The Effect of Voiceless-Voiced Consonants on Vowel Duration in Arabic

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Abstract

The phenomenon of vowel shortening before voiceless consonants (in contrast to vowel lengthening before voiced consonants) has been reported in many languages. The present study aims at examining the effect of postvocalic voicing of final stop consonants on the preceding vowels in Arabic. The durations of the Arabic vowels /a:/, /u:/ and /i:/ were measured in a CVC context where the final consonant was either /t/ or /d/. Three minimal pairs were read in a carrier sentence by ten native speakers of Arabic (three times each) and 180 tokens were obtained. A spectrogram was obtained for each token, and the duration of each vowel was measured. In addition, the closure durations of the final stops, i.e. /t/ and /d/, were also measured in an attempt to find out any correlation that may exist between the durations of the closure of these stops. The results of the analysis showed that the vowels before /d/ were significantly longer than those before /t/; though the duration difference average was not very long compared to English. As for closure duration, no significant difference was found. These results were discussed in relation to similar findings found in other languages.

1. Introduction

Research on vowel duration has shown that vowels tend to be shorter before voiceless consonants than before voiced ones (see for example Ladefoged and Maddieson, 1996, Reetz and Jongman, 2009, Ladefoged and Johnson, 2011). The phenomenon is claimed to be universally found across languages (Ladefoged and Maddieson, 1996, Maddieson, 1997, Cruttenden, 2008, Raphael et al., 2011); though some researchers have challenged this universality (Keating, 1985, cited in Hardcastle and Hewlett, 1999, Clark and Yallop, 1990). However, it is generally agreed that some extent of vowel difference before voiceless and voiced consonants exists in most languages, and that some languages, e.g. English, have longer durational differences than others (Reetz and Jongman, 2009).

English has been reported to show "unnaturally longer differences" between the durations of vowels preceding voiced and voiceless consonants (Raphael et al., 2011, p.151). This durational difference has been the focus of research in English by many researchers (see for example Fry, 1979, Clark and Yallop, 1990, Bybee, 2004, Cruttenden, 2008, Lodge, 2009, Ogden, 2009, Herd et al., 2010, Ladefoged and Johnson, 2011, among others). It is claimed that vowels in English could be twice as long before voiced consonants than before voiceless ones (Raphael et al., 2011, Ladefoged and Johnson, 2011).

This durational difference is not confined to vowels only. Nasals and liquids, in addition to vowels, seem to undergo the same effect, i.e. they are shorter before voiceless consonants and longer before voiced consonants (Cruttenden, 2008, Davenport and Hannahs, 2005). As for the type of the affecting consonants, both stops and fricatives exert this influence on the preceding vowels and sonorants.

The importance of vowel-duration difference before voiceless and voiced consonants has been tackled from a perceptual viewpoint (Fry, 1979, Port & Dalby, 1982, Bybee, 2004, Raphael, 2005). It has been proposed that this durational difference serves as an acoustic cue signalling the difference between final voiceless and voiced stops and fricatives (Raphael, 2005).

In addition to vowel-duration differences, closure duration has been proposed to correlate with vowel duration. Port and Dalby (1982) suggest that there is a "consonant/vowel ratio [that] serves as a primary acoustic cue for English voicing in syllable final position" (p.144). The present study aims at examining these vowel durational differences in addition to the relation between vowel and closure durations in Arabic, and attempts a comparison with similar findings related to other languages.

1.1 Variables Affecting Vowel Duration

There are certain variables that affect vowel duration in general and controlling these variables is of importance to the present study in order to examine the effect of final voiceless/voiced stop distinction on the preceding vowels. Ladefoged (2001, p.73) shows that vowel length depends on four things: first, the vowel's natural length; secondly, whether the vowel occurs in a stressed syllable; thirdly, the number of syllables in a word; finally the type of the syllable end. Of interest to the present study is the last point concerning what ends a syllable (i.e. a voiceless or a voiced stop in our case). Thus, the other variables are kept constant. The comparisons made in this study employ the same vowels in two different contexts (using minimal pairs with the final stop being either voiceless or voiced). As for the other two variables, all words used are monosyllabic so as to avoid any effect of stress that may exist on other syllables (see 4.1 for more details).

