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An Acoustic Study of Zilfaawi Arabic Vowels

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Abstract

The present research provides an acoustic description of vowel quality and quantity in Zilfaawi Arabic (ZA). The vowel duration and the first (F1) and second (F2) formants were measured. Acoustic analysis of the ZA vowels /i/, /i:/, /a/, /a:/, /u/, /u:/, /e:/, /o:/ was performed using eight monosyllabic CVC words. Ten native speakers of ZA each read the carrier phrase five times, producing a total of 400 tokens. This study also examines whether these aspects differ between men and women. The results revealed that the phonemic vowel inventory of this Saudi dialect comprises three short and five long vowels. The phonetic quality and duration of short and long vowels in ZA exhibited notable temporal differences, with speakers exhibiting long vowels of approximately twice the duration of short vowels. Close proximity was detected between adjacent vowel pairs /i/–/e:/ and /u/–/o:/ among women, with no statistically significant differences observed in their F1 values. In addition, the vowels produced by men displayed more retraction and height than those produced by women. Overall, the data indicated no significant difference in vowel duration between men and women.

Keywords: Zilfaawi Arabic, acoustic, vowels, formants, duration, gender

دراسة صوتية لصوائت اللهجة الزلفاوية

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هـ)14445/1/10 هـ ، ونشر في 1444/12/17 هـ، وقبل للنشر في 1444/12/4هـ وتم مراجعتها في 1444/10/29(قدم للنشر في

ملخص البحث :

يقدم البحث الحالي وصفًا صوتيًا للصوائت في اللهجة العربية الزلفاوية من حيث نوعيتها وطولها. وتعنى الدراسة بقياس مدة الصائت والتردد الرنيني الأول و الثاني (F1-F2). ويجرى التحليل الصوتي للصوائت / i /، / i: /، / a /، / a: /، / u /، / u: /، / e: /، / o: / في اللهجة الزلفاوية باستخدام ثماني كلمات أحادية المقطع CVC يقرؤها عشرة متحدثين أصليين للهجة خمس مرات في عبارة محددة، ليصبح المجموع 400 كلمة. وتبحث هذه الدراسة أيضًا في ما إذا كان هناك أي اختلافات في هذه الجوانب بين الذكور والإناث. ووفقًا للنتائج ، فهناك فرق كبير بين صفات الصوائت الطويلة والقصيرة. كما تظهر النتائج أن الصوائت في هذه اللهجة السعودية تتكون من ثلاثة صوائت قصيرة وخمسة طويلة. كما تُظهر الجودة والنوعية الصوتية ومدى هذه الصوائت القصيرة والطويلة اختلافات ملحوظة في مداها الزمني. وكما تظهر أطوال الصوائت الطويلة التي للمتحدثين من الذكور والإناث مدى يعتبر ضعف مدى الصوائت القصيرة. كما تظهر الدراسة تقارب كبير بين الأحرف المتحركة المتجاورة /e:/–/i/ و /o:/–/u/ بين الإناث ، مع عدم وجود فروق ذات دلالة إحصائية ملحوظة في قيم التردد الرنيني الأول الخاص بهم. بالإضافة إلى ذلك ، فإن الصوائت التي ينتجها الذكور تظهر تراجعًا في حيز الصوائت وكذلك طولًا أكبر مقارنة بتلك التي تنتجها الإناث. أخيرًا ، فتشير البيانات إلى عدم وجود اختلاف في مدى الصوائت بين الجنسين الذكور والإناث من متحدثي هذه اللهجة.

الكلمات المفتاحية: جنس، مدى، تردد، صوائت، صوتي، اللهجة الزلفاوية

1. Introduction

Phonetics investigates the physics of speech signals. Four reasons are generally given for describing speech sounds acoustically: to explain confusion, to characterize sounds more accurately, to understand computer reproduction and decoding, and to conduct efficient research on speech data (Ladefoged, 2006; Ladefoged & Johnson, 2011). Many researchers have argued that Arabic has received less research than other languages, necessitating more studies on its phonetics and other language levels (Alotaibi & Hussain, 2010). Research has focused extensively on the phonetic diversity of Arabic vowels across various dialects. According to Cowell (1964/2016), for example, the Syrian Arabic dialect comprises 11 vowels: five long and six short. Several scholars have asserted that Najdi Arabic comprises a total of eight distinct vowel sounds, consisting of five long vowels /i:/, /u:/, /a:/, /o:/, and /e:/, as well as three short vowels /i/, /u/, and /a/ (Alammar, 2017; Alghamdi, 1998; Ingham, 1994).

Previous studies on the Arabic language have concurred that temporal differentiations among vowels are concomitant with spectral differences. Several researchers have found linguistic and extralinguistic reasons why certain Arabic dialects exhibit a higher number of vowels than others (e.g., Abd Almisreb et al., 2016; Aldholmi, 2022; Amir et al., 2014; Guba, 2023). Many studies have revealed that long vowels in Arabic exhibit approximately twice the temporal duration of their shorter counterparts. Al-Ani (1970) reported that the proportion of short vowels to their long counterparts was 1:2.4. According to Hassan (1981), the proportion of long vowels to short vowels in Iraqi Arabic was approximately 2:1 or 1:1.8. In a recent study, Almbark and Hellmuth (2015) examined variability in both quantity and quality across eight distinct Arabic dialects from different regions, such as North Africa, Egypt, the Levant, Iraq, and the Arab Gulf. The short-to-long vowel ratio in these dialects varied, ranging from 1:1.7 (Egyptian Arabic) to 1:2.6 (Moroccan Arabic). Ahmed (2008) noted that Jordanian Arabic (Barkat-Defradas et al, 2003) and Egyptian Arabic (Cowan, 1970; Norlin, 1987) have the same number of vowels and found that long vowels exceeded short vowels in length by a factor of more than two. Furthermore, according to Ahmed (2008), the duration ratio of vowels in Libyan Arabic (0.41) was equivalent to that of Egyptian Arabic and Sudanese Arabic reported by Alghamdi (1998). Several authors have also highlighted the distinctive nature of the vowel length ratio in Libyan Arabic compared with Saudi Arabic (0.51; Alghamdi, 1998), Iraqi Arabic (0.50; Al-Ani, 1970), Jordanian Arabic (0.65; Mitleb, 1984), and Gulf Arabic (0.56; Hussain, 1985).

Regarding gender disparities, the literature has demonstrated several general tendencies. First, females exhibit a greater vowel space than males, even when measured on a logarithmic scale (Whiteside, 2001). This is evident in the ratio of the first formant (F1) values of the vowels /a/ to /i, u/. Simpson (2001) conducted a physiological study of the source of this phenomenon and verified the hypothesis that males have reduced F1 space, thereby producing F1 values that are more easily distinguishable for listeners than those produced by female speakers (Diehl et al., 1996; Liberman, 1982; Ryalls, 1982). Moreover, Martland et al. (1996) discovered that in the general northern British accent, females produced significantly lower front vowels (æ, i, and e) than males. Furthermore, when it came to vowel space, females created lower back vowels than males did. Second, women's vowels are usually longer than men's (Allatif & Abry, 2004; Almbark & Hellmuth, 2015; Mohammed, 2020; Whiteside, 2001). This effect has been noted by Simpson and Ericsdotter (2003), and its cause has been investigated physiologically (Simpson, 2001) and conceptually (i.e., assuming that women make more effort to communicate clearly; Byrd,1994). One reason proposed for women's

longer vowel duration is their relatively slower speaking rate. However, producing vowels at a faster speech rate results in shorter vowels (Allatif & Abry, 2004).

A relatively small cohort of researchers has explored the acoustic characteristics of Arabic vowel systems across genders, with a special emphasis on studies of Saudi dialects. Therefore, the current acoustic study aims to add to the literature on Arabic vowels by examining the quality and quantity of Zilfaawi Arabic (ZA) short and long vowels produced by men and women, which, to the researcher's knowledge, have not been previously described. We aim to address two primary inquiries:

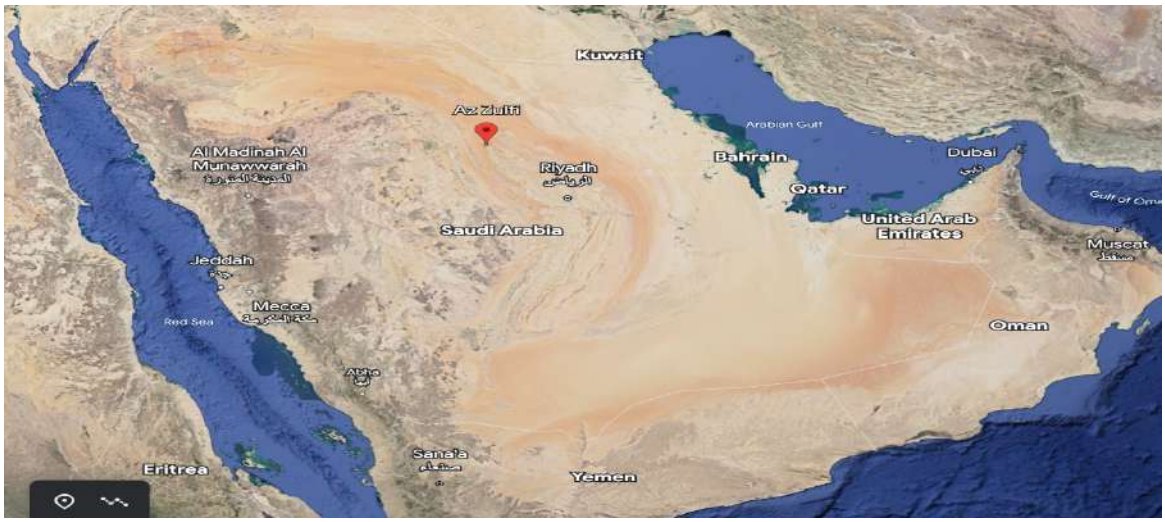
(1) What are the acoustic properties (F1 & F2) of vowels produced by male and female ZA speakers?

(2) What are the short and long vowel durations of male and female ZA speakers? Is there any gender-related effect on the production of vowels produced by ZA speakers?

