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The Effect of Coda Voicing Contrast on Vowel Duration in American English and Najdi Arabic: A Comparison Study

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***Abstract*—This paper presents a comparative study investigating the influence of consonant voicing status on the duration of preceding vowels in Najdi Arabic and American English. In this study, the phonetic correlates of the voicing feature in Najdi Arabic and American English were examined with regard to vowel duration were examined. In addition, acoustic measurements (duration, fundamental frequency, and second formant frequency levels) were taken. The vowel /a:/ is produced in monosyllabic /CVC/ forms by Najdi Saudi and American speakers. The goal of this study is to determine the effect of the voicing feature of the consonant on the preceding vowel in Najdi Arabic and American English by measuring the vowel duration. This study adopts some statistical analyses that might offer a novel perspective on speech recognition analysis.**

***Index Terms*—American English, Najdi Arabic, vowel duration, voicing effect**

I. Introduction

Vowels vary from language to language according to their qualities and duration. In addition, several factors affecting vowels are present in some languages and not in others. For example, the properties of vowels may differ because of different consonantal environments (Fairbanks et al., 1950). This paper examines the voicing effect of the coda on vowels, which is one of the most common factors influencing vowel duration. Najdi Arabic (NA) was chosen in this study as a counterpoint to American English (AE) to compare vowels in terms of their duration. This phonetic interference is a possible factor contributing to difficulties for Najdi speakers learning English, as these phonetic differences may lead to miscommunication in some cases. Catford et al. (1974) reported that Arab speakers produce all English vowels with the same length. As a result, this mechanism is used to detect the speaker's dialect when addressing difficulties that second-language learners experience because of their articulatory habits (Weinreich, 1953).

According to Fries (1945), in his contrastive analysis hypothesis, determining the new and similar sounds between two languages can help facilitate the learning of English as a second language. As the goal of this paper is to explore the phonetic distinctions between NA and AE regarding vowel duration, the analysis below will examine one of the most common pronunciation errors of Arabic speakers: shortening English vowels (Alahmari, 2022; Mitleb, 1978).

Such vowel pronunciation errors occur because Arabs are not sensitive to the voicing feature of the following consonant. While there is little relevant phonetic data for Arabic in general, a small number of studies address vowel duration and voicing effect (VE) in NA. Therefore, the first research question is as follows: How does the vowel variety in Najdi Arabic affect the universality claim of the voicing effect? This question leads us to consider two related questions that might be asked at this point: Does the voicing feature affect vowel duration in Najdi Arabic as opposed to vowel duration in American English? Is the difference in vowel duration due to the voicing effect one of the major difficulties for Najdi Arabic speakers?

The purpose of this study is to distinguish the voicing effect of the coda on vowel duration between NA and AE. This study will provide new phonetic data for NA, which will serve as a point of comparison to explain why NA speakers of English have difficulty producing vowels of varying duration according to the voicing feature of the following consonant.

This study begins with a review of the previous studies regarding the acoustic classification of these sounds, including English varieties according to the vowel system and Arabic colloquials followed by the vowel system of Arabic. Next, the focus of this study is outlined through a review of relevant studies on vowel duration and VE in AE and Arabic. The following section then explains the methodology of the experiment and describes the participants of this study, illustrating why vowels are tested within a /CVC/ syllable. The results section explains the phonetic

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differences among the vowels in NA and AE with regard to VE. Related analyses and observations are then discussed, and the last sections present conclusions, additional comments, and the limitations of this study.

II. Literature Review

A. Acoustic Classification

Bell invented the first phonetic classification in 1867, and he divided the speech sounds – or segments – into consonants and vowels according to their articulation in terms of airflow obstruction (Bell, 1867). Consonants have a varying degree of airflow obstruction, whereas vowels are open sounds with no obstruction in the vocal tract (Roach, 2001). However, the traditional classification is ambiguous because it considers all vowels to be syllabic and consonants to be marginal constituents (Hjelmslev, 1938). In fact, there are vowels which cannot function as a syllabic – semivowels – such as the glides in English sounds: [j] in [ˈjɛs] "yes" and [w] in [wiːp] "weep". Moreover, some vowels act like consonants in some syllables. For instance, the letter <u> is usually a vowel, but it functions as a consonant when it comes after the letter <q>, as in the word "unique" (LibreTexts, 2022). Therefore, Pike (1943) introduced a new acoustic dichotomy based on syllabic functions and phonetic form. In this system, he refers to vowels as vocoids and consonants as contoids. This classification system has four categories: syllabic vocoid, non-syllabic contoid, non-syllabic vocoids (semivowels), and syllabic contoids (like /l/ and /n/ sounds in "muddle" /mʌd.əl/ and "sudden" /ˈsə-dᵊn/, respectively).