1.2 Vowel Duration vs. Vowel Length

It is found necessary here to present the distinction between the two terms "duration" and "length". A useful explanation is provided by Ashby (2011) stating that:

> The terms *duration* and *length* both refer to how long a particular vowel-sound… lasts. Duration, however, is a physical, measurable and therefore phonetic concept, while length is a perceptual… term" (p.141)

Ashby (2011) adds that the word "length" is "also used by phonologists to refer to the relationship between sounds" (p.141), implying that it is a phonological term, in which case the distinction between "duration" and "length" becomes that of phonetic vs. phonological use of terminology. The same distinction is provided by Lodge (2009) who states that "it is preferable to distinguish between phonological *length* and phonetic *duration*" (p.120); see also Bickford and Floyd, 2006, p.81 and Scobbie and Stuart-Smith, 2008, p.98 for similar views. Ashby (2011), however, uses special terms for shortening of vowel duration in general, calling it "clipping", and the shortening of vowel duration before a syllable final voiceless consonant, calling it "pre-fortis clipping" (p.104). It is this "pre-fortis clipping" that is the main concern of the present study. The two terms "fortis" and "lenis" will be used henceforth in the present study instead of the terms "voiceless" and "voiced", respectively.

2. Aims of the Study

The present study has two aims. The first one is to examine the three Arabic long vowels /a:/, /u:/ and /i:/ before /t/ and /d/ and see whether the durations of the three vowels are shorter before a fortis stop and longer before a lenis one. The second aim is to see whether a correlation exists between the durations of the closure of the following stop consonants by comparing final stop closure durations of the two

stops /t/ and /d/ in an attempt to find a relation between vowel duration and the closure duration of the following stops.

3. Hypotheses

In order to achieve the aims of the study two hypotheses have been tested. The first one is related to vowel duration before fortis and lenis stops. It is hypothesized that vowel duration before a fortis stop is shorter than before a lenis one (or conversely, that vowel duration is longer before a lenis stop than before a fortis one). Thus, the null hypothesis is (H_0:μ1=μ2), where μ1 and μ2 represent vowel durations before /t/ and /d/, respectively; i.e. there is no significant difference between vowel durations before fortis and lenis stops. The alternative hypothesis is (H_1:μ1≠μ2), i.e. there is a significant difference between vowel duration before /t/ and /d/.

The second hypothesis is related to testing whether a correlation is found between the closure durations of fortis and lenis stops. It is suggested that fortis stops have longer closure durations than lenis stops (Raphael, 2005, p.192). Therefore, it is hypothesized that the fortis stop closure duration is longer than that of the lenis one (other things being equal). Thus, the null hypothesis is (H_0:μ3=μ4), where μ3 and μ4 represent closure durations of the final stops /t/ and /d/, respectively; i.e. there is no significant difference of closure durations of the fortis and lenis stops. The alternative hypothesis is (H_1:μ3≠μ4), i.e. there is a significant difference in closure durations of the two stops /t/ and /d/. The level of significance chosen is 0.05 for both hypotheses.

4. Method

A test was conducted in order to obtain vowel and closure durations. The details of the test are presented below.

4.1 Material

The three Arabic long vowels /a:/, /u:/ and /i:/ are used before /t/ and /d/ in three minimal pairs in a CVC context: /qa:t/-/qa:d/, /qu:t/-/qu:d/ and /qi:t/-qi:d/. The reason why the long vowels are chosen is that they provide high probability of detecting any durational difference that may exist in this context; short vowels may not reveal vowel durational differences due to their "natural" short duration (Ladefoged, 2001, p.73; see also section 1.1). It should be noted that the last pair contains nonsense words; this pair is used for the sake of comparison. This pair was taken from the near minimal pair /maqi:t/-/faqi:d/ that was used in order to examine vowel duration in identical contexts (see 4.3 below). A fortis uvula stop, viz. /q/, was used before the vowel in order to facilitate marking the onset of the following vowel. Table 1 includes the test data with their meanings.

