant difference between the durational results for males and females. Ammani–Jordanian Arabic has been studied by Zawaydeh (1997) and it has shown that the frequencies for the F1 formant in the low vowels in the uvularised environment are higher than F1 frequencies in the plain environment.

3. Methods

This section discussed the proposed method. A group of eight Malay speakers that comprised of 6 males and 2 females, ages ranged between 18 through 38 years is the database used in this research. The speakers are from different regions in Malaysia which are; Selangor, Melaka, Perlis, Johor Baharu, Perak, Pahang, Sabah, and Sarawak. In addition, all the subjects are students. Each subject is required to read and record all tokens in one session. The tokens have been pre-prepared in advance, and it consists of Consonant–Vowel (CV) syllables. Therefore, in total the number of syllables articulated by each speaker is 168 (28 consonants × 6 vowels) and the total number of recorded vowels is 1344 (168 tokens × 8 speakers).

The recording process is accomplished using SAMSON C03U USB multi-pattern condenser microphone. This microphone has the ability to record high-quality voice even in a noisy environment due to its built-in switchable high-pass filter and 10 dB pad. The chosen sampling rate for all the recording phonemes is 16,000 Hz, and 32 bits for mono channel. Audacity 2.0.3 software is used as the recording platform.

Table 1 presents the carrier vowels among all the Arabic alphabets and its International Phonetic Alphabets (IPA) representation.

4. Results based variability and overlapping

In this section, analysis of the vowels was conducted using Praat software (Boersma and Weenink, 2014).

4.1. Between-vowel category variability

Firstly, it was found that there exist variations between vowel categories. In order to compare the within-category variability between all categories, the dispersion range of each vowel category for both formants is calculated in Hz. Then, the dispersion for all vowel categories is presented using the bar graph as depicted in Fig. 1.

As observed in Fig. 1, the central mid vowel /a/ appears to be the most dispersed vowel on the front back dimension with F2 in the range of 2911.42 Hz. On the other hand, the least dispersed vowel seems to be the high front vowel /i:/, with F2 range at 510.176 Hz. The least dispersed vowel is F3 since it has the least range difference of 320.376 over all other vowels.

The fact that front vowels are less dispersed than back vowels is explained by Beckman et al. (1995) that suggested the articulatory configuration of /i/ is easier to obtain than that of /u/, resulting in less variability in the formants. High front vowels can be pronounced more precisely by stiffening the genioglossus muscle and sustaining the tongue laterally against the dental edge. By contrast, the articulation of the back vowels /u/ are not able to be obtained in a similar manner, leading to the less precise control of tongue height, which results in more dispersion in the production of this vowel.

Table 1 Carrier vowels.