1.1. Zilfaawi Arabic

The Zilfaawi variant of Arabic is a subcategory of Najdi Arabic, which is predominantly spoken in central Saudi Arabia. The Zilfaawi language variety is typically used by the inhabitants of Az Zilfi, an urban settlement of approximately 90,000 people located in the Najd region of central Saudi Arabia (Alammar, 2017). As shown in Figure 1 below, Az Zilfi is located approximately 290 kilometers northwest of the Saudi Arabian capital city, Riyadh, which is also located within the Najd region.

Figure 1
Google Map (n.d.) Showing Az Zilfi in Central Saudi Arabia



The Arabic language spoken in Az Zilfi exhibits distinct characteristics that differentiate it from both Modern Standard Arabic (MSA), commonly used in mass media, and Classical Arabic (CA), the language of the Quran and ancient Arabic poetry. While limited research has been conducted on the phonology and morphology of ZA, several studies have extensively examined these elements in other Saudi Arabic dialects (e.g., Ahyad & Becker,

2020; Alharbi & Alammar, 2022; Al Sweel, 1992; Bin-Muqbil, 2006; Johnston, 1967). More specifically, several studies have examined the phonological features of Najdi Arabic and uncovered distinctions among its varieties (Aljutaily & Alhoody, 2020; Alqahtani, 2014; Ingham, 1994).

The ZA dialect was chosen for this study because it is undocumented in any of the aforementioned texts despite its demonstrated distinctions from other Najdi varieties. For example, Al Sweel (1992) noted three fundamental perfective patterns in Najdi Arabic: faʕal, fiʕal, and fiʕil. In comparison, ZA demonstrates just one pattern, fʕal. As another example, at the phonological level, ZA implements deletions that do not occur in other Najdi dialects. For example, in ZA, upon the deletion of the initial vowel in the triliteral input word /katab/, the stress is placed on the syllable CCVC, as exemplified by [ktab] ‘he wrote.’ No such deletion takes place in other Najdi dialects.

Twenty-seven consonants and eight vowels make up the surface segmental inventory of ZA. As in other Najdi dialects, some sounds exist in ZA that do not occur in MSA, including [ts] (as in /tsibi:r/ ‘big’) and [dz] (as in [dzidir] ‘pot’) as the allophones of the phonemes /k/ and /g/, respectively (Mahzari, 2023). Table 1 displays the complete inventory of the ZA consonant system, illustrating the place and manner of articulation through the utilization of IPA symbols.

Table 1. The Consonantal Inventory of Zilfaawi Arabic Phonemes

	Bilabial	Labiodental	Interdental	Dental	Alveolar	Alveopalatal	Palatal	Velar	Uvular	Pharyngeal	Glottal
Stop	b			t d				k g			ʔ
Emphatic stop				tˤ							
Fricative		f	θ ð		s z	ʃ			χ ʁ	ħ ʕ	h
Emphatic fricative			ðˤ		sˤ						
Affricate						dʒ					
Nasal	m				n						
Liquid				l	r						
Glide	w						j				

Alammar (2015) claimed, with no phonetic analysis, that ZA preserves the three-vowel system of CA by having only three short phonemic vowels: /i/, /a/, and /u/. The following are examples of these short vowels in ZA:

[radd] ‘he rejected’

[min] ‘from’

[umm] ‘a mother’

In addition, ZA possesses five long vowels /i:/, /a:/, /u:/, /e:/, and /o:/, as shown in the following examples:

[fiːl] ‘an elephant’

[faːl] ‘omen’

[fuːl] ‘beans’

[ʕeːn] ‘an eye’

[ʕoːn] ‘help’

As suggested by such examples, the vowel inventory of regional dialects varies (Newman, 2002). Alghamdi (1998) has asserted that “the system of Arabic vowels is dialect-specific in terms of phonetic implementation, and the variation may serve as an acoustic cue that listeners use to identify the dialect” (p. 8). According to several scholars, Arabic long vowels are more peripheral, whereas short vowels are more central (e.g., Alghamdi, 1998; Saadah, 2011). Hence, in ZA, length might not be the sole distinction between short and long vowels. In addition, the allophonic realizations of these phonemic short and long vowels vary depending on context, such as when they are adjacent to emphatics or occur at the end of a word (Alammar, 2017).

One of the final three syllables of prosodic words receives stress in Arabic. Consequently, the stress in ZA does not fall on any syllable after the antepenult, similar to the stress systems in other Arabic dialects, such as Jordanian Arabic (AbuAbbas, 2003) and Syrian Arabic (Adra, 1999), as well as in other languages. If there are numerous heavy syllables, stress is placed on the rightmost syllable, as in [miʃ.taʁ.ˈlaːt] ‘working, [participle]’. As the final consonant is extrametrical in ZA, similar to other Arabic dialects, the final syllable is only stressed if it contains the syllable pattern CVVC or CVCC, as in [ʁa.na.ˈmaːt] ‘a group of sheep'. If the three last syllables are light, according to the iambic stress pattern of the language, the accent falls on the penultimate location, as in /ʔu.ˈma.ra/ ‘male princes.’ If the penultimate syllable is the sole heavy syllable in the word, it may draw emphasis, as in /la.ˈʕab.na/ ‘we played’ (Alammar, 2022).

2. Literature Review

2.1. Arabic Varieties

Arabic is a language of the Semitic family with its origins in the northern and central areas of the Arabian Peninsula and is widely spoken in the Arabian Peninsula and North Africa (Watson, 2002). As a diglossic language, Arabic varies regionally. Modern Standard Arabic (MSA) is the highest variant, whereas Moroccan Arabic, Egyptian Arabic, and Najdi Arabic are examples of low varieties that are spoken as mother tongues by their respective speakers (Ferguson, 1959). Presently, MSA is limited to written and formal speech, although its speech community has continued to expand. Identifying the precise moment at which a particular dialect shift occurs is not easy (Garbell, 1958). Thus, most ideas concerning the origins of Arabic dialects are limited to explanations of the dialects’ distinctions and similarities.

According to Ferguson (1959), it cannot be assumed that all Arabic dialects arose at the same time. Other hypotheses have attributed the phenomenon of variance to a polygenetic process, claiming that colloquial variation emerged as a result of the diverse languages that members of the Arab military brought with them (Versteegh, 2014). Furthermore, interactions with recent immigrant communities and intermarriages have led to a persistent process of creolization, as noted by Holes (2004). Recent investigations have challenged previous research by revealing the existence of rural dialects that predate MSA (Versteegh, 2014). This

finding supports the argument that Arabic colloquial expressions should not be viewed as deviations. According to Owens (2006), the existence of Arabic dialects predates CA, indicating that such variations are not a recent development.

2.2. Acoustic studies of Arabic dialects

Although developments in research on Arabic linguistics can be traced back to the second half of the 20th century, general phonological studies of Arabic dialects have remained predominant in the field (see, e.g., Alghazo, 1987; Al-Tamimi & Heselwood, 2011; Card, 1983; Kiparsky, 2003; Obrecht, 1968; Watson, 2002). These studies, among many others, concentrated on the distinctive qualities of CA consonants and vowels, including emphasis, laryngeal and pharyngeal consonants, geminate consonants, nasalization processes, and vowel alternations. In contrast, comparatively few scholars have investigated the acoustic properties of Arabic vowel systems, particularly in studies of Saudi dialects that have also examined the quality and quantity of vowel distinctions between male and female speakers. In the next few paragraphs, we explore the existing phonetic studies of MSA and modern Arabic dialects that are relevant to the current study.

Al-Ani (1970) conducted the first acoustic study on MSA vowels. However, in that study, the description of vowel formants and duration depended on recordings of vowels in isolation, along with minimal pairs and phrases, as produced by Al-Ani himself. The results showed essentially no discernible difference in quality between the high vowels /i:/ and /u:/ and their short equivalents. However, greater differences in the first (F1) and second (F2) formants were discovered between the vowel /a:/ and its short form /a/. The disparities in quantity between long vowels and their short counterparts were significantly larger than the differences in quality that existed between the two vowel types.

Alghamdi (1998) examined the MSA short and long vowels /a:/, /i:/, /u:/, /a/, /i/, and u/ in the speech of five speakers from Saudi Arabia, Sudan, and Egypt. The vowels were read in CVC monosyllables in which C was always sounded as /s/. Only short vowel contexts contained meaningless words. The findings revealed that the greatest distinctions between MSA vowels spoken by speakers of various origins lay in their F1 values. Additionally, he found that long vowels were nearly twice as long as their short counterparts. For Saudi, Sudanese, and Egyptian speakers, the average long-to-short vowel ratios were 0.45, 0.41, and 0.40, respectively. Alghamdi (1998) discovered that long and short vowels also differed qualitatively. In particular, the arrangement of the first two formant frequencies on a formant chart placed the long vowels at the outer edges, whereas their corresponding short vowels were situated toward the center.

Classical Arabic (CA) is arguably the most renowned and purest version of Arabic. Hence, Newman and Verhoeven (2002) focused on the vowels used in speakers' recitations of the Quran in CA. This study illustrated that there are a variety of ways to recite the Quran, and recitation speeds can range from very slow to quite rapid. Because Muhammad Sadiq al-Minshawi is well known for his classical orthoepy and unhurried recitation of the Quran, Newman and Verhoeven (2002) examined 30 minutes of his recitation of the holy text. They excluded vowels in pharyngealized settings in their sample to prevent any coarticulation effects, which would have resulted in an increase in F1 and a decrease in F2. They also used hand segmentation in a broadband spectrogram and acoustic analysis to analyze the recitation of the Quran. Throughout the course of their research, they analyzed 400 distinct vowel settings. In addition to the recitation of the Quran, Newman and Verhoeven (2002) conducted

an acoustic analysis of vowels in Egyptian Arabic as spoken in Cairo, for which they employed an Arabic translation of the "North Wind and the Sun" passage in Arabic. They found no substantial evidence to support the notion that CA was acoustically more pristine than MSA. In relation to the temporal aspect, the authors indicated that there was no statistically noteworthy distinction between the durations of long and short vowels in Cairene Arabic. This observation is not in agreement with the results obtained from MSA and other spoken dialects. One major limitation of Newman and Verhoeven's (2002) study is its insufficient number of participants (one participant for Quranic Arabic and one for Cairene Arabic).