Table (1) The data used in the test.

Token	Meaning	Token	Meaning
/qa:t/	type of plant	/qa:d/	(he) lead (v. past)
/qu:t/	food	/qu:d/	(you) drive (v. imperative)
/maˈqi:t/	hateful	/faˈqi:d/	Deceased

The test words were embedded in the carrier sentence /ˈʔana smiʕˈtu:ha _____/ "I heard it (as)_____". All the test words were examined in final position in order to avoid any effect of a following sound on the final stop of the test words which may affect closure duration and/or preceding-vowel duration. A following word would either begin with a fortis sound, a context in favour of the final fortis stop of the test word, i.e. /t/, or a lenis sound, a context in favour of the final lenis stop, i.e. /d/. Thus, the use of the test words in final position would eliminate any

such contextual effects. In addition, the test words were preceded by a vowel in the carrier sentence so as to avoid forming consonant clusters with the initial stop of the test words which could affect vowel duration.

4.2 Subjects

The test subjects were ten native speakers of Iraqi (Mosuli) Arabic (three females and seven males). All of them were educated and their ages ranged between 20 and 45 years. None of them reported any speech disorders.

4.3 Testing Procedure

The test words were printed in Arabic on flash cards (4 cm x 11.5 cm) using Times New Roman with a font size of 100. Each subject was presented with the test words and was asked to familiarize himself/herself with the words. In addition, the researcher explained the need to extract the second syllable in the last two words, i.e. /maˈqi:t/ and /faˈqi:d/ (see Table 1), and obtain the nonsense pair /qi:t/ and /qi:d/ (on separate flash cards) for comparison reasons. This last pair was added to the list of test words. Thus, the total number of flash cards used was eight. Each subject was asked to pronounce each test word in the carrier sentence /ˈʔana smiʕˈtu:ha _____/ "I heard it (as)_____" (see 4.1) when the researcher presented it. The subjects were asked to pronounce the carrier sentence in natural everyday speech without making any pauses between words. The test words were then randomized and presented again to the subject. There were three trials of recording for each subject. Thus, the total number of tokens obtained was 240 (8 words times 3 trials times 10 subjects). However, the tokens of the near minimal pair /maˈqi:t/-/faˈqi:d/ were not included in the analysis of the test, so that the final number of tokens used in the present study was (180). Each subject's performance was recorded individually in a quiet room.

4.4 Equipment

In order to record the test data, a laptop PC was used with a desktop microphone (type Logitech). The recording software used was Praat which was also used for duration measurement. The recording sampling rate was 44100 Hz using a mono channel.

4.5 Acoustic Measurements

Two things were acoustically measured: vowel duration and closure duration. In order to facilitate vowel-duration measurement, the vowel was placed between two stop consonants in a CVC context. The first stop was /q/ and the second stop was either /t/ or /d/. The silence period accompanying the stop articulation was clearly identified on a wideband spectrogram and thus constituted a well-defined border of the beginning and end of the vowel.

For marking vowel onset, the voicelessness period (i.e. aspiration) of the preceding stop /q/ was excluded from the vowel duration. This is because this period of voicelessness may vary considerably and thus affect vowel-duration measurements. Vowel duration was measured starting with the first vertical striation on the wideband spectrogram indicating voicing. The end of vowel duration was marked by the beginning of the closure of the following stop (see Figure 1. For the measured values of all the test words see Appendix 1).

