Secondary Tongue Retraction in Arabic Emphatics: An Acoustic Study

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Abstract

This study provides an acoustic investigation of the secondary articulation of Arabic emphatic sounds. The study observed seven male Arabic speakers from four dialects to investigate F1 and F2 of /aː/, /iː/ and /uː/ in emphatic and non-emphatic environments in 501 monosyllabic words. A repeated-measures ANOVA was conducted to examine the main and interaction effects of emphasis with consonant, vowel, and position factors. Regardless of the inter-subject variability, the Gaussian classification model shows limited differences among subjects.

Index Terms: Arabic, dialect, emphatics, formants

1. Introduction

In standard Arabic, the emphatic coronal consonants include /ṭ/, /ṣ/, /ḍ/, and /ẓ/ contrasted with /t/, /s/, /d/, and /ð/ respectively. Examples of minimal parts are /ṭaːb/ 'covered'vs. /taːb/ 'repented', and /ṣaːb/ 'targeted'vs. /saːb/ 'left'. Most of the Arabic dialects have at least three of these consonants and sometimes they have more than four. These sounds are produced with a primary articulation that involves the front of the tongue and a secondary articulation that involves the back of the tongue. Phonetically, the exact nature of the secondary articulation is subject to some controversy. Previous studies report articulatory correlates such as pharngealization [1, 2, 3] and uvularization [4, 5, 6], and other studies report that these sounds are characterized with both [7]. They are also phonologically problematic as they have been grouped with the guttural class [1, 4, 8] while other studies [9, 10] exclude them from such a class.

Acoustically, most previous studies [4, 6, 7, 9] attest that the acoustic correlates of emphatics are lowering F2 and raising F1 of the adjacent vowels. However, at least one study reported no significant raising of F1 [11]. This study reports on the acoustic properties of the emphatic consonants /ṭ/ and /ṣ/ on the neighboring long vowels /aː/, /iː/, /uː/ using seven native speakers of Arabic. The present study is a part of a wider investigation of the acoustic properties of the emphatics, uvulars and pharyngeals and the articulatory mappings of these sounds using ultrasound.

2. Method

2.1. Subjects

Seven male native speakers of Arabic participated in this study. Due to the lack of speakers from a single Arabic variety at the time of the data collection, the speakers were from four Arabic dialects: 2 Yemeni, 1 Jordanian, 2 Palestinian and 2 Egyptian. All Arabic dialects have the three long vowels /aː/, /iː/, and /uː/, and they also make use of the emphatic stop /ṭ/ and the emaphatic fricative /ṣ/ [12]. The Egyptian speakers were all from Cairo; the Palestinians were from north Palestine, the Jordanian speaker was from Amman, and the Yemeni speakers were from Dhamar. All the speakers were living within New Zealand, and they were recorded in Christchurch. All had been in New Zealand for less than five years and they did not have speech or hearing impairments. The speakers were in their mid-twenties and early thirties.

2.2. Stimuli

The target sounds to be investigated were /ṭ/ and /ṣ/ compared to /t/ and /s/ in monosyllabic words of the form CV:C. The three vowels /aː/, /uː/, /iː/ were either preceded or followed by the emphatic or the nonemphatic consonants. The total number of the words is 24 and each word was repeated three times in the carrier phrase [ɡaːlu................marratajn] "they said........twice". The speakers used their local varieties to read the words and there are slight variations in the first sound of the first phrase and the vowel in the last syllable of the second phrase. For example, the Egyptian and Palestinian speakers pronounce the /ɡ/ as /ʔ/.The vowel in the third syllable of the second phrase is pronounced as /eː/ and /iː/ by the Palestinian and Egyptian speakers, respectively. The total tokens for /aː/, /iː/ and /uː/ were 168, 168, and 165 respectively. Three tokens of /uː/ were not clear enough to be analyzed.

2.3. Procedures

The words were audio recorded simultaneously with ultrasound recording at the University of Canterbury in Christchurch, New Zealand. The audio was collected from the microphone of the SONY camera recording. Due to the interference from ultrasound, the resulting signals were very noisy, so no analysis of high frequency sounds was possible. Fortunately, the acoustic energy of the first two formants for the vowels being investigated was less than 2500 Hz, allowing a formant analysis to be performed. The audio files were stored as .wav files digitized at 44.1 KHz. Praat [13] was used for labelling and segmenting the vowels. To calculate the formant values and to create vowel spaces for the speakers, Emu and the EmuR package [14], and ggplot2 package [15] were employed. The statistical procedures were performed using R [16].