Short *fatha*		Long *fatha*		Short *dummah*		Long *dummah*		Short *kasrah*		Long *kasrah*	
Vowel	IPA	Vowel	IPA	Vowel	IPA	Vowel	IPA	Vowel	IPA	Vowel	IPA
أَ	aa	اَا	aaa:	أُ	au	أُو	auu:	إِ	ai	إِي	aii:
بَ	ba	بَا	baa:	بُ	bu	بُو	buu:	بِ	bi	بِي	bii:
تَ	ta	تَا	taa:	تُ	tu	تُو	tuu:	تِ	ti	تِي	tii:
ثَ	θa	ثَا	θaa:	ثُّ	θu	ثُو	θuu:	ثِ	θi	ثِي	θii:
جَ	dʒa	جَا	dʒaa:	جُ	dʒu	جُو	dʒuu:	جِـ	dʒi	جِي	dʒii:
حَ	ħa	حَا	ħaa:	حُ	ħu	حُو	ħuu:	حِـ	ħi	حِي	ħii:
خَ	xa	خَا	xaa:	خُ	xu	خُو	xuu:	خِـ	xi	خِي	xii:
دَ	da	دَا	daa:	دُ	du	دُو	duu:	دِ	di	دِي	dii:
ذَ	ða	ذَا	ðaa:	ذُ	ðu	ذُو	ðuu:	ذِ	ði	ذِي	ðii:
رَ	ra	رَا	raa:	رُ	ru	رُو	ruu:	رِ	ri	رِي	rii:
زَ	za	زَا	zaa:	زُ	zu	زُو	zuu:	زِ	zi	زِي	zii:
سَ	sa	سَا	saa:	سُ	su	سُو	suu:	سِـ	si	سِي	sii:
شَ	ʃa	شَا	ʃaa:	شُ	ʃu	شُو	ʃuu:	شِـ	ʃi	شِي	ʃii:
صَ	sˤa	صَا	sˤaa:	صُ	sˤu	صُو	sˤuu:	صِ	sˤi	صِي	sˤii:
ضَ	dˤa	ضَا	dˤaa:	ضُ	dˤu	ضُو	dˤuu:	ضِ	dˤi	ضِي	dˤii:
طَ	tˤa	طَا	tˤaa:	طُـ	tˤu	طُو	tˤuu:	طِ	tˤi	طِي	tˤii:
ظَ	ðˤ a	ظَا	ðˤaa:	ظُ	ðˤ u	ظُو	ðˤ uu:	ظِ	ðˤ i	ظِي	ðˤ ii:
عَـ	ʕa	عَا	ʕaa:	عُ	ʕu	عُو	ʕuu:	عِـ	ʕi	عِي	ʕii:
غَ	ʁa	غَا	ʁaa:	غُـ	ʁu	غُو	ʁuu:	غِـ	ʁi	غِي	ʁii:
فَ	fa	فَا	faa:	فُ	fu	فُو	fuu:	فِ	fi	فِي	fii:
قَ	qa	قَا	qaa:	قُ	qu	قُو	quu:	قِـ	qi	قِي	qii:
كَ	ka	كَا	kaa:	كُ	ku	كُو	kuu:	كِ	ki	كِي	kii:
لَ	la	لاَ	laa:	لُ	lu	لُو	luu:	لِ	li	لِي	lii:
مَ	ma	مَا	maa:	مُ	mu	مُو	muu:	مِـ	mi	مِي	mii:
نَ	na	نَا	naa:	نُ	nu	نُو	nuu:	نِـ	ni	نِي	nii:
هَ	ha	هَا	haa:	هُ	hu	هُو	huu:	هِ	hi	هِي	hii:
وَ	wa	وَا	waa:	وُ	wu	وُو	wuu:	وِ	wi	وِي	wii:
يَ	ja	يَا	jaa:	يُ	ju	يُو	juu:	يِـ	ji	يِي	jii:

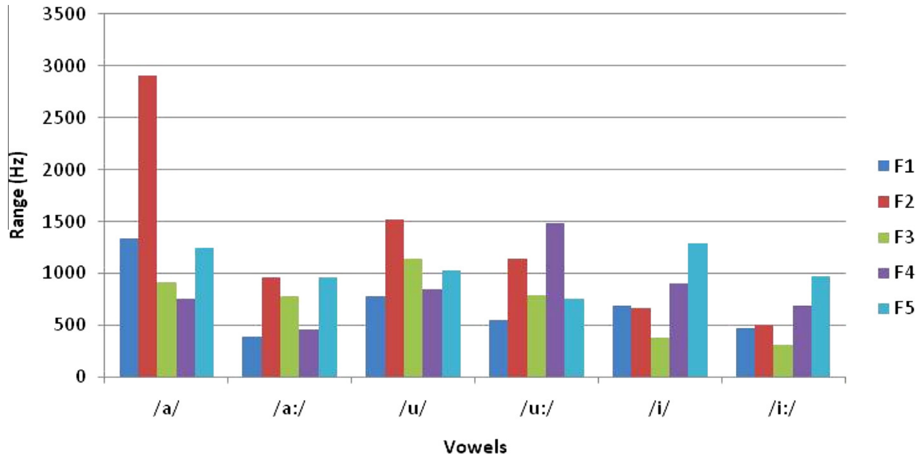

Figure 1 Vowel category dispersion (Range).

However, although range might give some idea about the dispersion of vowels, especially with regard to minimum and maximum points, it might not be the optimal measurement since there may exist some outliers that affect the measured dispersion in spite of the fact that they might be few in number. Another way to measure dispersion via computation of standard deviation is shown in Fig. 2 below.

As compared to Figs. 1 and 2 depicted similar plot patterns and hence minimal differences in the overall dispersion pattern. Here vowel /a/ is still the most dispersed vowel specifically F2, followed by the short vowel /u/ that is less dispersed. However, the vowel /a/ is still the most dispersed vowel as far as Fl is concerned while the vowel /i/ is the most dispersed vowel if F5 is considered. The least dispersion is shown by the long vowel /i:/. From these two plots, it can be summarized that long vowels are less dispersed than short vowels and front vowels are less dispersed than back vowels.