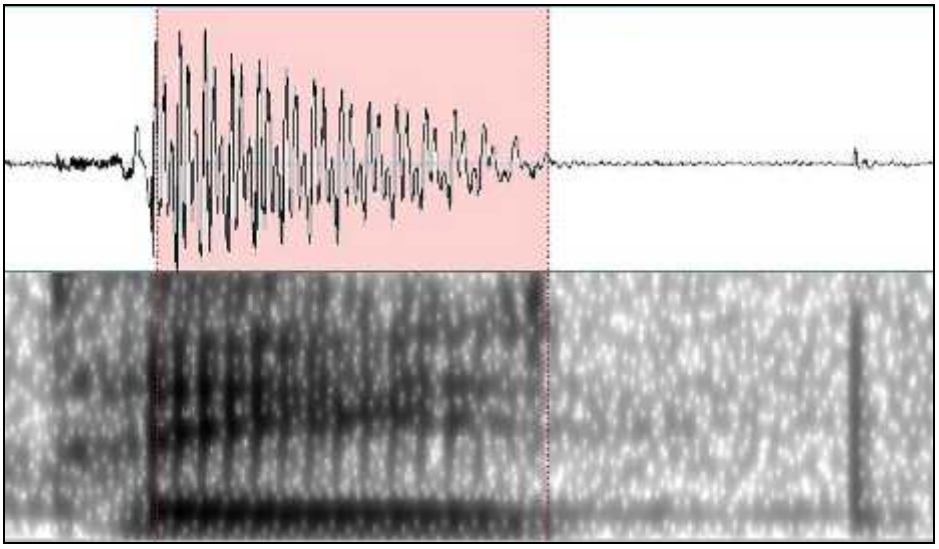

Figure 1. Acoustic measurement of vowel duration when the vowel is followed by the fortis stop /t/ in /qa:t/.

It was noticed that vocal-fold vibration extends from the vowel to the closure of the following lenis stop /d/. In this case the vowel duration end was marked by the absence of the second and third formants (F2 and F3) on the wideband spectrogram, and voicing through the stop closure was excluded (see Figure 2).

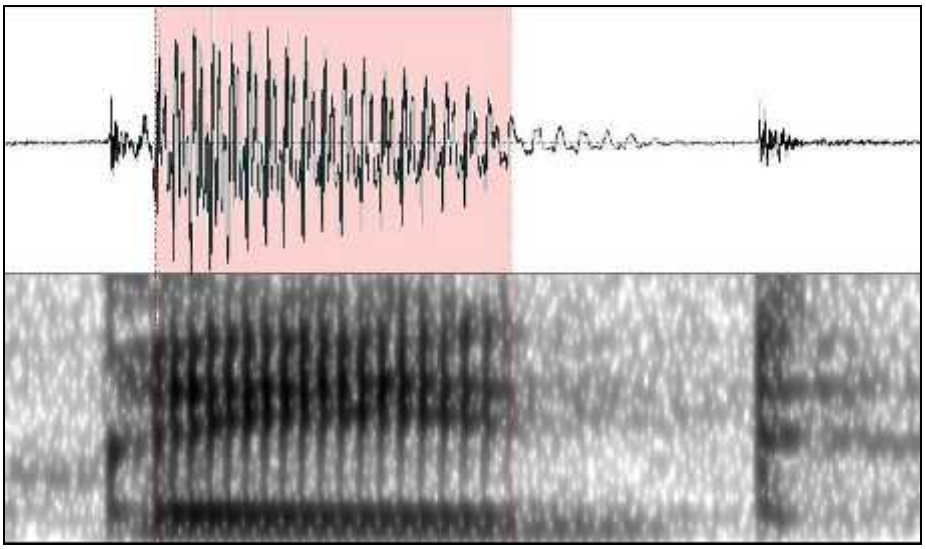

Figure 2. Acoustic measurement of vowel duration when the vowel is followed by the lenis stop /d/ in /qi:d/.

The second type of acoustic measurement was closure duration of the final stop. For this measurement, the vowel duration end was considered as the beginning of the closure duration. The end of the closure duration was marked by the release of the final stop (for the measured values of all the test words see Appendix 2).

It was observed that the final stop was unreleased in the performance of some subjects (see Appendix 2 and Figures 3 and 4). In such cases, closure duration was not obtained. In addition, those tokens containing missing values of the unreleased stops were replaced by the mean values obtained from closure durations for statistical analysis.