Visual inspection for formant tracks was performed for all of the data. There were errors in formant tracking due to the low amplitude of the high vowels /uː/ and /iː/, making it difficult for the automatic formant tracker to track acoustic energy. Hand correction was applied by redrawing the formant tracks for F1 and F2 based on a closer examination of the spectrogram of the vowels; 38% of the data was corrected. With regard to F3, it was difficult to redraw the formant track due to the high noise in the audio signal; therefore, this formant is excluded from the analysis. Based on the default setting in the formant tracker in Emu [14], formant values were calculated for the midpoint of the vowel identified, which is assumed to represent the steady state of the vowel.

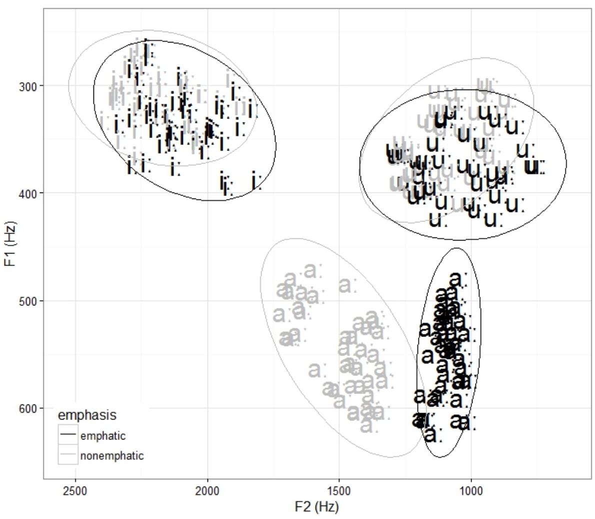

Figure 1: *F1-F2 of the vowels /aː/, /iː/ and /uː/ following the emphatics /ṭ/ and /ṣ/, and non-emphatics /t/ and /s/.*

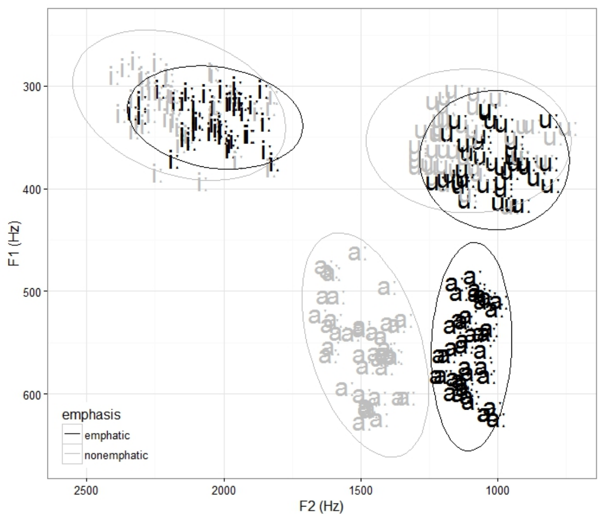

Figure 2: *F1-F2 of the vowels /aː/, /iː/ and /uː/ preceding the emphatics /ṭ/ and /ṣ/, and non-emphatics /t/ and /s/.*

3. Results

Table 1 shows the means for F1 and F2 of the vowels /aː/, /iː/, /uː/ preceded and followed by the emphatics /ṭ/ / and /ṣ/ and non-emphatics /t/ and /s/. The F1 means indicate that it is relatively higher in the emphatic context compared to the non-emphatic environment. F2 of /aː/ before or after the emphatics is substantially lower than F2 of /iː/ and /uː/. The plots in Figures 1 and 2 show the distribution of /aː/, /iː/, and /uː/ in the emphatic and non-emphatic conditions for all speakers in the CV and VC context respectively. The y axis represents F1 and the x axis represents F2. The distribution of the vowels in Figure 1 and Figure 2 exhibits the same behavior, where /aː/ before or after the emphatics has the greatest backing compared to the other vowels.