Ahmed (2008) investigated the production and perception of vowels by 20 native speakers of Libyan Arabic. The production portion examined the F1 and F2 values and the lengths of vowels. Ahmed's results indicated that Libyan Arabic comprises a total of eight vowels, of which five (/i:/, /u:/, /e:/, /o:/, and /æ:/) can be categorized as long vowels, while the remaining three (/ɪ/, /ʊ/, and /ə/) can be classified as short vowels. Ahmed (2008) found significant differences between short and long vowels in both quality and quantity, such that the short vowels in Libyan Arabic exhibited a greater degree of centralization, particularly in the case of the short /a/. He claimed that the phonemes /e:/ and /o:/ lacked short equivalents and were instead derived from the diphthongs /ai/ and /au/ in MSA. He also asserted that these two sounds did not share a short form. Ahmed (2008) noted that the number of vowels in Jordanian Arabic (Barkat-Defradas et al., 2003) and Egyptian Arabic is identical (Cowan, 1970; Gairdner, 1925; Norlin, 1987). He posited that long vowels exhibited durations more than twice those of short vowels. Ahmed (2008) also argued that the duration ratio of Libyan Arabic was analogous to that of Egyptian Arabic and could be likened to that of Sudanese Arabic (Alghamdi, 1998). However, it was emphasized that the vowel duration ratio observed in Libyan Arabic (0.41) deviated considerably from those observed in other Arabic dialects, such as Saudi Arabic (0.51; Alghamdi, 1998), Iraqi Arabic (0.50; Al-Ani, 1970), Jordanian Arabic (0.65; Mitleb, 1984), and Gulf Arabic (0.56; Hussain, 1985). One limitation of Ahmed's (2008) study is the lack of testing the gender-related differences in producing the vowels under study.

Saadah (2011) examined the phonetic characteristics of three distinct short and long vowel pairs (/i–i:, u–u:, and a–a:/) in Palestinian Arabic but did not include the vowel pairs /e–e:/ and /o–o:/ in the analysis. The three vowel pairs considered were produced in both nonpharyngeal and pharyngeal contexts. The author observed that the F1 values of the vowel pairs /i–u/ and /i:–u:/ were highly comparable, demonstrating that vowel heights were comparable regardless of whether the tongue was placed at the front or back of the oral cavity. Saadah (2011) also demonstrated differing F1 values for the vowel pair /a–a:/. Specifically, the F1 of the short /a/ exhibited slightly lower values than the F1 of the long /a:/. The author also measured F2 and found that the long vowel /i:/ exhibited greater fronting than the short vowel /i/, while the long vowel /u:/ demonstrated more retraction than the short vowel /u/. The results indicated that vowels of greater duration were generated at the periphery of the vowel space, whereas vowels of lesser duration were situated more centrally within the space. Additionally, the author found that the low vowel pair /a, a:/ exhibited comparable F2 values. As a result, she hypothesized that short vowels possessed a vowel space that was noticeably more condensed than long vowels in an acoustic space.

Kotby et al. (2011) conducted a study of the Cairene Arabic dialect with a sample of 60 participants, 30 male (aged 22–52) and 30 female (aged 21–42). The research examined short and long vowel counterparts, with a specific focus on the vowels /i, e, ɛ, ɑ, ɔ, u, ʊ/. The results showed a significant difference between males and females in their F1 and F2 values for the

short and long vowels /i, e/, with males exhibiting lower values than females. However, for the short and long vowels /ɛ/, it was observed that only F2 displayed a statistically significant variation between male and female speakers. Additionally, a statistically significant disparity was noted in the F1 and F2 frequencies of the phoneme /ʊ/ as articulated by male and female speakers. In contrast, gender-based disparities were not observed in the magnitudes of the remaining short and long vowel sounds (/ɑ, u, ɔ/). Formant frequencies displayed a correlation with the vowel quality, but only for short vowels. Considerable fluctuations in F1 measurements were detected in male subjects across all vowels, with the exception of /e/ and /ɔ, u, ʊ/, as well as between /u/ and /ʊ/. Similarly, it was noted that among female participants, the variations in F1 were ascribed to the caliber of the vowel sound for all vowels, except for the F1 assessment between the vowel sounds /i, e/ and /ɔ, u/, as well as between /ɔ/ and /u/ and between /u/ and /ʊ/. Discrepancies in the F2 measurements were noted for both male and female speakers across all vowel phonemes, except for the /i/ and /e/ sounds. The analysis of long vowels suggested that the F1 and F2 values were dependent on the specific vowel quality. The vowel /a:/ displayed elevated F1 values compared to the other vowels, while the vowel /i/ manifested the highest F2 values among all the vowels. The authors failed to offer a justification for the lack of discrepancies noted between the male and female speaker data.

The study conducted by Ammar et al. (2014) aimed to analyze the acoustic signals, specifically the F1 and F2 values, of MSA as spoken by a group of 11 Tunisians and five Moroccans. The primary objective was to investigate the differentiation between long and short vowels and to identify potential evidence of Tunisian and Moroccan Arabic dialects within MSA. The researchers identified both quantitative and qualitative traces of the two dialects in their corresponding MSA outputs. Tunisian speakers maintained the distinction between long and short vowels in their regional dialect by utilizing significantly longer long vowels in MSA, at a ratio of 1:63. In comparison, Moroccan speakers maintained the differentiation between long and short vowels in MSA in two ways: first, by utilizing significantly extended long vowels, at a ratio of 1:9; and second, by distinguishing the quality of short vowels, which are comparatively more centralized than their long vowel counterparts. Such processes denote vestiges of the Moroccan Arabic variety, which exhibits a limited distinction between long vowels and their short counterparts.

Amir et al. (2014) examined two Arabic dialects spoken in Israel, one spoken in the region of Galilei (GD) and the other in the region of Muthallath (MD). For each dialect, the study employed a sample of 20 male and 20 female Muslim participants, with participation restricted to young people receiving an education in both Arabic and Hebrew. The stimulus set included 24 monosyllabic words and six disyllabic words, all of which contained short vowels (/i, u, a, e, o/) and their long vowel counterparts (/i:, u:, a:, e:, o:/). Participants were exposed to these vowels via carrier sentences. The findings revealed that the duration of long vowels was twice that of their short counterparts. The statistical analysis of the long vowel data revealed no significant gender differences in the GD and MD conditions. In both dialects, the low vowel (/a:/) had higher F1 values than the mid vowels (/e:, o:/). The MD data analysis revealed no statistically significant differences in the height of the high front vowel /i:/ and high back vowel /u:/. The F1 values of /i:/ were statistically significantly lower than those of /u:/ in the GD data. In terms of tongue advancement (front vs. back) for long vowels, /i:/ was the most fronted vowel, whereas /u:/ was the most backed. The vowel /e:/ is classified as mid-front, while the vowel /o:/ is classified as mid-back. In terms of short vowels, the MD data revealed that /i/ and /e/ overlapped in both male and female speaker data, whereas the GD data revealed a distinct distinction between /i/ and /e/. Male and female GD speakers exhibited

relatively symmetrical vowel space patterns. However, males demonstrated significantly lower formant frequencies for both short and long vowels compared to females. One limitation of Amir et al.'s (2014) study was the different dialectal use of stimuli for monosyllabic and disyllabic forms of words, such as /fe:n/ and /we:n/ for 'where' and /ridel/ and /ider/ for 'leg.'

Almbark and Hellmuth (2015) conducted an acoustic investigation of the Syrian Arabic vowel system with 15 participants (10 males and five females), who were all residents of Damascus. However, they did not report the results for male and female participants separately. To ensure the precise production of vowels, authentic monosyllabic /CVC/ Syrian Arabic words were utilized alongside a nonsensical /hVd/ context. The phonemes /i/ and /u/ were found to have allophonic variations in the form of mid short vowels [e] and [o], respectively. The authors found that Syrian Arabic contained three short vowels (/i/, /a/, and /u/) in addition to five long vowels (/i/, /e/, /a/, /o/, and /u/). According to Almbark and Hellmuth (2015), the Syrian Arabic vowel system exhibited a triangular shape akin to that of MSA, albeit with more centrally located mid vowels. As in many Arabic dialects, the short vowels in Syrian Arabic are more centralized than their long counterparts. In the Syrian Arabic vowel system, the long vowels /i:/, /a:/, and /u:/ are much farther apart than their short counterparts /i/, /a/, and /u/, whereas the mid long vowels /e:/ and /o:/ exhibit closer phonetic proximity to their respective short vowel counterparts /e/ and /o/ (Almbark & Hellmuth, 2015). The results also indicated that the ratio of short-to-long vowel durations among speakers was less than double.

Mohammed (2020) described the acoustic characteristics of vowels in Hiti Iraqi Arabic (HIA) and Mosuli Iraqi Arabic (MIA) to illustrate the correlation between vowel quality and quantity. He analyzed the temporal and spectral acoustic properties of these two speech groups and, in particular, whether there was a connection between geographical and gender differences in vowel duration and spectral variances. He found that compared with the HIA ratio (1:2.2), MIA had a higher ratio of short-to-long vowel durations (1:2.4). Furthermore, gender played a larger role in HIA than in MIA. Men speaking HIA demonstrated significantly longer durations of /a/, /u/, and /a:/ than HIA-speaking women, but in MIA, only the length variation of /i/ was related to gender. Concerning spectral differences, vowels in MIA were lower and more retracted than their HIA counterparts, although the two dialects differed more in F2 than in F1. The influence of vowel quality on vowel duration was found to be statistically significantly greater in HIA than in MIA. Moreover, women speaking this dialect had the most significant differences in /u/ and /a/, whereas males had the most significant differences in /i/ and /a/. Finally, although /u/ and /u:/ were statistically shorter than /a/ and /a:/, the results showed that /i/ was substantially shorter than /a/. Mohammed's (2020) investigation is limited by the fact that there were only three participants per dialect.

As evidenced by this brief review of acoustic studies of Arabic vowels, ZA, as a subdialect of Najdi Arabic, has not received considerable attention in terms of experimental studies. Thus, the current investigation adds to the body of research on ZA by providing an acoustic description of vowels that have not previously been thus described. The following sections provide details of the acoustic properties of these vowels, including their formant structures and vowel durations, as produced by male and female speakers of the dialect.