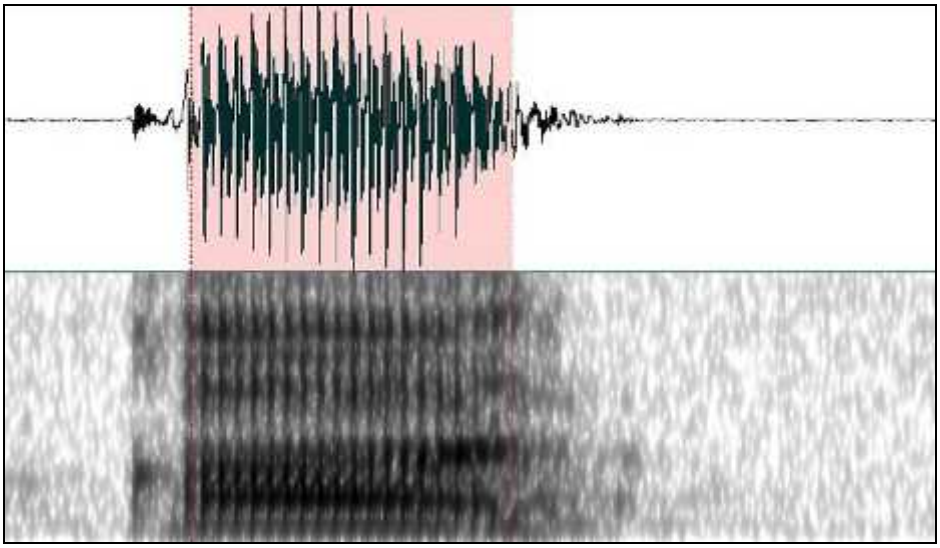

Figure 3. An example of a vowel followed by an unreleased fortis stop in /qa:t/.

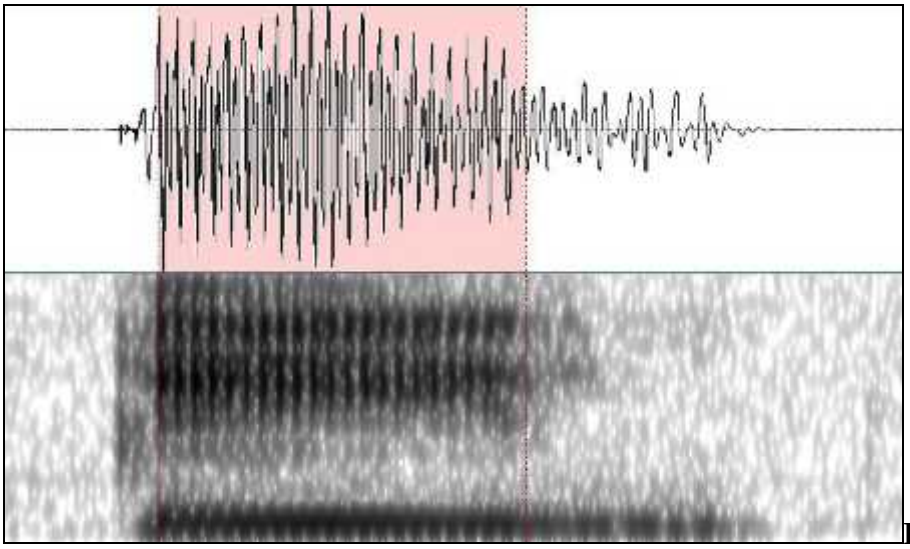

Figure 4. An example of a vowel followed by an unreleased lenis stop in /qi:d/.

5. Results

The results of the statistical analysis of vowel duration and closure duration are presented in the following subsections.

5.1 Vowel Duration

The first part of Table 2 below shows the mean values of vowel durations obtained from the test in addition to Standard Deviation values. A look at the table reveals that the mean values of vowel durations before /d/ are higher than those before /t/. In order to test whether this mean difference is significant a paired-samples T-test was utilized using PASW Statistics 18 (Predictive Analytics Software, formerly known as SPSS, Statistical Package for Social Sciences). The second part of Table 2 shows the statistics of the test result of the comparison.