Table 1: *F1 and F2 means of the vowels for all speakers (E= emphatic, N= non-emphatic).*

	F1		F2	
vowel	E	N	E	N
/aː/	551	548	1090	1484
/iː/	332	315	2059	2166
/uː/	373	352	1021	1100

A series of three-factor ANOVA with repeated measures was performed to test the main and interaction effects of the independent variables (emphasis, vowel, position, and consonant type) on the dependant variables F1 and F2. The factors with 2 degrees of freedom or more need to be tested for the Sphericity assumption, which states the variances of the differences between all possible combinations of groups (levels) are equal. Whenever the assumption of Sphericity was violated, Huynh-Feldt and Greenhouse-Geisser corrections were applied on degrees of freedom and p-value for all within-subject comparisons. The first repeated measures ANOVA was conducted to test the main and interaction effects for the emphasis, vowel and position factors on the dependent factors, F1 and F2. Apart from the highly significant effect of the vowel on F1 (F (2, 12) =190.0, $p[GG] < 0.00$) and F2 (F (2, 12) =215.2, $p[GG] < 0.00$), the result shows that emphasis has a significant effect on both formants (F1: F (1, 6) =13.0, $p < 0.01$, F2: F (1, 6) =187.0, $p < 0.00$). There is also significant two-way interactions by emphasis and vowel relating to F2 (F (2, 12) =27.1, $p[GG]$ <0.00). As for the position factor, there was no significant effect and there were no other interaction effects upon F1 and F2.

The second repeated measures ANOVA was conducted to assess the main and interaction effect of emphasis, vowel and consonant type on the dependent variables F1 and F2. Similar to the previous test, the significant effect of vowel on F1 (F (2,12)=191.5, $p[GG]$ <0.00) and F2 (F (2,12)=222.2, $p[GG] <$ 0.00) was to be expected since there are three different vowels. The main effect of the emphasis factor is significant on raising F1 (F (1, 6) =12.3, p <0.01), but it does not interact significantly with the other factors. Concerning F2, emphasis lowers F2 significantly (F (1, 6) =140.4, p <0.00) and it interacts significantly with the vowel factor (F (2, 12) =26.1, $p[GG]$ <0.00). No other significant main and interaction effects were related to F1 and F2. It is important to note that standard two-way ANOVAs were conducted to determine if the subject variable has effects on F1 and F2 and whether it interacted with emphasis; the results show no significant main or interaction effects upon F1 and F2.

Since emphatics have a significant effect on the two formants, a post-hoc evaluation was carried out to investigate the effects of the emphatic consonants on the two formants of each preceding and following vowel /aː/, /iː/, and /uː/ compared to the formants of these vowels preceding or following the non-emphatic consonants. As illustrated in Table 2, the results indicate that there is a highly significant difference between /aː/ in the emphatic and non-emphatic environment related to lowering F2. Similarly, emphatics cause significant lowering of F2 for the high vowels /iː/ and /uː/ compared to the non-emphatics. F1 is not significantly raised for the low vowel /aː/ when preceded or followed by the emphatic. However, F1 of the high front vowel /iː/ is significantly raised when adjacent to emphatics compared to the non-emphatics. Raising of F1 is also significant in the case of the high back vowel /uː/.

To show there were no dialect effects in the result, an open test Gaussian classification was conducted. On the basis of F1 and F2, the three vowels were categorized as emphatic and

Table 2: *Significant effects of emphatics on raising F1 and lowering F2 of the adjacent vowels (E= emphatic, N= non-emphatic)*

	F1	F2
vowel	E-N	E-N
/aː/	$t(6)$=-0.3 p = .200	$t(6)$=9.1 p < .000
/iː/	$t(6)$=-5.5 p < .004	$t(6)$=4.0 p < .020
/uː/	$t(6)$=-4.2 p < .016	$t(6)$=3.5 p < .036