3. Methods

The following subsections describe the methodology used in the study.

3.1. Materials

The eight Arabic vowels tested were [i], [i:], [a], [a:], [u], [u:], [e:], and [o:]. The stimuli comprised eight Arabic words, all of which were monosyllabic with the voiced stop consonant (/d/) at the end and the first glottal consonant being (/h/). The target words were included in the Arabic carrier phrase "write the word hVd again" to produce a more realistic production. These hVd words were chosen to create a consistent phonetic environment and simplify the process of identifying the vowel on the spectrogram. The dataset consisted of 400 elements in total: five repetitions, eight vowels, and 10 speakers.

3.2. Participants

Five men and five women who spoke ZA as their first language were chosen to participate in the study. Their ages ranged from 20 to 26 years (M = 22, SD = 1.32). All participants were born, raised, and educated in the city of Az Zulfi. To prevent any influence from other dialects or languages, speakers who did not speak this particular dialect or who had substantial exposure to other foreign languages were removed (one participant speaking Hijazi Arabic). None of the participants mentioned having any vision or hearing issues. All were unpaid volunteers, and consent to participate was obtained from all participants.

3.3. Procedures

The recordings were created at Majmaah University inside quiet rooms, in which a microphone (BadAax CM40 Studio Mic) was directly connected to a Windows laptop. The information was saved as .wav files with a sampling rate of 44 kHz and a quantization of 16 bits. Each participant was recorded individually. Each participant read the randomized list of the eight vowels in the carrier phrase "write the word … again" five times in the hVd environment. To eliminate list effects, the words were delivered to the participants one at a time via PowerPoint slides. The participants were instructed to read out words again if their first production was spoken artificially or inaccurately. Diacritics were used with the words /hi:d/ 'هِيد' and /he:d/ 'هَيد' to help differentiate between the two words, which are written with the same vowels in Arabic. No spoken examples were provided, but alternative terms that rhymed with the desired results were suggested when necessary. The vowels and the terms used to elicit their pronunciations are listed in Table 2.

Table 2. Vowels and Words Used to Elicit Productions

Vowel	Target word	The word in a sentence	English gloss
a	هَد	اكتب هَد مرة ثانية	ɪktɪb had marra θa:nja
ɪ	هِد	اكتب هِد مرة ثانية	ɪktɪb hɪd marra θa:nja
u	هُد	اكتب هُد مرة ثانية	ɪktɪb hʊd marra θa:nja
a:	هاد	اكتب هاد مرة ثانية	ɪktɪb ha:d marra θa:nja
i:	هِيد	اكتب هِيد مرة ثانية	ɪktɪb hi:d marra θa:nja
u:	هُود	اكتب هُود مرة ثانية	ɪktɪb hu:d marra θa:nja
e:	هيد	اكتب هيد مرة ثانية	ɪktɪb he:d marra θa:nja
o:	هود	اكتب هود مرة ثانية	ɪktɪb ho:d marra θa:nja

3.4. Analysis

Audio files were also evaluated acoustically using the Praat acoustic program (Boersma & Weenink, 2023). As in most vowel-related research, the first two formants (F1 and F2) were measured and documented, as they are crucial for the perception of vowel quality (e.g., Flemming & Johnson, 2007; Hawkins & Midgley, 2005). To segment the target vowels, a broadband spectrogram was employed in conjunction with the matching waveform and auditory evaluation. The vowel F1 and F2 were measured near the midpoint of the vowels as this was often the point at which they were at their most stable.

4. Results

4.1. Comparing short Arabic vowels with their longer counterparts

The following sections present the analysis of the formants and durations of ZA speakers' Arabic vowels. Pairwise t-test comparisons between short versions and their corresponding long versions tested the differences in F1, F2, and duration. Then, analyses of variance (ANOVAs) were used to compare vowels of the same length. A total of 58 pairwise comparisons were conducted. The Bonferroni correction method was used to overcome the multiple comparison problem.

4.1.1. Men

4.1.1.1. F1

The differences in F1 and F2 between short and long Arabic vowels of the same type for male and female ZA speakers are shown in Figure 2. Table 3 compares only the men's data for the described comparisons.

Figure 2. Vowel Spaces for Eight Arabic Vowels by Speaker Gender

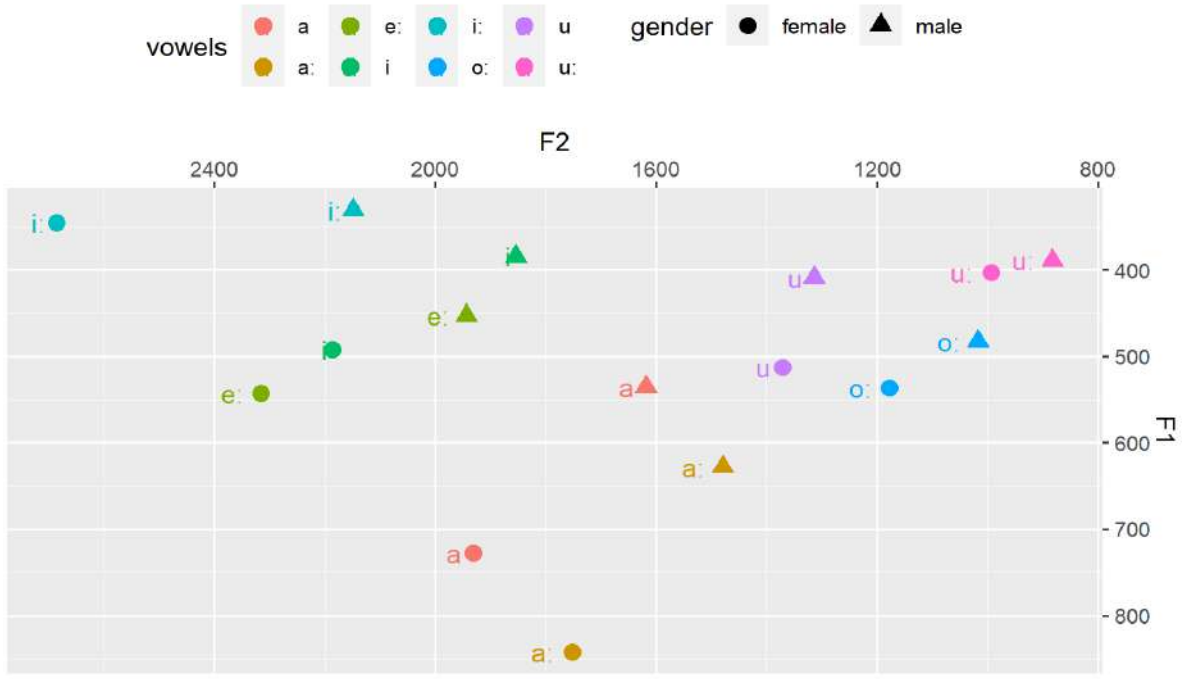


Table 3. Differences in F1 Between Arabic Short and Long Vowels of the Same Type for ZA Men

Vowels	Short	Long	Mean difference	*t*	*p*	Significance after Bonferroni correction
/i/–/iː/	383.92	330.72	–53.20	–4.54	$.04*10^{-3}$	**
/a/–/aː/	535.47	628.01	92.54	4.40	$.05*10^{-3}$	**
/u/–/uː/	408.91	389.03	–19.88	–2.10	.04	

First, no significant difference in F1was found for the pair /u/–/uː/ for ZA men. Second, men significantly differed in F1 for the pairs /i/–/iː/ and /a/–/aː/, such that /i/ was lower than /iː/ and /aː/ was lower than /a/ in the vowel space.

4.1.1.2. F2

The differences in F2 between short and long Arabic vowels of the same type for ZA men are shown in Table 4.

Table 4. Differences in F2 Between Arabic Short and Long Vowels of the Same Type for ZA Men

Vowels	Short	Long	Mean difference	*t*	*p*	Significance after Bonferroni correction
/i/–/iː/	1853.84	2148.52	294.67	7.56	$.01*10^{-7}$	***
/a/–/aː/	1618.61	1479.29	–139.31	–3.05	$.04*10^{-1}$	
/u/–/uː/	1314.07	882.24	–431.82	–9.07	$.02*10^{-9}$	***

The results showed significant differences for the pairs /u/–/uː/ and /i/–/iː/, but not for /a/-/aː/. Male ZA speakers' productions of /i/ were more back than their /iː/, and their /u/ was more front than their /uː/ (see Table 4 for means, mean differences, and *p*-values).

4.1.1.3. Duration

The differences in duration between short and long Arabic vowels of the same type for ZA men are given in Table 5.

Table 5. Differences in Duration Between Arabic Short and Long Vowels of the Same Type for ZA Men

Vowels	Short	Long	Mean difference	*t*	*p*	Significance after Bonferroni correction
/i/–/iː/	.08	.14	.06	8.29	$.06*10^{-8}$	***
/a/–/aː/	.09	.15	.06	9.59	$.01*10^{-9}$	***
/u/–/uː/	.07	.14	.06	11.68	$.01*10^{-12}$	***

As expected, all vowels differed significantly. In particular, all three long vowels were longer in duration than their corresponding short versions.

4.1.2. Women

4.1.2.1. F1

The differences in F1 between short and long Arabic vowels of the same type for ZA women are presented in Table 6.

Table 6. Differences in F1 Between Arabic Short and Long Vowels of the Same Type for ZA Women

Vowels	Short	Long	Mean difference	*t*	*p*	Significance after Bonferroni correction
/i/–/iː/	491.83	344.93	–146.89	–4.82	$.02*10^{-3}$	**
/a/–/aː/	727.81	842.35	114.53	3.40	$.01*10^{-1}$	
/u/–/uː/	512.87	402.64	–110.22	–6.40	$.01*10^{-5}$	***

First, no significant difference in F1 was found for the pair /a/–/aː/ among female speakers of ZA. Second, the results showed that ZA women significantly differed in F1 for the pairs /i/–/iː/ and /u/–/uː/, such that /i/ was lower than /iː/ and /u/ was lower than /uː/ in the vowel space.