The tendency for high front vowels to be less dispersed than other vowels might be explained by the fact that most of the consonants preceding and/or following all vowels in the data material are coronals, which have an anterior place of articulation, which is similar to that used in the articulation of the high front vowels. The tongue does not need to move over a long distance to/from the consonant in order to produce the vowel. This leads to less influence on front rather than back vowels and makes them less dispersed. Moreover, low vowels require jaw lowering, which requires more time for the tongue to move to/from the articulatory position of a low vowel, which makes this vowel more liable to consonantal effects.

4.2. Vowel quality overlap

Here, overlapping of vowels will be elaborated. Some vowels were found to be overlapped and this might be partially attributed to the high degree of variability these vowels exhibit. For example, the acoustic space for the long and short *dummah* vowels overlapped one another. Similarly, the long and short *kasrah* vowels overlapped one another too. Fig. 3 showed the overlapping between /u/ and /u:/ while Fig. 4 depicted the overlapping between /i/ and /i:/.

Acoustic overlap in the vowel space is common. For example, Peterson and Barney (1952) found a considerable overlap in the production of American vowels by native speakers. This overlap was attributed to several factors namely the differences in the vowel tract size and the context in which these vowels are produced (Ryalls, 1996). When there is variation in the vowel produced by the same speaker, listeners use structural estimation (Nusbaum and Morin, 1992). That is, they rely on the different cues found in the vowel produced to identify it. For example, listeners benefit from F0 and F3 in addition to F1 and F2 in order to recognize the vowel. However, when different vowels are produced by the same speaker sound

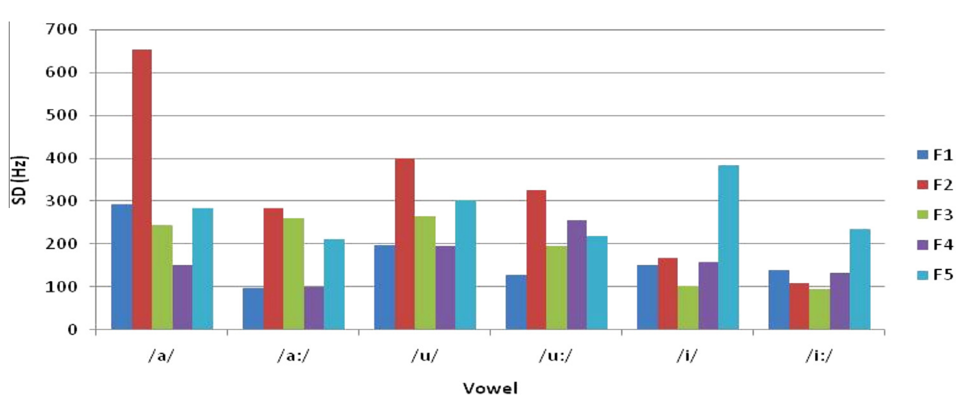

Figure 2 Vowel category dispersion (SD).

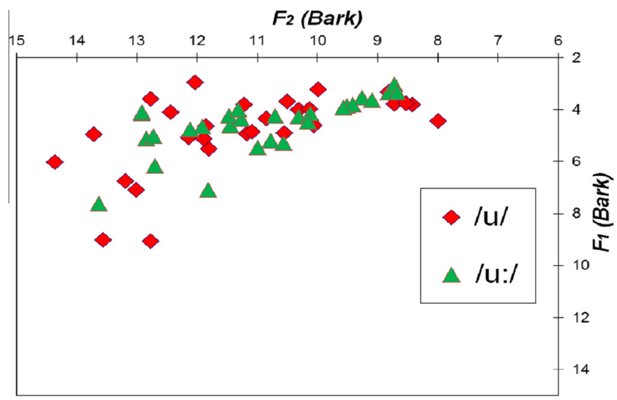

Figure 3 Overlapping between /u/ and /u:/.

similar, listeners rely on a contextual tuning mechanism (Nusbaum and Morin, 1992). In this kind of normalization, listeners try to benefit from contextual information external to the vowel. Information relating to other sounds and utterances found near that vowel is used as an additional cue found in higher levels including lexical, grammatical, and semantic cues.