In 1968, Chomsky and Halle introduced a phonetic feature system influenced by the generative grammar framework to analyse the structure of sounds. They proposed a binary opposition in terms of + or - values within a list of major classes based on phonetic properties, including the manner of articulation features, major class features, source features, cavity features, and prosodic features. These distinctive features are called a feature matrix, enabling us to differentiate speech sounds. For instance, the English segment [d] can be characterized as [-syllabic, +consonantal, +voice]. Nevertheless, the Chomsky–Halle feature has not accurately fulfilled the criteria for determining the vowel quality because the physical scale of only two points is insufficient. Instead, multivalued scales are needed.

Although methods such as x-ray show the speaker's sound-producing movements, the whole process of phonetic articulation needs to be observed to measure the exact degree of vocalicness, and contrast features cannot be generalized to all languages (Ladefoged, 1972). Unlike the consonant, all vowels are produced without friction or obstruction of airflow, and they share some basic features: [+sonorant, +voice, +continuant]. Moreover, vowels have no absolute boundaries in terms of describing their types because some vowels take place between high and low positions (Ladefoged & Johnson, 2014). Hence, the categorization of vowels requires a multi-level scalar to describe sound quality based on the position of the tongue and lips.

Jones (1956) proposed a set of eight cardinal vowels that can be used or compared to any vowel in any language: /i/, /e/, /ɛ/, /a/, /ɑ/, /o/, /u/, and /ɔ/. This universal vowel system has three parameters, height, backness, and rounding (lip rounding), with variant degrees of each vowel in each language. Overall, the vowels /ɑ/, /o/, /u/, and /ɔ/ have a back rounded position, while /i/, /e/, /ɛ/, and /a/ are characterized as front unrounded vowels (Catford, 1988). The following sections outline additional vowel variations in NA and AE.

B. English Varieties

The variety of English accents arises mostly from differences in producing vowels. A particular accent can be recognized from the speaker's use of vowels. The most common forms of English are Standard Southern British English (SSBE; usually referred to as the Received Pronunciation) and American English (AE; sometimes called General American English), which is spoken in most regions of the United States except in southern and eastern states (McMahon, 2002). The main differences between AE and SSBE can be found in the manner of articulation. For instance, AE has /ɑː/ in the words *god* and *stop*, whereas it is pronounced as /ɒ/ in SSBE. In addition, the word *trap* has a different utterance as it is produced as /trap/ in SSBE and /træp/ in AE (McMahon, 2002).

Another major factor distinguishing between the British and American forms is rhoticity: SSBE is considered a non-rhotic accent, and AE is a rhotic accent. Therefore, the vowel quality differs in SSBE to differentiate between words with the same pronunciation. For instance, the words *heart* and *hot* are pronounced similarly because of omitting /r/ -non-rhotic-, so the vowel quality would be changed in the word *hot* /hɑt/ to /hɒt/ to distinguish it from the word *heart* [ˈhɑːt].

In contrast, the Standard Scottish English (SSE) forms do not have short-long vowel distinctions. For instance, *bit* and *beat* have the same vowel length, so they are homophones in SSE. Moreover, there is no distinction between /æ/ and /ɑː/; therefore, the vowels in *father* and *had* are pronounced the same in Scottish English. Hence, the vowel length in Scottish English is considered to be non-phonemic (Cao & Jin, 2017). However, certain vowels can be shortened or lengthened in some cases according to the Scottish Vowel-Length Rule (SVLR), depending on the environment of the vowels (Aitken, 1981; Scobbie et al., 1999).

As a final example, New Zealand English has certain distinct phonetic characteristics compared to AE. For instance, the vowel in *trap* is pronounced as /trɐp/ instead of /træp/ in AE (McMahon, 2002). Overall, the examples above illustrate that accent differences in English can be deduced from systemic differences and contrasts in vowel treatment.

C. Arabic Varieties

Arabic is one of the Semitic languages spoken in North Africa and the Arabian Peninsula, originating from the peninsula's northern and central regions (Watson, 2002). The Arabic language is variable, as it is a diglossic language. It includes a high variety, such as the Modern Standard Arabic language (SA), and a low variety that refers to an acquired dialect spoken as a mother tongue, such as Moroccan Arabic, Egyptian Arabic, and Najdi Arabic (Ferguson, 1959). Currently, SA remains restricted to written and formal speech while the speech community grows continually (Al Suwaiyan, 2018).