4.1.2.2. F2

The differences in F2 between short and long Arabic vowels of the same type for ZA women are presented in Table 7.

Table 7. Differences in F2 Between Arabic Short and Long Vowels of the Same Type for ZA Women

Vowels	Short	Long	Mean difference	*t*	*p*	Significance after Bonferroni correction
/i/–/iː/	2185.66	2686.11	500.44	5.61	$.01*10^{-4}$	***
/a/–/aː/	1931.61	1751.93	–179.67	–5.78	$.08*10^{-5}$	***
/u/–/uː/	1371.13	993.38	–377.75	–7.58	$.01*10^{-7}$	***

Comparisons of ZA women's data showed significant differences for all three pairs. For /u/–/uː/, /u/ was more front than /uː/; for /i/–/iː/, /i/ was more back than/iː/; and for /a/–/aː/, /a/ was more front than /aː/ (see Table 7 for means, mean differences, and *p*-values).

4.1.2.3. Duration

The differences in duration between short and long Arabic vowels of the same type for ZA women are provided in Table 8.

Table 8. Differences in Duration Between Arabic Short and Long Vowels of the Same Type for ZA Women

Vowels	Short	Long	Mean difference	*t*	*p*	Significance after Bonferroni correction
/i/–/iː/	.08	.18	.09	8.08	$.03*10^{-7}$	***
/a/–/aː/	.10	.15	.05	7.52	$.01*10^{-7}$	***
/u/–/uː/	.08	.17	.09	7.96	$.01*10^{-6}$	***

Similar to the duration data for male ZA speakers, all vowels differed significantly in productions by female ZA speakers. In particular, all three long vowels were of longer duration than their corresponding short versions.

4.2. Comparison of vowels by length

4.2.1. Short vowels

4.2.1.1. Men

4.2.1.1.1. F1

Comparisons of the F1 values of short vowels for ZA men are given in Table 9. To compare /i/, /a/, and /u/, a one-way ANOVA was conducted, and the results were significant: $F(2,72) = 55.96$, $p < .001$. Table 9 shows the results of the post hoc Tukey honestly significant different (HSD) test for finding significance in pairwise comparisons.

Table 9. Tukey HSD F1 Comparisons of Short Arabic Vowels Among ZA Men

Vowels	$Mean_1$	$Mean_2$	Mean difference	*p*	Significance after adjustment
/i/–/a/	383.92	535.47	– 26.81	$.01*10^{-7}$	***
/u/–/a/	408.91	535.47	52.66	$.01*10^{-7}$	***
/u/–/i/	408.91	383.92	79.47	.24	

The post hoc test showed that ZA men had a higher average F1 (lower in the vowel space) for /a/ than they did for both /i/ and /u/. There were no significant differences in F1 between /i/ and /u/.

4.2.1.1.2. F2

The F2 values of the short vowels were analyzed with a one-way ANOVA, and the results were significant: $F(2,72) = 133.6$, $p < .001$. Table 10 shows the results of the post hoc Tukey HSD for finding significance in pairwise comparisons.

Table 10. Tukey HSD F2 Comparisons of Short Arabic Vowels Among ZA Men

Vowels	$Mean_1$	$Mean_2$	Mean difference	*p*	Significance after adjustment
/i/–/a/	1853.84	1618.61	235.23	$.01*10^{-7}$	***
/u/–/a/	1314.07	1618.61	–304.53	$.01*10^{-7}$	***
/u/–/i/	1314.07	1853.84	–539.77	$.01*10^{-7}$	***

For ZA men, all three short vowels were significantly different in terms of F2: /i/ was more front than both /a/ and /u/, while /a/ was more front than /u/.

4.2.1.1.3. Duration

The durations of the short vowels were also compared, the results of which are provided in Table 11. The one-way ANOVA yielded significant results: $F(2,72) = 3.29$, $p < .05$. Table 11 shows the results of the post hoc Tukey HSD for finding significance in pairwise comparisons.

Table 11. Tukey HSD Duration Comparison of Short Arabic Vowels Among ZA Men

Vowels	$Mean_1$	$Mean_2$	Mean difference	*p*	Significance after adjustment
/i/–/a/	.08	.09	–.01	.17	
/u/–/a/	.07	.09	.01	.04	*
/u/–/i/	.07	.08	–.01	.78	

The only significant difference was found for the pair /u/–/a/, where /a/ had a slightly longer duration than /u/. No significant results were found for the /i/–/a/ or /i/–/u/ pairs.

4.2.1.2. Women

4.2.1.2.1. F1

The same tests and comparisons were repeated for ZA women's production of short Arabic vowels. A one-way ANOVA was used to analyze the results, which were significant: $F(2,72) = 35.91$, $p < .001$. Table 12 shows the results of the post hoc Tukey HSD for finding significance in pairwise comparisons.

Table 12. Tukey HSD F1 Comparisons of Short Arabic Vowels Among ZA Women

Vowels	$Mean_1$	$Mean_2$	Mean difference	*p*	Significance after adjustment
/i/–/a/	491.83	727.81	–235.98	$.01*10^{-7}$	***
/u/–/a/	512.87	727.81	–214.94	$.01*10^{-7}$	***
/u/–/i/	512.87	491.83	21.0	.77	

The post hoc test results showed that ZA women had a higher average F1 (lower in vowel space) for /a/ than they did for both /i/ and /u/. There were no significant differences in F1 between /i/ and /u/, which mirrored the results for ZA men.

4.2.1.2.2. F2

The F2 values of the short vowels were analyzed with a one-way ANOVA. The results were significant: $F(2,72) = 105.9$, $p < .001$. Table 13 shows the results of the post hoc Tukey HSD for finding significance in pairwise comparisons.

Table 13. Tukey HSD F2 Comparisons of Short Arabic Vowels Among ZA Women

Vowels	$Mean_1$	$Mean_2$	Mean difference	p	Significance after adjustment
/i/–/a/	2185.66	1931.61	254.05	$.09*10^{-3}$	***
/u/–/a/	1371.13	1931.61	–560.48	$.01*10^{-7}$	***
/u/–/i/	1371.13	2185.66	–814.53	$.01*10^{-7}$	***

Again, similar to the men's results, ZA women significantly differentiated among all three short vowels in terms of F2: /i/ was more front than /a/, which, in turn, was more front than /u/.

4.2.1.2.3. Duration

The durations of the short vowels were also compared. The one-way ANOVA yielded significant results: $F(2,72) = 3.74$, $p < .02$. Table 14 shows the results of the post hoc Tukey HSD for finding significance in pairwise comparisons.

Table 14. Tukey HSD Duration Comparison of Short Arabic Vowels Among ZA Women

Vowels	$Mean_1$	$Mean_2$	Mean difference	p	Significance after adjustment
/i/–/a/	.088	.101	–.012	.09	
/u/–/a/	.085	.101	.015	.03	*
/u/–/i/	.085	.088	.003	.90	

The only significant difference was found for the pair /u/–/a/, where /a/ had a slightly longer duration than /u/. There were no significant differences between /i/–/a/ or /i/–/u/, thus replicating the men's results for these vowel durations.

4.2.2. Long vowels

4.2.2.1. Men

4.2.2.1.1. F1

Comparisons of the F1 values of long vowels for ZA men are provided in Table 15. To compare /iː/, /aː/, /uː/, /eː/, and /oː/, a one-way ANOVA was conducted, and the results were significant: $F(4,120) = 136$, $p < .001$. Table 15 shows the results of the post hoc Tukey HSD for finding significance in pairwise comparisons.

Table 15. Tukey HSD Post Hoc F1 Comparisons of Long Arabic Vowels Among ZA Men

Vowels	$Mean_1$	$Mean_2$	Mean difference	p	Significance after adjustment
/eː/–/aː/	452.89	628.01	–175.12	$.01*10^{-7}$	***
/iː/–/aː/	330.72	628.01	–297.29	$.01*10^{-7}$	***
/oː/–/aː/	482.47	628.01	–145.53	$.01*10^{-7}$	***
/uː/–/aː/	389.03	628.01	–238.98	$.01*10^{-7}$	***
/iː/–/eː/	330.72	452.89	–122.16	$.01*10^{-7}$	***
/oː/–/eː/	482.47	452.89	29.58	.19	
/uː/–/eː/	389.03	452.89	–63.85	$.07*10^{-3}$	***
/oː/–/iː/	482.47	330.72	151.75	$.01*10^{-7}$	***
/uː/–/iː/	389.03	330.72	58.30	$.03*10^{-2}$	***
/uː/–/oː/	389.03	482.47	–93.44	$.01*10^{-7}$	***

All long vowels were significantly different in F1, with the single exception of the /oː/–/eː/ pair. For the rest, the results were as follows: /aː/ was lower in the vowel space than /eː/, /iː/, /oː/, and /uː/; /eː/ was lower than /iː/ but higher than /uː/ and the same as /oː/; /oː/ was lower than /iː/ and /uː/; and /uː/ was lower than /iː/.

4.2.2.1.2. F2

Comparisons of the F2 values of long vowels for ZA men are given in Table 16. To compare /iː/, /aː/, /uː/, /eː/, and /oː/, a one-way ANOVA was conducted. The results were significant: $F(4,120) = 258.2$, $p < .001$. Table 14 shows the results of the post hoc Tukey HSD for finding significance in pairwise comparisons.

Table 16. Tukey HSD F2 Comparisons of Long Arabic Vowels Among ZA Men

Vowels	$Mean_1$	$Mean_2$	Mean difference	p	Significance after adjustment
/eː/–/aː/	1943.36	1479.29	464.06	$.01*10^{-7}$	***
/iː/–/aː/	2148.52	1479.29	669.22	$.01*10^{-7}$	***
/oː/–/aː/	1016.82	1479.29	–462.47	$.01*10^{-7}$	***
/uː/–/aː/	882.24	1479.29	–597.04	$.01*10^{-7}$	***
/iː/–/eː/	2148.52	1943.36	205.16	$.04*10^{-2}$	***
/oː/–/eː/	1016.82	1943.36	–926.53	$.01*10^{-7}$	***
/uː/–/eː/	882.24	1943.36	–1061.11	$.01*10^{-7}$	***
/oː/–/iː/	1016.82	2148.52	–1131.69	$.01*10^{-7}$	***
/uː/–/iː/	882.24	2148.52	–1266.27	$.01*10^{-7}$	***
/uː/–/oː/	882.24	1016.82	–134.57	.04	*

Remarkably, all long vowels were significantly different in F2. In particular, /iː/ was the most front vowel, followed, respectively, by /eː/, /aː/, /oː/, and /uː/, which was the most back vowel.