5. Vowel duration measurements

As claimed by Flege and Port (1981), measuring of vowel duration is from the onset of energy in F1 to the offset of energy in F1 and F2, which with vowel boundaries can be determined from the start to the end. Fig. 5 illustrates a sample of vowel waveform and its corresponding spectrogram. This figure demonstrates the location of the vowel and the area between the two lines representing the duration of the vowel.

5.1. Reliability of the vowel duration measurements

Reliability is mainly concerned with the consistency of measurement done, that is, whether the measurements taken are consistent and repeatable (Bryman, 2001). With regard to the production results and in order to check the reliability of the formant measurements, suggestions made by Ladefoged (2003) are followed.

Foremost, upon completion of all measurements, repetitions of measurement are done too. Due to the large number of tokens, it required about one month to complete all measurements and one more month to repeat them. The two repetitions are then compared, and if there is a significant divergence between the first and the second measurements of a certain formant, a third measurement is made to ensure which is more precise among the two.

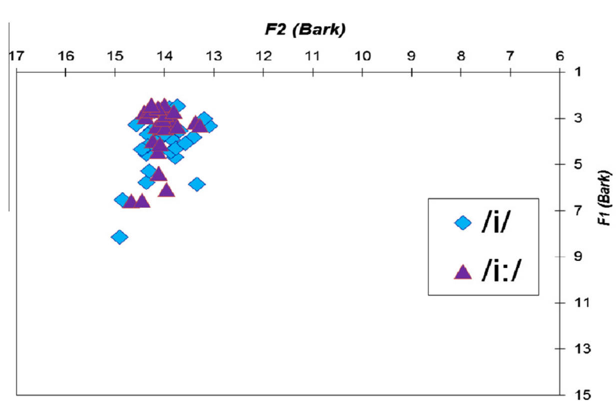

Figure 4 Overlapping between /i/ and /i:/.

Since all tokens were recorded twice, the second step is to ensure reliability to compare the formants of the two repeated tokens. If, there is a difference of more than 50 Hz between the two repetitions of the same formant, they were checked once more to ensure that there was no error in the measurements.

The next step is ensuring the reliability of the measurements that is by plotting all tokens uttered by a specific speaker for a certain vowel on the formant plane. This process would highlight any outliers in the production of each speaker's vowel. When an outlier is found, the formant measurement of that outlier is taken again. If no errors or outliers are found, the data are accepted as showing intra-speaker variability. The same procedure is done for duration measurements.

5.2. Duration analysis results

In order to present and discuss the results of the duration analysis, the overall duration of all vowels is presented first before looking closely at the duration patterns of each vowel separately.

As examined in Table 2, it was revealed that Arabic vowels could be divided into two groups, that is as far as duration is concerned known as short and long vowels. The short vowels are three specifically /a/, /u/ and /i/. On the other hand, the long vowels are the other three that are /a:/, /u:/ and /i:/.

The mean duration of the three short vowels is 0.376 s while that for the three long vowels is 0.689 s. Table 2 also showed the directional similarity within these two groups. The high front /i:/ has the shortest duration among long vowels while the low front /a/ has the shortest duration among the short vowels.

High vowels being shorter than low vowels are attributed to the extra time needed for lowering the jaw when low vowels are produced (Lehiste, 1970; Lindblom, 1967). As presented in Table 2, Malay speakers tended to pronounce long vowels longer than short vowels and high short vowels longer than low short vowels.

Next, Fig. 6 shows that there is a considerable variation in durational patterns between short and long vowels. However, the distinctive difference in duration between short vowels and long ones is still obvious. It is observed that if the duration of a short vowel is high, the duration of a long counterpart produced by the same speaker is still significantly higher in order to preserve the distinction in duration between short and long vowels.

Table 3 shows all durations of short *fatha* vowel with the Arabic phonemes. The average mean of these durations is 0.364 s. The longest duration is 0.547 s for the short *fatha* with phoneme /z (ز)/, which is a voiced phoneme. On the other hand, the shortest duration is 0.251 s for the short *fatha* with the phoneme /ð (ذ)/, which is also a voiced phoneme. As observed in Table 3, for short *fatha* vowels both shortest and longest durations belong to voiced phonemes.