It is challenging to determine the exact time when a given change in dialects occurred (Blau, 1961; Garbell, 1958). Versteegh (1984) found that the evolution of language has no specific beginning because of a lack of agreement on chronology; it is not clear whether dialects descending from Old Arabic should be viewed as a sudden break or a gradual development. Most theories about the origins of the Arabic dialects limit their scope to an explanation of the differences and similarities between the dialects. Moreover, Ferguson (1959) mentioned that no assumption is made that all the varieties of the Arabic language have emerged simultaneously. Some theories have explained this phenomenon as a polygenetic process, asserting that the colloquial variety has appeared because of the Arab armies and different dialects accompanying them (Miller, 1986; Versteegh, 2014). In addition, communications with new immigrant populations and mixed marriages led to long-term creolization (Holes, 2004). Some studies disagree with previous findings, discovering forms of rural dialect which are much older than SA; this discovery could support the idea that Arabic colloquials should not be considered to be deviations (Versteegh, 2014). Owens (2006) claimed that Arabic dialects already existed even before Classic Arabic and are not innovative.

Diglossia helps explain the varieties of SA:

> A language situation in which two or more varieties of the same language are used by some speakers under different conditions in many speech communities where many speakers speak their local dialect at home or among family or friends of the same dialect area but use the standard language in communicating with speakers of other dialects or on public occasions. (Ferguson, 1959, p. 325)

However, Arab colloquial dialects were not generally written down nor given literary status or grammatical legitimacy, and they never reached separate language status (Ryding, 2005).

One of the most common Arabic colloquials is NA, which is spoken in the central area of Saudi Arabia. It is similar to SA in many ways. NA enjoys prestige by virtue of its conservatism and relative closeness to SA, and it is the dialect of the Saudi government (Omar & Nydell, 1975). However, there is no official or geographical limitation for the area called Najd. Still, it usually refers to the area lying from Yemen to the south to the borders of Jordan to the north, and from Ahsa Oasis to the east of the mountains of Hijaz and the plains of Asiir to the west (Al-Sweel, 1987). Some studies divide the Najdi dialect into Southern Najdi and Northern Najdi (Abboud, 1979; Ingham, 1994). The Najdi dialect shares more phonological characteristics with SA than other dialects and is considered one of the major spoken dialects. Although NA is the closest form to SA, some sounds exist in NA that cannot be found in SA: [ts] and [dz] as the allophones of the phoneme /k/ and /q/, respectively (AlAmro, 2015; Ingham, 1994).

The SA vowel inventory consists of six vowels with three different qualities: the close front vowel, [i], the central open vowel [a], and the back close vowel [u]. The long vowels are about twice as long as the short vowels and are indicated by doubling the long vowel symbols /aa, ii, uu/ (Al-Ani, 1970; Gairdner, 1925; Newman, 2002; Ryding, 2005). The differences between long vowels and short vowels can be found in their quality, as the short vowels are significantly more centralized, while long vowels are peripheral (Kalaldeh, 2018). However, the vowel inventory varies among the regional dialects (Newman, 2002). Alghamdi (1998) concludes that "the system of Arabic vowels is variant according to the dialects in terms of phonetic implementation and the difference could be an acoustic cue to identify the dialect". Although NA features the same length contrast as SA vowels /a/, /u/, and /i/, it also includes the back mid vowel /o:/ and the front high mid vowel /e:/, which have no long counterparts (Al Mahmoud, 2021; Ingham, 1994; Johnstone, 1967).

D. Vowel Duration

Duration of American English Vowels

The acoustic characterisation of vowel length in AE has been clearly documented. Rositzke (1939) investigated the American vowel length of monosyllabic words, including stop-vowel-stop and stop-vowel. His results align with Meyer's (1903) findings, as he found that the percentage of lengthening for the vowels [i, u, e, o] is .38 to .55, and for [ə, ɑ, ɔ], it is .26 to .31. He concludes that the duration in General American (GA) vowel pattern is not phonemic and varies because of speech habit; additionally, it is affected by the nature of the following consonant. As a result, he classifies the vowels in GA into two groups that are only based on the vowel position before mediae, long vowels [i, u, e, o, æ, ɔ, ɑ], and short vowels [ʊ, ʌ, ɪ, ɛ].