4.2.2.1.3. Duration

The durations of the long vowels were also compared. The one-way ANOVA yielded insignificant results: $F(4,120) = .77$, $p > .05$. Table 17 shows the results of the post hoc Tukey HSD for pairwise comparisons, illustrating that all long vowels had more or less the same length among ZA men.

Table 17. Tukey HSD Duration Comparison of Long Arabic Vowels Among ZA Men

Vowels	$Mean_1$	$Mean_2$	Mean difference	p	Significance after adjustment
/eː/–/aː/	.157	.152	.005	.95	
/iː/–/aː/	.145	.152	–.006	.92	
/oː/–/aː/	.149	.152	–.002	.99	
/uː/–/aː/	.145	.152	–.006	.93	
/iː/–/eː/	.145	.157	–.012	.56	
/oː/–/eː/	.149	.157	–.007	.86	
/uː/–/eː/	.145	.157	–.012	.57	
/oː/–/iː/	.149	.145	.004	.98	
/uː/–/iː/	.145	.145	0	.99	
/uː/–/oː/	.145	.149	–.004	.98	

4.2.2.2. Women

4.2.2.2.1. F1

The same tests and comparisons were repeated to analyze the production of Arabic long vowels by female ZA speakers. A one-way ANOVA was conducted to analyze the results, which were significant: $F(2,72) = 97.39$, $p < .001$. Table 18 shows the results of the post hoc Tukey HSD for finding significance in pairwise comparisons.

Table 18. Tukey HSD F1 Comparisons of Long Arabic Vowels Among ZA Women

Vowels	$Mean_1$	$Mean_2$	Mean difference	p	Significance after adjustment
/eː/–/aː/	542.75	842.35	–299.60	$.01*10^{-7}$	***
/iː/–/aː/	344.93	842.35	–497.42	$.01*10^{-7}$	***
/oː/–/aː/	536.44	842.35	–305.90	$.01*10^{-7}$	***
/uː/–/aː/	402.64	842.35	–439.71	$.01*10^{-7}$	***
/iː/–/eː/	344.93	542.75	–197.81	$.01*10^{-7}$	***
/oː/–/eː/	536.44	542.75	–6.30	.99	

/u:/–/e:/	402.64	542.75	–140.10	$.01*10^{-3}$	***
/o:/–/i:/	536.44	344.93	191.51	$.01*10^{-7}$	***
/u:/–/i:/	402.64	344.93	57.71	.23	***
/u:/–/o:/	402.64	536.44	–133.80	$.03*10^{-3}$	***

The F1 results for ZA women were identical to those for ZA men. Specifically, all long vowels differed significantly in F1, with the single exception of the pair /o:/–/e:/. For the rest, the results were as follows: /a:/ was lower in the vowel space than /e:/, /i:/, /o:/, and /u:/; /e:/ was lower than /i:/ but higher than /u:/ and the same as /o:/; /o:/ was lower than /i:/ and /u:/; and /u:/ was lower than /i:/.

4.2.2.2.2. F2

The F2 values of the short vowels were analyzed with a one-way ANOVA. The results were significant: $F(4,120) = 227.2$, $p < .001$. Table 19 shows the results of the post hoc Tukey HSD for finding significance in pairwise comparisons.

Table 19. Tukey HSD F2 Comparisons of Long Arabic Vowels Among ZA Women

Vowels	$Mean_1$	$Mean_2$	Mean difference	*p*	Significance after adjustment
/e:/–/a:/	2315.57	1751.93	563.63	$.01*10^{-7}$	***
/i:/–/a:/	2686.11	1751.93	934.17	$.01*10^{-7}$	***
/o:/–/a:/	1177.15	1751.93	–574.78	$.01*10^{-7}$	***
/u:/–/a:/	993.38	1751.93	–758.55	$.01*10^{-7}$	***
/i:/–/e:/	2686.11	2315.57	370.54	$.02*10^{-4}$	***
/o:/–/e:/	1177.15	2315.57	–1138.41	$.01*10^{-7}$	***
/u:/–/e:/	993.38	2315.57	–1322.19	$.01*10^{-7}$	***
/o:/–/i:/	1177.15	2686.11	–1508.95	$.01*10^{-7}$	***
/u:/–/i:/	993.38	2686.11	–1692.73	$.01*10^{-7}$	***
/u:/–/o:/	993.38	1177.15	–183.77	.04	*

Again, similar to the men's results, for the women, all long vowels were significantly different in F2. In particular, /i:/ was the most front vowel, followed, respectively, by /e:/, /a:/, and /o:/, and /u:/. Among these, /u:/ was the most back vowel.

4.2.2.2.3. Duration

The duration of the long vowels was also compared, although the one-way ANOVA yielded insignificant results: $F(4,120) = 2.35$, $p > .05$. Table 20 shows the results of the post hoc Tukey HSD for pairwise comparisons. In short, all long vowels had approximately the same length among ZA women.

Table 20. Tukey HSD Duration Comparison of Long Arabic Vowels Among ZA Women

Vowels	Mean$_1$	Mean$_2$	Mean difference	*p*	Significance after adjustment
/eː/–/aː/	.188	.157	.030	.13	
/iː/–/aː/	.180	.157	.030	.42	
/oː/–/aː/	.157	.157	0	.99	
/uː/–/aː/	.179	.157	.021	.46	
/iː/–/eː/	.180	.188	–.008	.96	
/oː/–/eː/	.157	.188	–.030	.12	
/uː/–/eː/	.179	.188	–.009	.95	
/oː/–/iː/	.157	.180	–.022	.42	
/uː/–/iː/	.179	.180	0	.99	
/uː/–/oː/	.179	.157	.021	.45	

4.3. Formant comparisons of adjacent vowels

4.3.1. Men

4.3.1.1. F1

The differences in F1 between adjacent Arabic vowels were analyzed. The results of these comparisons are presented in Table 21.

Table 21. Differences in F1 Between Adjacent Arabic Vowels Among ZA Men

Vowels	Mean$_1$	Mean$_2$	Mean difference	*t*	*p*	Significance after Bonferroni correction
/i/–/iː/	383.92	330.72	–53.20	–4.54	$.04*10^{-3}$	**
/i/–/eː/	383.92	452.89	–68.96	–5.69	$.08*10^{-5}$	***
/u/–/oː/	408.91	482.47	–73.56	–6.48	$.01*10^{-5}$	***
/u/–/uː/	408.91	330.72	78.19	8.66	$.02*10^{-9}$	***

The results showed significant differences between all pairs. In particular, /u/ was lower in the vowel space than /uː/ but higher than /oː/, while /i/ was lower in vowel space than /iː/ but higher than /eː/ (see Table 21 for means, mean differences, and *p*-values).

4.3.1.2. F2

The F2 differences between the adjacent Arabic vowels were analyzed using t-tests. The pairwise comparison results are provided in Table 22.

Table 22. Differences in F2 Between Adjacent Arabic Vowels Among ZA Men

Vowels	Mean$_1$	Mean$_2$	Mean difference	*t*	*p*	Significance after Bonferroni correction

/i/–/iː/	1853.84	2148.52	294.67	7.56	$.01*10^{-7}$	***
/i/–/eː/	1853.84	1943.36	–89.51	–2.56	.01	
/u/–/oː/	1314.07	1016.82	297.24	7.23	$.04*10^{-7}$	***
/u/–/iː/	1314.07	2148.52	–834.45	–20.51	$.01*10^{-14}$	***

The results showed that ZA men's /iː/ was more front than both /uː/ and /i/. In addition, /u/ was more front than /oː/, while there was no difference in F2 between /i/ and /eː/ (see Table 22 for means, mean differences, and *p*-values).

4.3.2. Women

4.3.2.1. F1

The same analyses were conducted on ZA women's data. The F1 differences between the adjacent Arabic vowels were analyzed using t-tests. The pairwise comparisons are given in Table 23.

Table 23. Differences in F1 Between Adjacent Arabic Vowels Among ZA Women

Vowels	$Mean_1$	$Mean_2$	Mean difference	*t*	*p*	Significance after Bonferroni correction
/i/–/iː/	491.83	344.93	–146.89	–4.82	$.02*10^{-3}$	**
/i/–/eː/	491.83	542.75	–50.91	–1.42	.16	
/u/–/oː/	512.87	536.44	–23.57	–0.99	.32	
/u/–/iː/	512.87	344.93	167.93	7.72	$.06*10^{-8}$	***

The results showed that ZA women's /iː/ was higher in the vowel space than both /uː/ and /i/. In contrast, no difference in F1 was found between /u/ and /oː/ or between /i/ and /eː/ (see Table 23 for means, mean differences, and *p*-values).

4.3.2.2. F2

The F2 differences between the adjacent Arabic vowels were analyzed using t-tests. The pairwise comparisons are provided in Table 24.

Table 24. Differences in F2 Between Adjacent Arabic Vowels Among ZA Women

Vowels	$Mean_1$	$Mean_2$	Mean difference	*t*	*p*	Significance after Bonferroni correction
/i/–/iː/	2185.66	2686.11	500.44	5.61	$.01*10^{-4}$	***
/i/–/eː/	2185.66	2315.57	–129.90	–1.62	.11	
/u/–/oː/	1371.13	1177.15	193.97	3.59	$.08*10^{-2}$	*
/u/–/iː/	1371.13	2686.11	–1314.98	–17.31	$.01*10^{-14}$	***

Among ZA women speakers, /iː/ was more front than both /i/ and /u/. In addition, /u/ was more front than /oː/. No significant differences were found between /i/ and /eː/.

4.4. Gender differences in formants and durations

4.4.1. F1

In this section, comparisons of the Arabic vowels produced by ZA men and women in terms of F1, F2, and duration are presented. T-tests were used to compare the group means, and the respective results are given in Tables 25, 26, and 27.