Table 4 shows all durations of the long *fatha* vowel with the Arabic phonemes. The average mean of these durations is 0.690 s. The longest duration is 0.939 s for the long *fatha* with

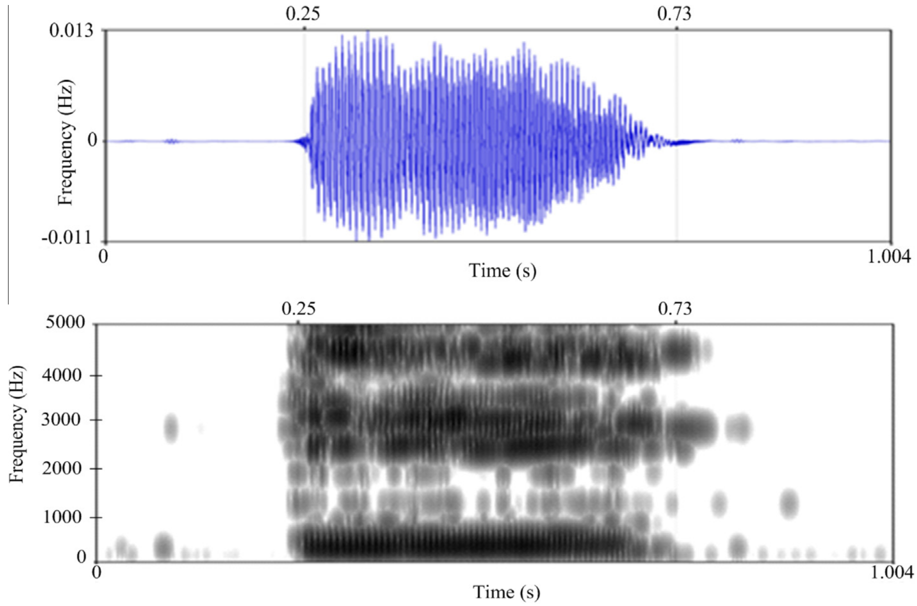

Figure 5 Waveform and spectrogram illustrate the vowel place and duration measurements.

Table 2 Statistical measurements of vowel durations in seconds.

Vowels	/a/	/a:/	/u/	/u:/	/i/	/i:/
Max	0.547	0.939	0.521	0.901	0.558	0.882
Min	0.251	0.527	0.231	0.524	0.231	0.505
Range	0.296	0.412	0.29	0.377	0.327	0.377
Mean	0.364	0.690	0.386	0.691	0.378	0.688
Ratio	0.527		0.558		0.550	
SD	0.079	0.099	0.096	0.100	0.084	0.096

phoneme /ʃ (شَا)/, which is a voiceless phoneme. In contrast, the shortest duration is 0.527 s for the long *fatha* with the phoneme /t (تَا)/ which is also voiceless phoneme. As noticed, for long *fatha* vowels both shortest and longest durations belong to voiceless phonemes.

Table 5 shows all durations of the short *dummah* vowel with Arabic phonemes. The average mean of these durations is 0.386 s. The longest duration is 0.521 s for the short *dummah* with phoneme /ðˤ (ظُ)/ which is a voiced phoneme. It is observed that the shortest duration is 0.231 s, for the short *dummah* with the phoneme /ð (ذُ)/ also as the voiced phoneme. It is also seen that for short *dummah* vowels, both shortest and longest durations belong to voiced phonemes.

Table 6 shows all the durations of long *dummah* vowel with the Arabic phonemes. The average mean of these durations is 0.691 s. The longest duration is 0.901 s for the long *dummah* that is the phoneme /sˤ (صُو)/ which is a voiceless phoneme while the shortest duration is 0.524 s for the long *dummah* with the phoneme /t (تُو)/ which is also a voiceless phoneme. This showed that for long *dummah* vowels both shortest and longest durations belong to voiceless phonemes.

Table 7 shows all durations of the short *kasrah* vowel with Arabic phonemes. The average mean of these durations is 0.378 s. The longest duration is 0.558 s for the short *kasrah* with phoneme /x (خِ)/, which is a voiceless phoneme, while the shortest duration is 0.231 s for the short *kasrah* with the