Table (2) Paired samples statistics and test result of vowel duration comparison.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	qa:t	13.9000	30	3.69856	.67526
	qa:d	15.2333	30	3.95390	.72188
Pair 2	qu:t	13.0333	30	3.44897	.62969
	qu:d	14.5000	30	4.12520	.75315
Pair 3	qi:t	11.8333	30	3.98344	.72727
	qi:d	12.6667	30	4.02863	.73552

Paired Samples Test

		Paired Differences					T	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	qa:t – qa:d	-1.33333	2.26416	.41338	-2.17879	-.48788	-3.225	29	.003
Pair 2	qu:t – qu:d	-1.46667	2.16131	.39460	-2.27371	-.65962	-3.717	29	.001
Pair 3	qi:t – qi:d	-.83333	1.74363	.31834	-1.48441	-.18225	-2.618	29	.014

The significance level values for /qa:t/-/qa:d/, /qu:t/-/qu:d/ and /qi:t/-qi:d/ are 0.003, 0.001 and 0.014, respectively (see the Sig. values in the last column of Table 2). All these values are lower than 0.05 (i.e. the level of significance chosen for testing the hypothesis; see section 3). In this case, the null hypothesis is rejected and the alternative hypothesis

is accepted; i.e. vowel durations before /d/ were significantly longer than those before /t/.

5.2 Closure Duration

The first part of Table 3 shows the mean values and Standard Deviation values obtained for the final stop closure durations. Here, the mean values of the fortis stop closure appear higher than those of the lenis counterpart. In order to test the significance of this mean difference, the paired-samples T-test was used. The second part of Table 3 shows the statistical-analysis results.

Table (3) Paired samples statistics and test result of closure duration comparison.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	qa:t	11.2333	30	2.73777	.49985
	qa:d	10.9333	30	3.20488	.58513
Pair 2	qu:t	10.4000	30	2.51341	.45888
	qu:d	9.7667	30	2.40235	.43861
Pair 3	qi:t	11.7333	30	2.98194	.54442
	qi:d	11.3333	30	4.33378	.79124

Paired Samples Test

		Paired Differences					T	df	Sig. (2-taile)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	qa:t – qa:d	.30000	2.58844	.47258	-.66654	1.26654	.635	29	.531
Pair 2	qu:t – qu:d	.63333	2.25118	.41101	-.20727	1.47394	1.541	29	.134
Pair 3	qi:t – qi:d	.40000	2.88396	.52654	-.67689	1.47689	.760	29	.454

The significance level values obtained for the final stop closure of the three pairs of words /qa:t/-/qa:d/, /qu:t/-/qu:d/ and /qi:t/-qi:d/ are 0.531, 0.134 and 0.454, respectively (see the Sig. values in the last column of Table 3), all of which are higher than the level of significance chosen, i.e. 0.05. Thus, the null hypothesis is accepted concerning closure duration, i.e. there is no significant difference between final stop closure durations of the two stops /t/ and /d/.

6. Discussion

The following subsections present a discussion of the results obtained in this research.

6.1 Vowel Duration

The results of examining vowel duration before fortis and lenis stops show that all the three vowels examined are significantly longer before /d/ than before /t/. This finding goes in line with the same observation made in other languages (see for example Ladefoged and Maddieson,

1996). The durational differences of the three vowels /a:/, /u:/ and /i:/ are 1.33 ms, 1.46 ms and 0.83 ms, respectively (see Table 2). Expressed in ratios, i.e. the mean value of /t/ divided by the mean value of /d/, the durational differences of the three vowels are 0.91, 0.89 and 0.93, respectively. These values are close to those found in other languages. Chen (1970, cited in Hassan, 1981, p.69) investigated vowel-duration differences before fortis and lenis consonants in English, French, Russian and Korean. He found that the ratios of vowel durational differences were 0.61, 0.87, 0.82, and 0.78, respectively. In addition, he reported data from Spanish and Norwegian showing ratio differences of 0.86 and 0.82, respectively. Hassan (1981, p.308) also found significant vowel-duration differences between the two vowels /a:/ and /a/ in Spoken Iraqi Arabic, i.e. /a:/ and /a/ were significantly longer before /d/ than before /t/.