Table 25. Differences in F1 in Arabic Vowels Between ZA Men and Women

Vowels	Men	Women	Mean difference	*t*	*p*	Significance after Bonferroni correction
/i/	383.92	491.83	–107.90	–3.93	$.04*10^{-2}$	*
/a/	535.47	727.81	–192.34	–6.85	$.02*10^{-6}$	***
/u/	408.91	512.87	–103.95	–6.70	$.01*10^{-5}$	***
/iː/	330.72	344.93	–14.20	–0.80	.42	
/aː/	628.01	842.35	–214.34	–7.63	$.02*10^{-7}$	***
/uː/	389.03	402.64	–13.61	–1.13	.26	
/eː/	452.89	542.75	–89.86	–3.48	$.01*10^{-1}$	
/oː/	482.47	536.44	–53.97	–2.53	.01	

Among all eight vowels, only four showed significant differences in F1 between men and women. There were no significant differences in F1 between ZA men and women for the vowels /iː/, /uː/, /eː/, and /oː/. However, the /i/, /a/, /u/, and /aː/ vowels were all lower in the vowel space for ZA women than for ZA men.

4.4.2. F2

We compared the F2 values of all vowels for ZA men and women. The results are given in Table 26.

Table 26. Differences in F2 in Arabic Vowels Between ZA Men and Women

Vowels	Men	Women	Mean difference	*t*	*p*	Significance after Bonferroni correction
/i/	1853.84	2185.66	–331.82	–4.82	$.02*10^{-3}$	**
/a/	1618.61	1931.61	–313.00	–9.18	$.04*10^{-10}$	***
/u/	1314.07	1371.13	–57.06	–1.39	.17	
/iː/	2148.52	2686.11	–537.58	–7.09	$.03*10^{-6}$	***
/aː/	1479.29	1751.93	–272.64	–6.29	$.04*10^{-5}$	***
/uː/	882.24	993.38	–111.13	–2.00	.05	
/eː/	1943.36	2315.57	–372.21	–5.97	$.09*10^{-5}$	***
/oː/	1016.82	1177.15	–160.33	–2.97	$.04*10^{-1}$	

There were no significant differences in F2 between men and women for /u/, /u:/, and /o:/. The /i/, /i:/, /a/, /a:/, and /e:/ vowels were consistently more front for ZA women than for ZA men.

4.4.3. Duration

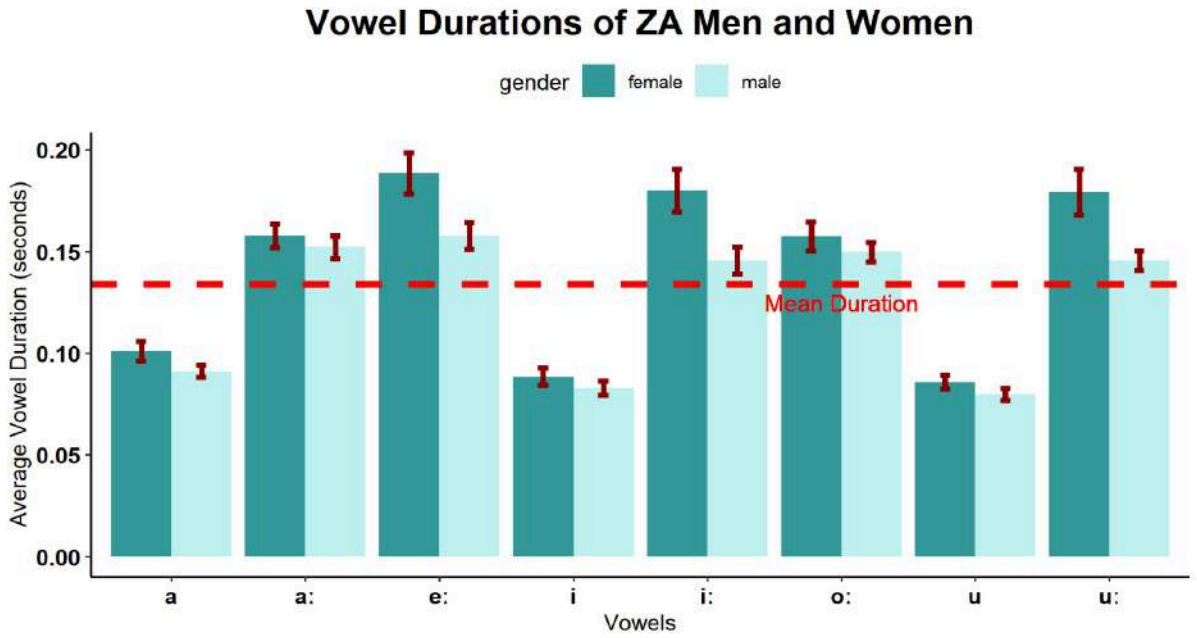
The durations of all vowels for ZA men and women were also compared using t-tests. The results are provided in Table 27.

Table 27. Differences in Duration of Arabic Vowels Between ZA Men and Women

Vowels	Men	Women	Mean difference	*t*	*p*	Significance after Bonferroni correction
/i/	.082	.088	–.005	–1.01	.31	
/a/	.091	.100	–.009	–1.73	.09	
/u/	.079	.085	–.006	–1.35	.18	
/i:/	.145	.180	–.034	–2.76	$.08*10^{-1}$	
/a:/	.152	.157	–.005	–0.68	.49	
/u:/	.145	.179	–.033	–2.75	$.09*10^{-1}$	
/e:/	.157	.188	–.030	–2.52	.01	
/o:/	.149	.157	–.007	–0.89	.37	

As indicated in Table 27, there were no significant differences for any of the vowels. Both short and long vowels were produced at approximately the same durations by ZA men and women.

Figure 3. Vowel Durations for All Eight Arabic Vowels Produced by ZA Men and Women



The differences in duration between ZA men and women for all eight Arabic vowels are presented in Figure 3.

5. Discussion

As indicated by the results provided in section 4, the phonetic inventory of ZA comprises a set of eight distinct vowel phonemes, consisting of three short vowels /i/, /a/, and /u/, and five long vowels /i:/, /e:/, /a:/, /o:/, and /u:/. This finding is in line with other studies reporting the same number, quality, and quantity for other Arabic dialects (e.g., Al-Ani, 1970; Alghamdi, 1998; Almbark & Hellmuth, 2015; Amir et al., 2014; Ingham, 1994; Kabrah, 2004; Mohammed, 2020; Norlin, 1987). Such alignment notwithstanding, other researchers have reported vowels with different qualities, such as the central vowel /ə/ instead of the low vowel /a/ (Ahmed, 2008). Researchers have also added short mid vowels to the vowel inventory of Arabic dialects such as Syrian and Lebanese Arabic (Khattab & Al-Tamimi, 2008).

In comparisons of short vowels with their long counterparts, ZA men demonstrated a significant difference in F1 (height) and F2 (frontness) for the members of the vowel pair /i/–/i:/. For the vowel pair /u/–/u:/, a significant difference was found in F2 (frontness) but not in F1 (height). In contrast, there was a significant difference in F1 (height) but not in F2 (frontness) between the members of the low vowel pair /a/–/a:/. Among ZA women, the members of the vowel pairs i/–/i:/ and /u/–/u:/ differed significantly in F1 (height) and F2 (frontness). However, although there was a significant difference in F2 between the vowel pair members /a/–/a:/, there was no difference in F1.

Based on the results for ZA men and women, the F1 for short vowels was higher than the F1 in their long counterparts, except for /a/ and /a:/. In other words, short vowels are generated lower in the acoustic vowel space than their long counterparts. However, the short low vowel /a/ is produced higher in the vowel space than the long /a:/. Regarding F2, the F2 for short vowels was higher than the F2 in their long counterparts, except for the vowel pair /i/ and /i:/. Therefore, non-front short vowels (/u/ and /a/) are farther front than their long counterparts. These results are in line with what has been reported by Alotaibi and Hussain (2009) in their analysis of MSA. The only contrast between their work and the current study is that the F2 of all short vowels in their study was smaller than that of their long counterparts.

Based on the reported F1 and F2 values of all vowels, F1 was high for the vowel /a/, medium for /u/, and low for /i/. Regarding F2, it was high for the vowel /i/, medium for /a/, and low for /u/. A comparison of the long vowels showed the same height (F1) and advancement (F2) rankings shown by their short counterparts.

The short–long vowel pairs differed in duration. The long vowels (/i:/, /u:/, and /a:/) were significantly longer than their short counterparts (/i/, /u/, and /a/). Moreover, these long vowels were more peripheral than their short counterparts. This result is in line with findings of previous studies in the Arabic literature (Alghamdi, 1998; Alotaibi & Hussain, 2009; Amir et al., 2014; Cowell, 1964/2016; Saadah, 2011). However, this result showing the quantitative difference between short vowels and their long counterparts contradicts a previous finding reported by Allatif and Abry (2004), as cited in Almbark (2012) in his analysis of Syrian Arabic, that the members of the vowel pair /i/–/i:/ do not differ in quantity.

In this study, the short-to-long vowel ratios averaged across speakers were 1:1.8 for men and slightly larger, at 1:1.9, for women. The result for men is in line with what has been reported by Hassan (1981) for Iraqi Arabic (1:1.8). However, it differs from findings for other Arabic varieties, being slightly higher than the ratios reported for Syrian Arabic (1:1.63;

Almbark, 2012) and Egyptian Arabic (1:1.7; Almbark, 2015) but somewhat lower than those reported by Almbark (2015) for Lebanese Arabic (1:2.08), Moroccan Arabic (1:2.6), and Iraqi Arabic (1:2.4). Furthermore, the ratio for Mosuli Iraqi Arabic is slightly larger (1:2.4) than that for Hiti Iraqi Arabic (1:2.2), according to Mohammed (2020). In addition, Kotby et al. (2011) reported that the duration of long vowels in Cairene Arabic is more than double that of short vowels.