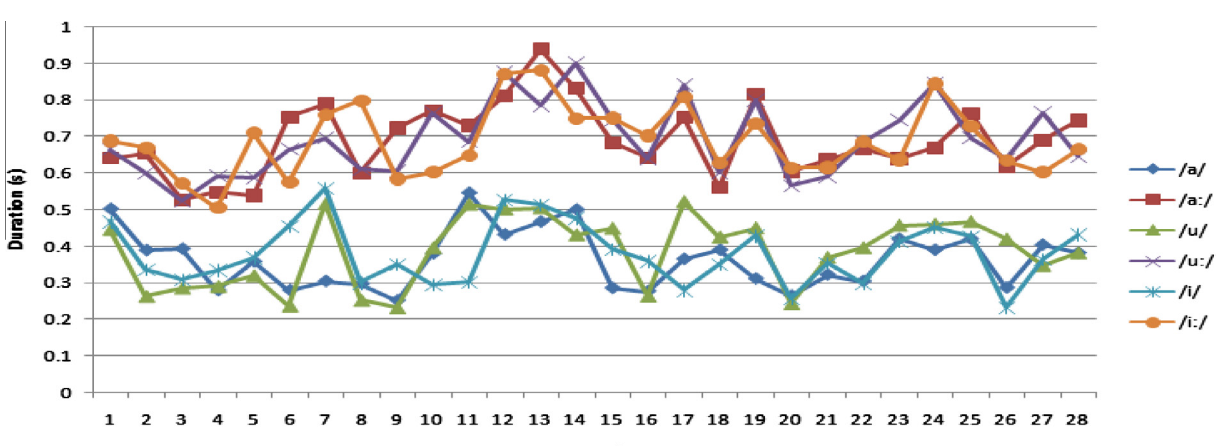

Figure 6 Long and short vowel distribution.

Table 3 Short *fatha* durations.

Short *fatha*		Duration	Short *fatha*		Duration
أَ	aa	0.503	ضَ	dˤa	0.285
بَ	ba	0.389	طَ	tˤa	0.277
تَ	ta	0.393	ظَ	ðˤ a	0.365
ثَ	θa	0.279	عَ	ʕa	0.390
جَ	dʒa	0.358	غَ	ʁa	0.311
حَ	ħa	0.279	فَ	fa	0.264
خَ	xa	0.304	قَ	qa	0.322
دَ	da	0.297	كَ	ka	0.304
ذَ	ða	0.251	لَ	la	0.420
رَ	ra	0.380	مَ	ma	0.390
زَ	za	0.547	نَ	na	0.420
سَ	sa	0.432	هَ	ha	0.286
شَ	ʃa	0.467	وَ	wa	0.404
صَ	sˤa	0.501	يَ	ja	0.382

phoneme /h (ه)/ which is also a voiceless phoneme. As observed in Table 7, for short *kasrah* vowels both shortest and longest durations belong to voiceless phonemes.

Table 8 shows all durations of the long *kasrah* vowel with Arabic phonemes. The average mean of these durations is 0.688 s. The longest duration is 0.882 s for the long *kasrah* with the phoneme /ʃ (شِي)/, which is a voiceless phoneme while the shortest duration is 0.505 s for the long *kasrah* with the phoneme /θ (ثِي)/, which is also a voiceless phoneme. As tabulated in Table 8, for long *kasrah* vowels both shortest and longest durations belong to voiceless phonemes.

5.3. Long versus short vowels duration

In this section, short vowels and their long counterparts will be compared. That is, the vowels /a, u, i/ will be compared with / a:, u:, i:/. First, some descriptive statistics of the duration are introduced earlier in Table 2.

As tabulated in Table 2, long vowel duration owned more than twice as compared to their short counterparts. The average mean for short vowels is 0.376 s and that for long vowels is 0.689 s, with a ratio of 0.545. Duration seems to represent a more robust distinguishing factor between short and long vowels. Table 2 also shows that the shortest duration is exhibited by the high front long vowel and low front short vowels. For instance, the difference between the high long vowel /i:/ and the nearest duration, that is found in the low front vowel /a:/ is 0.002 s. On the other hand, the durational difference between the low short vowel /a/ and the nearest duration in the group of short vowels, which is found in /i/, is 0.014 s.

Table 4 Long *fatha* durations.

Long *fatha*		Duration	Long *fatha*		Duration
اَا	aaa:	0.640	ضَا	dˤaa:	0.683
بَا	baa:	0.654	طَا	tˤaa:	0.642
تَا	taa:	0.527	ظَا	ðˤ aa:	0.751
ثَا	θaa:	0.547	عَا	ʕaa:	0.560
جَا	dʒaa:	0.538	غَا	ʁaa:	0.814
حَا	ħaa:	0.753	فَا	faa:	0.605
خَا	xaa:	0.788	قَا	qaa:	0.636
دَا	daa:	0.599	كَا	kaa:	0.666
ذَا	ðaa:	0.723	لَا	laa:	0.639
رَا	raa:	0.770	مَا	maa:	0.669
زَا	zaa:	0.729	نَا	naa:	0.763
سَا	saa:	0.810	هَا	haa:	0.618
شَا	ʃaa:	0.939	وَا	waa:	0.690
صَا	sˤaa:	0.832	يَا	jaa:	0.744

Table 5 Short *dummah* durations.