Black (1949) measured the American vowel in CVC syllables, and he found that the duration of the vowel /æ/ is about 210 ms, and for /ɑ/, it is 198 ms. Although the findings of Van Santen (1992) showed identical vowel patterns to Black (1949) in the vowel /ɑ/, the vowel /æ/ is slightly shorter in connected speech (200 ms). However, Crystal and House (1988b) measured the vowel duration of AE over different tempos in continuous speech. Their categorization of the vowel according to length is identical to Rositzke's (1939). They found that the duration of both vowels /æ/ and /ɑ/

showed a similar vowel pattern (ranging from 173 to 175 ms). They found that the average duration of the long vowels is approximately 130 ms, and 72 ms for the short vowels. According to Hillenbrand et al. (1995), the average duration of the vowel /æ/ is 311 ms – produced by males, females, and children. As noted in the previous studies, the mean duration of the long vowels is almost twice that of the short vowels.

Flege (1979) reported that the duration of the long Saudi Arabic vowel /aa/ is 176 ms and the short vowel /a/ is 98 ms. On the other hand, Tsukada (2009) reported that vowel length in Arabic – as uttered by different dialectical speakers, some of them Saudi – is 108 ms for the short vowel /a/ and 250 ms for the long vowel /aa/. Al Mahmoud (2021) conducted a study to investigate the identification of Najdi vowels /a/ versus /ɛ/ by the duration cue, and he found that the duration of /a/ is 245 ms.

Since the dialect of Jordanian speakers is similar to NA speakers in many phonetic specifications, it is essential to report that the duration of English vowels /ɪ, æ, a/ – as produced by Jordanians – are in the range of 79–132 ms, which is shorter than those vowels produced by Americans (Mitleb, 1978). Port et al. (1979) show similar results for Saudi speakers.

E. Voicing Effect

Many studies have shown that vowel duration is affected by the voicing feature – called the voicing effect (VE) – of certain consonants, as it is known that the duration of vowels before voiced consonants is longer than those preceding voiceless counterparts (Chomsky & Halle, 1968; Heffner, 1937; Mitleb, 1982; Rositzke, 1939; Thomas, 1947). Belasco (1953) explained this phenomenon: "Voiceless consonants require greater force to be produced than their voiced counterparts that will tend to shorten the preceding vowel" (p. #). VE can be observed in English vowels, such as in beat [biːt] versus bead [biːd] (Delattre, 1962). Peterson and Lehiste (1960) reported that the duration of long vowels is 188 ms before /p/ and 307 ms before /b/, 210 ms before /t/ and 318 ms before /d/, 200 ms before /k/ and 314 ms before /g/. Chen (1970) also measured the vowel duration before voiceless and voiced consonants. He reported that the vocalic duration in pre-voiceless consonants is 146 ms and 238 ms in pre-voiced consonants, with a ratio of 61%. Hillenbrand et al. (2001) supported the results of that study, and they reported that the average duration of the vowel /æ/ in a CVC syllable is 234 ms before unvoiced consonants and 309 ms before voiced consonants. Moreover, it has been confirmed that vowels produced in voiced environments are longer than those produced in voiceless cognates (House & Fairbanks, 1953).

On the other hand, several studies claim that VE has no effect on AE vowels. Crystal and House (1982, 1988a) analysed the impact of VE on AE vowels in connected speech produced by fast and slow speakers and reported no change in vowel duration. In addition, Klatt (1975) investigated the effect of postvocalic consonants and concluded that they have a non-significant influence on vowel duration.

In the Arabic context, many studies show that the VE does not exert an effect on the preceding vowel. In other words, the universal principle cannot be applied to Arabic. Mitleb (1984) and Flege (1984) found that the duration of /æ/ is not affected by the voicing of post-consonants. Flege and Port (1981) found a minor effect of consonant voicing on vowel duration produced by Arabic speakers, with a ratio of 96.62% as calculated from their results. Mitleb (1981) reported a similar finding for Arabic speakers. Moreover, Mitleb (1984) investigated the voicing-dependent vowel duration variation of [æ] in Saudi Arabic and concluded that VE has no effect on vowel duration. Similarly, Flege (1979) reported that there is a minor effect of the post-stop consonant on the duration of the vowel [æ] in Saudi Arabic. He concluded that the vowel duration contrast produced by Saudis is 7 ms compared to 30 ms for Americans, which reveals a significant difference in vowel duration between Americans and Saudis. In other words, the vowel duration contrast before voiced/voiceless stop consonants in Arabic is smaller than the VE of English (Port et al., 1979). Moreover, Hussein (1994) argued that there is no noticeable difference in the vowel duration of /æ/ in the pre-voiceless and pre-voiced environments for SA as compared with AE vowels. Moreover, he found that the length of /æ/ (177.7 ms) is almost identical to Flege's (1979) study (177 ms).