The vowel-duration difference in English is noticed to be much greater than in other languages. Raphael (2005) ascribes this durational difference in English to the enhancement of discriminability of the final fricatives and stops since these consonants are devoiced in final position (p.195). As such, vowel-duration differences play an important role in English. However, the values obtained in the present study are lower than those of English. This suggests that vowel-duration differences, in as much as the data and context investigated in the present study are concerned, may not be utilized in the discrimination of final /t/ and /d/ in Arabic. Thus, though vowel-duration differences seem to be a universal tendency found in many languages, the specific values of the differences seem to vary from one language to another (see Chen, 1970, cited in Hassan, 1981, for a similar view). Stevens (2000, p.574), in discussing contextual effects on vowels, states that “it is expected that the contextual modifications of vowels in a given language are different depending on the inventory of vowels in the

language". These "modifications", including vowel duration, are certainly different between Arabic and other languages, including English. This finding opens a new area for investigating final fortis/lenis stop distinction since this distinction, as the findings of the present study suggest, seems to play different roles in different languages.

One last aspect related to vowel duration is whether the final stop is released or not. It has been suggested that the fortis/lenis distinction of the final stops could be enhanced by the durational differences of the preceding vowel when the final stops are unreleased (Reetz & Jongman, 2009, p.46, Raphael, et al., 2011, p.211). A look at Appendix 2 reveals that the number of tokens of unreleased stops is 10 out of 180 (or 5.5 %). This shows that the majority of the stops in the data examined are released in final position (94.5 %), which means that in Arabic vowel-duration difference does not lead to postvocalic fortis/lenis distinction (as far as the data examined in the present study are concerned). The high percentage of final-stop release may explain the low vowel-duration differences found in the present study.

6.2 Closure Duration

Closure duration has been reported to correlate with the distinction between fortis and lenis stops. Lisker (1957) experimented on the distinction of /p/ and /b/ in intervocalic position and showed that his experiments "point to closure duration as a major cue to the voiced-voiceless distinction in intervocalic stops" (p.47), the closure being longer for /p/. The same observation was also made by Raphael et al. (2011) who stated that "…longer closure durations cue /p,t,k/, the voiceless stops….short closure durations cue the voiced stops, /b,d,g/" (p.216).

Furthermore, Port and Dalby (1982, p.141) suggest that closure duration correlates with vowel duration in that a ratio exists between the consonants and vowels. This closure duration correlation was not found in the data investigated in the present study. Although the mean values of the closure duration for /t/ were found to be higher than those for /d/ (see Table 3), the difference was not found to be significant. However, Hassan (1981, p.308) found a significant difference between final /t/ and /d/ in the two pairs of words /ba:t/ vs. /ba:d/ and /bat/ vs. /bad/. The inconsistency in these findings is also found in a study on vowel and closure durations by Lucy and Charles-Lucy (1985) who show that "differences in the closure durations of the voiced and voiceless stops tend to be small and exhibit considerable variance in production" (p.1956). In addition, Raphael (2005) states that the closure-duration difference in medial position is "more marked than in final position, where the cue is less salient when stops are unreleased" (p.193). The stops examined in the present study were in final position and some of them were unreleased. Therefore, failure to find closure-duration differences could be attributed, mostly, to the position of the stops. The "variance" in closure duration calls for further research to explore the nature of closure duration and its relation to preceding vowels. Lucy and Charles-Lucy (1985) showed that "closure duration *failed* to consistently distinguish voicing categories [emphasis added]" (p.1949).

7. Conclusion

This study investigated the effect of postvocalic fortis/lenis stops on preceding vowel duration in monosyllabic words in Arabic. The results of the investigation showed that vowels before /d/ were significantly longer than before /t/, indicating that Arabic is similar in this respect to many languages in which this phenomenon of vowel-duration differences occurs. Final stop-closure duration was also

examined to see whether a correlation is found between the closure durations of fortis and lenis stops. The result of the examination showed no significant difference. Closure-duration differences seem to require further research since the results of the present study differ from those of other studies.