Short *dummah*		Duration	Short *dummah*		Duration
أُ	au	0.445	ضُ	dˤu	0.448
بُ	bu	0.262	طُ	tˤu	0.263
تُ	tu	0.285	ظُ	ðˤ u	0.521
ثُ	θu	0.289	عُ	ʕu	0.424
جُ	dʒu	0.319	غُ	ʁu	0.449
حُ	ħu	0.236	فُ	fu	0.242
خُ	xu	0.516	قُ	qu	0.369
دُ	du	0.251	كُ	ku	0.395
ذُ	ðu	0.231	لُ	lu	0.456
رُ	ru	0.395	مُ	mu	0.459
زُ	zu	0.514	نُ	nu	0.466
سُ	su	0.500	هُ	hu	0.419
شُ	ʃu	0.504	وُ	wu	0.347
صُ	sˤu	0.430	يُ	ju	0.381

Table 6 Long *dummah* durations.

Long *dummah*		Duration	Long *dummah*		Duration
أُو	auu:	0.665	ضُو	dˤuu:	0.746
بُو	buu:	0.601	طُو	tˤuu:	0.640
تُو	tuu:	0.524	ظُو	ðˤ uu:	0.841
ثُو	θuu:	0.592	عُو	ʕuu:	0.601
جُو	dʒuu:	0.587	غُو	ʁuu:	0.799
حُو	ħuu:	0.665	فُو	fuu:	0.565
خُو	xuu:	0.696	قُو	quu:	0.591
دُو	duu:	0.610	كُو	kuu:	0.686
ذُو	ðuu:	0.605	لُو	luu:	0.745
رُو	ruu:	0.764	مُو	muu:	0.845
زُو	zuu:	0.686	نُو	nuu:	0.696
سُو	suu:	0.875	هُو	huu:	0.638
شُو	ʃuu:	0.785	وُو	wuu:	0.765
صُو	sˤuu:	0.901	يُو	juu:	0.645

Table 7 Short *kasrah* durations.

Short *kasrah*		Duration	Short *kasrah*		Duration
إِ	ai	0.466	ضِ	dˤi	0.391
بِ	bi	0.336	طِ	tˤi	0.358
تِ	ti	0.307	ظِ	ðˤ i	0.278
ثِ	θi	0.333	عِ	ʕi	0.348
جِ	dʒi	0.368	غِ	ʁi	0.428
حِ	ħi	0.454	فِ	fi	0.254
خِ	xi	0.558	قِ	qi	0.352
دِ	di	0.299	كِ	ki	0.298
ذِ	ði	0.350	لِ	li	0.411
رِ	ri	0.293	مِ	mi	0.451
زِ	zi	0.301	نِ	ni	0.426
سِ	si	0.527	هِ	hi	0.231
شِ	ʃi	0.512	وِ	wi	0.364
صِ	sˤi	0.476	يِ	ji	0.431

Table 8 Long *dummah* durations.

Long *kasrah*		Duration	Long *kasrah*		Duration
اِي	aii:	0.688	ضِي	dˤii:	0.751
بِي	bii:	0.670	طِي	tˤii:	0.702
تِي	tii:	0.572	ظِي	ðˤ ii:	0.808
ثِي	θii:	0.505	عِي	ʕii:	0.626
جِي	dʒii:	0.710	غِي	ʁii:	0.736
حِي	ħii:	0.575	فِي	fii:	0.614
خِي	xii:	0.761	قِي	qii:	0.615
دِي	dii:	0.799	كِي	kii:	0.686
ذِي	ðii:	0.583	لِي	lii:	0.636
رِي	rii:	0.602	مِي	mii:	0.846
زِي	zii:	0.649	نِي	nii:	0.728
سِي	sii:	0.873	هِي	hii:	0.633
شِي	ʃii:	0.882	وِي	wii:	0.603
صِي	sˤii:	0.749	يِي	jii:	0.665

However, the high back long vowels and low long vowels do not show much difference in their duration.