In contrast, Port et al. (1980) supported the study of Chen (1970) on the influence of the voicing of postvocalic consonants on the vowel duration of the short and long /æ/. In addition, they presented evidence for temporal compensation in trisyllabic words. This implies that the voicing change of medial stops has a significant effect on the duration of SA vowels. In general, it has been noted that the VE on preceding vowel duration in English is greater than in Arabic.

However, the voicing effect is not constant. It varies due to several phonetic factors, such as a variety of speech rates (Cuartero Torres, 2002). For example, the voicing effect is reduced when the speaker talks fast. In addition, the height of the vowel is one of the universal factors affecting vowel length in all languages (Chomsky & Halle, 1968). Several studies have found that lower vowels are longer than high vowels because of the time spent opening the jaw to produce the low vowels (Lehiste, 1970; Solé & Ohala, 2010). The findings of Mitleb (1984b) support this fact, indicating that the Arabic and English languages have the same height effect on vowel duration.

III. Methodology

Two groups were examined in this study. The first group included five native NA speakers, and the second group included five native AE speakers. To assess whether L1 features of the VE can be carried over into L2 production, it

was necessary to recruit Najdi Saudis with a background in English from middle and high school. All participants were males between the age of 22 and 30. To ensure dialect homogeneity, the selected native Arabic speakers had lived in Najd for their entire lives, and the native English group had grown up in the southeastern United States and did not speak with a strong regional accent. The sample was composed exclusively of male participants to minimize random results (Disner, 1986) and avoid the higher frequency of formants from female participants (Samuelsson, 2006). All participants gave their consent to participate in this study.

In these recordings, each group was instructed to read a randomised list of the words presented below. Furthermore, the Najdi group were asked to read two lists of words, both in their native language and in English. Each tested word was articulated in the same context for each language to minimise the speakers' bias (Alsager, 2020).

The context of words:

- qul _____ marra ɵanya "Najdi Arabic context"
- 'say ____ again'. "English context"

The Arabic subjects were encouraged to utter the words informally in their Najdi dialect, and all participants were allowed to repeat the sentence as many times as they wished.

A. Najdi Arabic Data

-Alveolar Fricatives

/da:s/ '' stepped on '' /da:z/ ''running fast ''

-Alveolar Stops

/ma:d/ '' extend '' /ma:t/ ''died ''

-Velar Stops

/ða:g/ ''tasted'' /ða:k/ ''that''

B.American English Data

-Alveolar Stops

/mæd/ ''mad'' /mæt/ ''mat''

-Bilabial Stops

/kæb/ ''cab'' /kæp/ ''cap''

-Velar Stops

/bæg/ ''bag'' /bæk/ ''back''

The long vowel [a:] was chosen because its qualities correlate with the AE vowels [æ] and [a] (Flege, 1979; Holes, 1990; Mitchell, 1990). Three CV(V)C monosyllabic NA minimal pairs (voiced versus voiceless final consonant) were used as stimuli. In addition, three CV(V)C monosyllabic AE minimal pairs were used.

Voices were recorded with an iPhone (model: iPhone 12 Pro Max, Apple, USA) using a voice memo application. The recordings were submitted to acoustic analysis to determine the differences in acoustic parameters for the two sets of utterances. The vowel duration and the mean of F1 and F2 of the vowel /a:/ were examined using Praat acoustic measuring software (Boersma & Weenink, 2001). The quality of the vowels is displayed at various frequencies; therefore, the higher the frequency of F1, the lower the vowel height, while F2 correlates inversely with the vowel backness. Thus, the low front vowel /æ/ has a high F1 and F2 (Essner, 1947). Also, the manner of articulation can determine the formant frequencies; therefore, the low vowel [a] has an F1 value which is interpreted as high frequency (Flanagan, 1955; Sundberg, 1977). The settings used with the Praat software were the default settings of 0.0 s time step, a maximum formant frequency of 5000 Hz, a maximum of five formants, a window length of 0.025 s, and a dynamic range of 30 dB.