The comparisons of short vowels showed similar results for men and women. As expected, in terms of F1, men and women showed significant differences between the low vowel /a/ and the other two non-low vowels /i/ and /u/ because they appear in opposite regions of the acoustic vowel space. However, men and women showed no significant differences in terms of F1 between the high vowels /i/ and /u/, which appear within the same high plane of the acoustic vowel space. Regarding F2, men and women showed significant differences among all three short vowels due to the scattering of these three vowels across the three different segments of the vowel space. These results for short vowels indicate that ZA, like many other Arabic dialects, has two height categories for short vowels: high and low (e.g., Al-Ani, 1970; Mohammed, 2020; Saadah, 2011). However, other researchers have reported different height categories for some Arabic dialects (e.g., Libyan Arabic) that have two categories of short vowels: high and mid (Ahmed, 2008).

Regarding duration, men and women showed no significant length differences between the shortest vowels. The only significant difference in duration was found between the high back vowel /u/ and the low vowel /a/, where the latter had a slightly longer duration. This difference in low vowel length can be attributed to the time it takes the jaw to move to produce low vowels compared with the production of non-low vowels. This result is similar to those reported by other researchers in various dialects and languages (Hassan, 1981; Lehnert-LeHouillier, 2007, 2000; Toivonen et al., 2014).

Men and women demonstrated similar results for the long vowels as well. Almost all the long vowels produced by ZA men and women showed significantly distinct F1 values. As expected, the mid vowel pair /o:/–/e:/ showed no significant F1 difference, since they occupy the same height category of the vowel space. Although the long high vowels /i:/ and /u:/ were expected to fall within the same height category, they differed significantly. This considerable difference between these two long high vowels may suggest a subcategorization of the high category into high and high mid. This result is similar to that found in Galilean Arabic spoken in Israel, in which the long high back vowel /i:/ has been found to be higher than the back vowel /u:/ (Amir et al., 2014).

Regarding F2, all long vowels produced by men and women showed significantly distinct F2 values, including the front vowels /i:/ and /e:/ and the back vowels /u:/ and /o:/. Moreover, there were no significant length differences between pairs of long vowels as produced by ZA men and women. Therefore, in terms of duration, the long vowels of ZA produced by men showed a good overall correlation between height and length and are ordered as follows: /a:/, /e:/, /u:/, /i:/, and /o:/,.

The results for men showed a significant difference between most non-mid vowel pairs in F1 and F2. Furthermore, significant differences were demonstrated between the vowel pairs (i-i:) and (a-a:) in F1 and (i-i:) and (u-u:) in F2 by both male and female speakers. Such findings are in contrast to those reported by researchers such as Kotby et al. (2011), who reported no significant differences between formant values for short and long counterparts in Cairene Arabic. However, in this study, several vowel overlaps were also observed, which aligns with

observations by previous studies. For example, men and women showed no significant difference in F2 between the adjacent vowels /i/ and /e:/. Moreover, the results for women showed no significant difference in the F1 of vowel pairs /u/–/o:/ and /i/–/e:/. Almbark (2012) reported an overlap between mid and high vowels in Syrian Arabic, although in that dialect both mid and high vowels were short. Similarly, Amir et al. (2014) found an overlap of the adjacent vowels /i/-/e/ and /u/-/o/ among male speakers speaking the Muthallath Arabic dialect in Israel. The research conducted by Peterson and Barney (1952) also revealed a substantial degree of overlap in the articulation of American vowel sounds among native speakers. The presence of such vowel overlaps can be partially attributed to a number of factors, such as the high degree of variability exhibited by these vowels and the length of the vowel tract in women (Ryalls, 1996).

The F1 and F2 values of both men and women were compared to look for any effect of gender on production. For F1, women's productions of the high short vowels /i/ and /u/ and the low vowel pair /a/–/a:/ were significantly lower than those by men. These reported results, as well as the visual inspection of the vowel space of ZA men and women (see Figure 2), support prior assertions that women have a larger vowel space than men due to a greater distance between the highest vowel /i:/ and the lowest one /a:/ (Hillenbrand et al., 1995; Whiteside, 2001). Moreover, the vowels produced by women tend to be lower than those produced by men (Martland et al., 1996). The findings of the present study diverge from those reported by Kotby et al. (2011), however, who reported that male speakers of Cairene Arabic exhibited lower short and long front vowels /i, e/ than female speakers. In the present study, the F1 and F2 values for men and women were not significantly different in the production of the long back vowels /u:/ and /o:/. Regarding F2, all vowel comparisons were significantly different between men and women, except for the back rounded vowels /u/, /u:/, and /o:/, which were produced similarly between men and women. The lack of significant differences between the back vowels may be explained by Beckman et al.'s (1995) proposal that the articulation of high front vowels is characterized by a greater degree of precision than for back vowels. Accordingly, back vowels are produced with relatively imprecise control of tongue height, which could result in this unanticipated difference between men and women in ZA. The results of this study showed that vowels produced by men were more retracted and higher than those produced by women.

Regarding duration, women's vowels were slightly longer than those produced by men, but no statistically significant duration differences were found. The results of the current work are similar to those reported by Newman and Verhoeven (2002), who also found no significant durational difference between men and women. However, our study's results do not align with others reported in the literature regarding significant durational differences by gender (Amir et al., 2014; Mohammed, 2020; Simpson & Ericsdotter, 2003). One possible explanation is that this study's female participants were supervised by a male unrelated to them, which is uncommon in their local conservative community. Therefore, these women may have read the phrases of the study more rapidly than men due to shyness, resulting in a smaller vowel length difference between ZA men and women (Allatif & Abry, 2004; Almbark & Hellmuth, 2015).

This study conducted a thorough acoustic analysis of the different qualities and lengths of ZA vowels in CVC contexts as produced by both men and women. The results offer numerous implications. First, we have added to the literature on Arabic vowels by describing the acoustics of ZA vowels, which, to the researcher's knowledge, have not been previously described. Second, our characterization of the subtle phonetic details of ZA vowels will provide helpful scaffolding for future phonological studies. Third, this acoustic analysis of the ZA

vowel system may help people interested in learning English as a foreign language (EFL) understand the problems that might arise due to the different vowel qualities among ZA male and female EFL learners. Fourth, as evidenced in this study, ZA has just three short vowels (/i/, /a/, /u/) in its short vowel system. This small inventory may increase the challenges for ZA speakers when attempting to comprehend and articulate a foreign language with a more extensive short vowel range, such as English. Understanding such challenges may help educators anticipate possible problems and offer solutions for addressing them in EFL learning.

6. Conclusion

This study described the acoustic characteristics of Arabic vowels produced by ZA speakers. Based on the analysis, the author argues that the phonemic vowel inventory of this Saudi dialect comprises three short and five long vowels. This vocalic system is similar to those of other Arabic varieties reported by other researchers (Alghamdi, 1998; Almbark & Hellmuth, 2015; Amir et al, 2014).

Comparisons of short vowels with their corresponding long vowels revealed notable distinctions for men in the F1 and F2 values of the vowel pair /i/–/iː/, the F2 frequency of the vowel pair /u/–/uː/, and the F1 frequency of the vowel pair /a/–/aː/. For women, there was a notable distinction in the F1 and F2 values between the vowel sounds i/–/iː/ and /u/–/uː/. In general, short vowels were produced lower in the acoustic vowel space, as indicated by a higher F1 value, than their long vowel counterparts. In addition, the short low vowel /a/ was articulated higher in the vowel space than the long /aː/ vowel. In relation to F2, short vowel F2 values exhibited greater frequency than their long counterparts, except for the phonemes /i/ and /iː/. In terms of temporal extent, the pairs of short and long vowels exhibited distinct differences in both phonetic quality and duration. The long vowels were situated at a greater distance from the center than their shorter counterparts. The present study determined that the mean short–long vowel ratio across speakers was 1:1.8 for male participants and slightly higher, at 1:1.9, for female participants.

Similar outcomes were observed among men and women in relation to short vowels. As hypothesized, there were significant differences in F1 between men and women when producing the low vowel /a/ compared with the non-low vowels /i/ and /u/. A significant differentiation among all three short vowels in F2 was observed in both male and female speakers. The study also revealed that the sole noteworthy distinction in the duration of short vowels between men and women was observed in the high back vowel /u/ and the low vowel /a/, wherein the latter exhibited a marginally longer duration than the former.

In relation to the F1 and F2 of long vowels, a notable majority of long vowels generated by male and female speakers exhibited statistically significant differences. However, there was no significant difference in the length of long vowels produced by ZA men and women.

There was also no statistically significant difference observed among women in terms of the F1 of adjacent vowel pairs, specifically those between /u/–/oː/ and /i/–/eː/. The near overlap of the two vowels in question may be attributed to high degree of variability exhibited by these vowels and the length of the vowel tract in women (Ryalls, 1996). With respect to F2, all comparisons involving vowels were statistically significant, except for the back rounded vowels /u/, /uː/, and /oː/. In terms of gender comparison, the vowels produced by men exhibited greater retraction and height than those produced by women. In terms of duration, no

significant variations in the duration of any of the vowels were observed between ZA men and women.

7. Limitations and Future Work

While this study has contributed important discoveries about ZA speakers and the acoustic properties of their vowels, its limitations must be acknowledged. One restriction is the limited sample size, with only four hundred datapoints collected across five men and five women, each articulating eight vowels. This small sample size inherently limits the generalizability of our findings and decreases the statistical power of this study. In other words, there was an increased risk of statistical Type II errors, but Type I error rate was kept constant through correction. Nevertheless, this study sheds important light into the acoustic characteristics of ZA vowels and reveals nuanced patterns in gender-specific vowel pronunciation in ZA. Future research would greatly benefit from larger sample sizes, potentially using stratified sampling to ensure representation across different age groups, ethnicities, and socioeconomic statuses, while continuing to explore the complex interactions among these factors. Another limitation of the study is that finding real monosyllabic CVC /hVd/ words as target vowels was difficult, so we had to use nonsense words instead. The third limitation is our use of monosyllabic CVC /hVd/ words ending in a voiced /d/ but no counterpart words ending in /t/. Using both voiced and voiceless consonants helps check for any potential lengthening effect of the voiced /d/ on the preceding vowel. For future studies, the selection of data should be expanded to include a variety of contexts and speech patterns. To obtain a more comprehensive description of how Saudis produce vowels, future research should include a larger sample size. In addition, future research should include perceptual assessments to investigate how speakers perceive vowels.

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