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Appendix 1. Durations of the three vowels /a:/, /u:/ and /i:/ (in ms.). S=subject, T=token

		S1			S2			S3			S4			S5			S6			S7			S8			S9			S10		
		T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	/qa:t/	19	20	17	17	17	16	13	16	13	13	9	9	9	10	11	12	11	10	14	17	16	12	14	13	10	20	20	9	9	12
2	/qa:d/	18	20	19	15	18	17	12	16	14	17	13	10	13	10	11	14	13	11	17	18	18	16	15	15	18	20	17	10	11	12
3	/qu:t/	15	17	21	15	18	17	11	13	10	13	8	10	8	9	10	11	11	10	13	14	13	11	13	12	16	18	16	10	11	11
4	/qu:d/	18	19	20	18	20	18	10	12	14	19	13	9	11	11	10	11	11	10	13	18	14	13	14	10	22	20	23	12	11	13
5	/qi:t/	13	16	12	15	14	16	10	8	11	9	9	5	9	7	8	6	10	8	8	13	16	16	14	10	12	22	18	19	10	11
6	/qi:d/	10	18	15	17	17	17	9	10	11	9	7	8	10	8	8	11	10	9	13	17	15	12	11	12	19	18	22	12	13	14

Appendix 2. Closure durations of the final stops (in ms.). S=subject, T=token, n/r= no release

		S1			S2			S3			S4			S5			S6			S7			S8			S9			S10		
		T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	/qa:t/	15	14	12	9	13	15	15	n/r	14	14	13	15	6	7	6	9	10	10	n/r	10	12	10	10	7	13	10	8	12	13	13
2	/qa:d/	12	13	12	13	13	18	15	18	15	14	11	11	7	8	6	8	6	6	n/r	12	n/r	10	9	n/r	7	12	9	11	11	11
3	/qu:t/	10	15	10	14	9	10	n/r	15	12	14	12	13	9	9	6	9	12	13	n/r	11	8	8	7	7	9	9	10	11	11	10
4	/qu:d/	14	10	10	12	10	9	15	13	12	15	12	10	7	8	9	9	9	10	8	9	8	10	8	6	9	8	7	13	11	10
5	/qi:t/	14	13	11	13	10	11	17	22	14	12	12	13	8	8	10	8	9	13	15	n/r	11	10	11	10	8	10	9	12	12	13
6	/qi:d/	10	14	13	12	11	9	11	32	13	11	10	14	7	7	8	9	9	10	n/r	10	9	12	12	n/r	12	10	8	10	12	13

تأثير الأصوات الصحيحة المهموسة والمجهورة على مدة أصوات العلة في اللغة العربية

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الملخص

شوهدت في العديد من اللغات ظاهرة تقصير مدة الصائت (vowel) عندما يكون متبوعاً بأصوات صامتة مهموسة (voiceless consonants) (أو على العكس إطالة مدة الصائت عندما يكون متبوعاً بأصوات صامتة مجهورة voiced consonants). تهدف الدراسة الحالية الى فحص تأثير الأصوات الصامتة الانفجارية من حيث الهمس و الجهر في ما يسبقها من صوائت في اللغة العربية عندما تكون هذه الأصوات في نهاية الكلمة. قيست مدد الصوائت العربية /a:/ و /u:/ و /i:/ في السياق (CVC) و كان الصوت الأخير في هذا السياق /t/ أو /d/. اختيرت ثلاث ثنائيات صغرى (minimal pairs) وقرأها عشرة أشخاص من الناطقين باللغة العربية (ثلاث مرات لكل واحد منهم)، فحصلنا على ١٨٠ نموذج (tokens). قيست مدة كل صائت باستخدام التحليل الطيفي (spectrogram) لكل نموذج، فضلا عن قياس مدة الإغلاق (closure duration) للأصوات الصامتة الإنفجارية المنتهية بها الكلمات في محاولة لإيجاد ارتباط بين مدد الإغلاق للأصوات الإنفجارية الصامتة المجهورة والمهموسة. بينت نتائج الدراسة أن مدد الصوائت المتبوعة بصوت الـ /d/ كانت أطول من تلك المتبوعة بصوت الـ /t/، في حين لم يكن هناك أي فرق ذي دلالة إحصائية بين مدد الاغلاق للصوتين /t/ و /d/. نوقشت هذه النتائج مع نتائج مشابهة حصل عليها باحثون آخرون في لغات مختلفة.