Data Collection: Context-Dependency

In everyday speech, vowels tend to appear within a context. The vast majority of studies indicate that the characteristics of vowels can be identified more easily in a specific formant pattern within a syntactic or semantic context rather than in their isolated form (Maurer, 2016). These static articulatory positions are considered the goal states when coarticulating vowels in syllabi contexts (MacNeilage, 1970). Therefore, the concept of a static, context-free target to discriminate between vowels is insufficient (Strange, 1989). Moreover, Lindblom (1963), Stevens and House (1963), Verbrugge et al. (1976) and others have shown that when vowels are coarticulated with consonants in consonant-vowel-consonant (CVC) syllables in continuous speech at different rates, they can be identified with surprising accuracy, but "the canonical acoustic (and articulatory) targets are often not reached" (Strange, 1989, p. #). Therefore, based on the former studies, the vowels in this study were analysed in the form of a CVC syllable.

IV. Results and Discussion

The phonetic correlates of vowels in NA and AE differ in certain respects. There are differences in vowel duration in both languages when followed by a voiced consonant, and the effect appears to be greater in AE than in NA. However, it is interesting to note that the productions of the two groups when producing English words are affected by the voicing condition even though it shows a slight difference in NA speakers' production.

The long monophthong /a:/ represents the letter 'alif' (ا), and this vowel quality is one of the most common in the vowel inventories of almost all languages (Lindblom, 1986; Newman, 2002). Figure 1 shows the averaged F1 and F2 values for /a:/ before voiced and voiceless consonants across all NA participants.

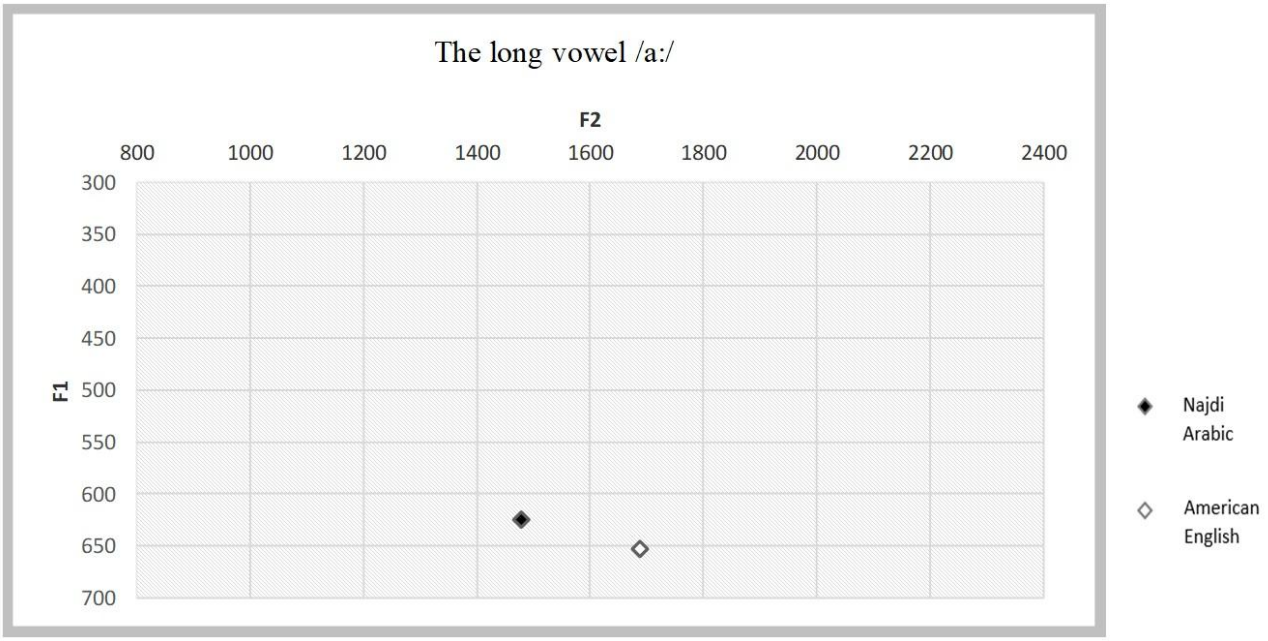

Figure 1. Averaged F1 and F2 Values of /a:/ by Najdi Arabic Speakers and American English Speakers

The pattern of voicing effects was assessed by calculating the mean duration for each subject, and the average mean duration across all subjects was extracted. The mean duration of the focused words was measured within a sentence-medial context.

It can be deduced from Figure 1 that the vowel /a:/ in NA is located at a low and central back position in the vowel space with a height (F1) in the range of 550–600 Hz, while F2 is in the range of 1400–1600 Hz. In the AE values, the vowel is more centralized (F2 mean ~1688 Hz) and has a lower position (F1 mean ~653 Hz). Notably, the AE system has a lower and more fronted quality for the vowel /a:/ as compared to NA.