5.4. High versus low vowel duration

Lowering the jaw is known to have a positive effect on vowel duration (Klatt, 1976; Lindblom, 1967). Therefore, it is expected that low vowels would be longer than high vowels due to the amount of jaw lowering required by the production of low vowels. Conversely, Malay speakers tend to articulate low short vowels shorter than high long vowels whereby /a/ shorter than /u/ and /i/ by 0.027 and 0.014 s respectively. While in the case of long vowels, the low long vowel /a:/ is longer than the high front long vowel /i:/ but the difference is only 0.002 s. In contrast, the low long vowel /a:/ is shorter than the high back long vowel /u:/ and the difference is 0.001 s. The finding that the low short vowels are unexpectedly shorter than its high counterpart can be partially attributed to the fact that the Malay speakers do not lower their jaw during the pronunciation of the low short vowel.

Eventually, comparisons in terms of the number of participants, as presented in Table 9, and in terms of duration, as illustrated in Table 10, are accomplished between several studies of Arabic vowels and the current study. Several dialects that have been investigated in a single study such as Algeria, Tunisia, Libya, Egypt, Jordan, and Iraq are studied by Ghazeli (1979) and Qatar, Lebanon, Saudi Arabia, Tunisia, Syria, Sudan, United Arab Emirates, and Jordan by Haidar (1994). Moreover, different researchers addressed the same dialect such as Jordanian dialects which is addressed by Al-Ani (1970), Ghazeli (1979), Haidar (1994). Table 9 includes several studies that were carried out to explore Arabic vowel properties. It involves the conducted dialect and number of participants in each study.

Another comparison is conducted based on the duration of various Arabic dialects and the current study. Table 10 shows that Malay speakers articulated Arabic vowels slower than other native speakers. The study addressed by Al-Ani (1970) showed closer vowel length to the vowels articulated by Malay speakers.

Table 9 A comparison between several studies that handled the Arabic vowel topic in term of dialects and number of participants.

Research by	Dialect	Participants
Al-Ani (1970)	Iraqi	8
	Jordanian	2
Ghazeli (1979)	Algeria, Tunisia, Libya, Egypt, Jordan, and Iraq	12
Haidar (1994)	Qatar, Lebanon, Saudi Arabia, Tunisia, Syria, Sudan, United Arab Emirates, and Jordan	8 (1 participants per dialect)
Alghamdi (1998)	Saudi Arabia, Sudan, and Egypt	15 (5 participants per dialect)
Newman and Verhoeven (2002)	Quran vowels	1
	Cairene	1
Ahmed (2008)	Libya	20
Alotaibi and Husain (2009)	Saudi Arabia	10 (9 males and 1 child)
Saadah (2011)	Palestine	6
This study	Arabic by Malay speakers	8

Table 10 Vowel duration (in seconds) of several Arabic dialects.

Study	Dialect	Vowels					
		i	i:	a	a:	u	u:
Al-Ani (1970)	Iraqi	0.300	0.600	0.300	0.600	0.300	0.600
Mitleb (1984)	Jordanian	0.076	0.116	0.090	0.145	0.083	0.124
Hussain (1985)	Gulf Arabic	0.085	0.155	0.106	0.190	0.093	0.165
Alghamdi (1998)	Saudi	0.111	0.248	0.133	0.311	0.114	0.137
	Sudanese	0.117	0.275	0.128	0.295	0.116	0.304
	Egyptian	0.098	0.255	0.122	0.316	0.110	0.253
Ahmed (2008)	Libyan	0.054	0.138	0.063	0.150	0.064	0.148
Saadah (2011)	Palestine	0.084	0.219	0.097	0.247	0.090	0.226
This study	Arabic by Malay	0.378	0.688	0.364	0.690	0.386	0.691

6. Conclusion

As a conclusion, the investigation of Arabic vowel properties is conducted with Malay individuals articulated the carrier tokens. Duration, variability, and overlapping attributes of the Arabic vowels among the speakers have been discussed. The presented attributes have been addressed according to articulated vowels covering all the Arabic phonemes, which lead to an overview on how the pronunciation of the vowels has been done. This study will be able to assist researchers to suggest suitable manners for articulating Arabic vowels and a deeper understanding of the pronunciation process. Additionally, it will also assist to investigate the differences and similarities of pronunciation between native speakers and non-native speakers of the Arabic language.

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