Figure 2 shows the average duration in milliseconds (ms) of the vowel /a:/ when followed by voiced or voiceless consonants in all NA-tested words across all NA participants.

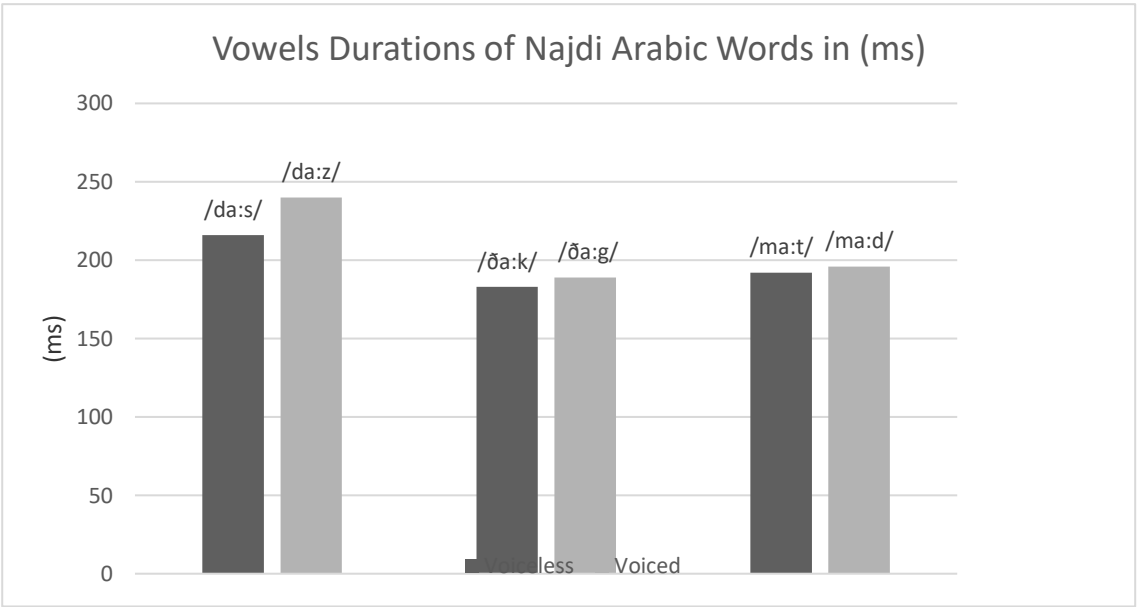

Figure 2. Average Duration of /a:/ in NA Test Words Across all NA Participants

It should be noted that the vowel /a:/ was tested before stop consonants except for /da:z/ and /da:s/, which are fricatives. Many observations can be made from Figure 2. First, there is a significant effect of the voicing feature of alveolar fricatives on vowel duration: /a:/ is ~216 ms in داس /da:s/, compared to ~240 ms in داز /da:z/. On the other hand, the mean duration of /a:/ in the velar stops minimal pair /ða:k/ and /ða:g/ showed a slight difference in vowel duration: /a:/ is ~1830 s before the voiceless consonant in /ða:k/ and ~189 ms in /ða:g/. Moreover, the difference in the duration

of /a:/ in /ma:t/ (~1920 s) and /ma:d/ (~196 ms) showed a minimum difference among other minimal pairs. Based on NA vowel findings, the difference in the vowel duration of /a:/ is insignificant in voiced and voiceless contexts.

Overall, the average duration of /a:/ is 208 ms before a voiced consonant, whereas it is 197 ms before voiceless consonants. Furthermore, the overall ratio of /a:/ across voiced-voiceless minimal pairs is 95%, which indicates that the duration of NA vowels is similar to Arabic vowels, as they both have no major differences caused by VE.

TABLE 1
AVERAGED VOWEL DURATION (IN MS) OF /A:/ IN ALL ENGLISH TESTED WORDS FOR BOTH GROUPS (NA AND AE), MEAN DURATION DIFFERENCES, AND DURATION PERCENTAGES (RATIOS) ACROSS MINIMAL PAIRS IN MEDIAL UNFOCUSED POSITION

	American English		**Najdi English**	
	ms	%	ms	%
cab	209.8		176	
cap	158.6	75.59	158	89.77
	51.2		18	
bag	207.8		184	
back	186	89.50	172	93.47
	21.8		12	
mad	229		162	
mat	158.2	69.08	164	98.78
	70.8		-2	
voiced	215.53		174	
voiceless	167.6	77.76	164.66	94.63
	47.93		9.34	

The vowel duration of the low central vowel /a:/ before voiced consonants was longer than the duration before voiceless consonants. Even when accented, the test words showed a slight increase in vowel duration that resulted from the voicing feature of the following consonant except for the minimal pair (mad-mat), which shows contradictory data. It should be noted that no consistent vowel duration differences emerged between vowels before exclusively voiced consonants and vowels before voiceless consonants. However, the major difference in vowel duration between such pairs of words in AE is greater than in NA, as shown in Table 1.

For NA speakers, there is a minor difference in vocalic duration of /a:/ in the minimal pair cab/cap, with a voicing ratio of 89.79%. For AE, in contrast, there is an obvious decrease in the vowel duration resulting from the voiceless consonant (75.59%). In their productions of /a:/ followed by /g-k/, the vowel duration difference of the native English group (21.8 ms) is longer than that of the NA group (12 ms). However, the NA acoustic data of mad/mat showed a striking result that reports a slightly shorter vowel duration before the voiced consonant (162 ms) compared to (164 ms) before the voiceless one. In addition, AE shows a greater amount of vowel lengthening before /d/ (215.53 ms) and before /t/ (158.2 ms).

In conclusion, duration differences in the vowel /a:/ in the minimal pairs of voiced/unvoiced consonants are non-significant in NA compared to duration differences in American speakers' production. The voicing effect in the data in Table 1 shows that the durational range of /a:/ before voiceless-voiced consonants in AE is about a third larger than in NA. The overall English ratio is 77.76%, and the difference ratio of NA is 94.63%. For Najdi-accented English, the results showed a similar voicing effect (94.63%) to those in NA test words (95%), which was still weaker than the AE effect.

The results of this study are comparable to similar findings in other studies on vowel duration. First, the average of /a:/ duration in the test words produced by AE is 192 ms, shorter than the 210 ms reported in Black (1949). The average vowel length for NA reported here (203 ms) is longer than that reported in Flege (177.7 ms) and shorter than the 245 ms reported in Al Mahmoud (2021). The 77.76% ratio of /a:/ in pre-voiceless and pre-voiced consonants in AE is close to the 76% ratio found by Heffner (1937) and Hillenbrand et al. (2001) in /CVC/ syllables. By contrast, the corresponding ratio of NA (95%) was found to be similar to the 97% reported in Flege's (1979) study of Saudi Arabic. Moreover, the ratio of vowel duration in a voiceless environment to that in a voiced one in Najdi-accented English (94.63%) is similar to Mitleb (1981), who investigated the ratio of voicing effect on English vowels produced by Jordanian speakers (91%). In the case where the vowel is longer before the voiceless consonant /t/ than before the voiced /d/ in Najdi speakers (98.78%), Hussein (1994) reported a similar slight difference in vowel duration in these contexts of about 5.4 ms. He reported an overall ratio of 98% in focused and unfocused contexts, as there is a lack of VE in some subjects' production. Moreover, Hussein interprets the lack of voicing effect as being due to the pre-dental environment.

V. CONCLUSION

The results of this comparison between coda voicing-conditioned vowel duration in AE and NA productions replicate those of previous single-language studies of English and Arabic. Previous studies have found that the effect of coda voicing on preceding vowel duration is highly variable. In particular, vowel duration differences are greatly intensified in AE compared to NA. Thus, both AE and NA exhibit various vowel durations that are highly dependent on various linguistic factors like the voicing effect. On the other hand, the NA results of this study provide practical evidence of

Mitleb's (1984) claim that the voicing effect on the vowel duration cannot be a universal rule. Finally, the findings of phonetic interference in NA speakers showing a tendency to shorten vowels could contribute to a better description of this phenomenon. This information can be useful in speech recognition or for TESOL purposes.

VI. Limitations

Since the acoustic analysis relies on the respective fundamental frequencies of the sounds, the higher the fundamental frequency, the more difficult it becomes to determine the expected spectral envelope peaks. It also becomes increasingly difficult to determine the formants within the existing analytical frameworks (Maurer, 2016), and sounds at a fundamental frequency substantially above 350 Hz can no longer be clearly distinguished. However, indications of dependence of F1 on the fundamental frequency of the vowel /a:/ in the last records may prove to be weak, and corresponding observations may require a comparison of sounds with a very extended vocal range (Maurer, 2016).

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