non-emphatic. Since the experiment employed seven speakers from four dialects, a "round-robin" procedure was performed in which the tokens from a single speaker were used as a test set and the tokens for other speakers were considered as the training set. In Table 3, the Yemeni speaker YEM02 was tested against the remaining 6 speakers. As illustrated below, the diagonals represent the correct classification while other cells show the misclassifications. For example, the emphatic /aː/ was correctly classified with 100% reliability, and there were no misclassifications. The same result obtains with the non-emphatic /aː/. However, the classification rate of /iː/ in the emphatic and non-emphatic environments was 66% and 76% respectively. Finally, the hit-rate was 58% for the emphaic /uː/ whereas it was 91% for the non-emphatic condition. The overall hit rate across all vowel categories is 81% with correct separation. The same procedure was repeated with all of the speakers in turn and Table 4 presents the overall classification. The hit-rate per vowel class is 98%, 70%, and 61% for the emphatic /aː/, /iː/ and /uː/ and 100%, 61% and 71% for the non-emphatic /aː/, /iː/, and /uː/ respectively. This result indicates that regardless of the different speakers, the vowels were 77% classified correctly on the basis of emphasis.

Table 3: *Classification for YEM02 (E= emphatic, N= non-emphatic).*

		/aː/		/iː/		/uː/	
		E	N	E	N	E	N
/aː/	E	12	0	0	0	0	0
	N	0	12	0	0	0	0
/iː/	E	0	0	8	4	0	0
	N	0	0	3	9	0	0
/uː/	E	0	0	0	0	7	5
	N	0	0	0	0	1	11

Table 4: *Classification for all the speakers (E= emphatic, N= non-emphatic).*

		/aː/		/iː/		/uː/	
		E	N	E	N	E	N
/aː/	E	83	01	0	0	0	0
	N	0	84	0	0	0	0
/iː/	E	0	0	59	25	0	0
	N	0	0	32	52	0	0
/uː/	E	0	0	0	0	50	31
	N	0	0	0	0	24	60

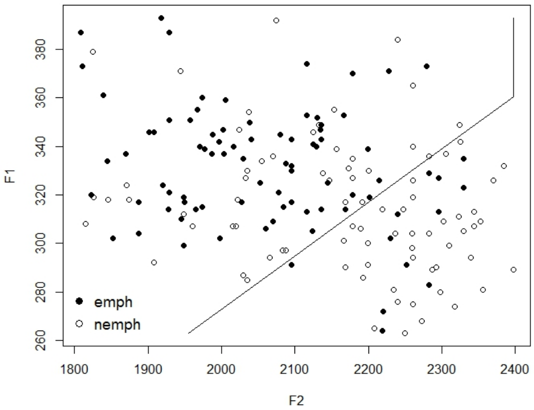

Figure 3: *Scatter plot of F1 and F2 of /iː/ with a discriminant line in the emphatic (emph) and non-emphatic (nmph) environments .*

4. Discussion

The goal of this study was to investigate the midpoint of F1 and F2 for the long vowels (/aː, iː, uː/) preceding and following the emphatics compared to the non-emphatics. The acoustic results of the repeated measures ANOVAs suggest that the emphatic consonants have distinctive coarticulatory effects on the adjacent vowels compared to the non-emphatic consonants across the speakers of the four Arabic dialects (Yemeni, Palestinian, Jordanian and Egyptian). The acoustic study supports earlier studies in that the most salient acoustic feature of the emphatics is lowering F2 [4, 6, 7, 9, 10, 17]. The significance level of the lowering F2 depends on the vowel type. The greatest lowering of F2 occurs with the low vowel /aː/ as shown in Table 1, followed by the high front /iː/ and the high back /uː/. To illustrate, data in Figures 1 and 2 show that the distribution of /aː/ in the emphatic environment is more tightly clustered than the other two vowels, and there is also less overlap. The ANOVAs indicate that the lowering of F2 in the vowels /aː/ and /iː/ can be considered a reliable indicator for the presence of an emphatic consonant. Because a high back vowel /uː/ has a low F2, the impact of emphasis is less.

Although it has been reported that F1 bears no cues for emphasis[11], the present study shows that it is relatively raised in the context of emphatics. Raising F1 is not as salient and systematic as F2. For example, unlike [4] and [6], the repeated measures ANOVA shows that raising F1 is not significant when the low vowel /aː/ is adjacent to the emphatics. With respect to the high vowels /iː/ and /uː/ and similar to [6], the repeated measure and post-hoc tests show that F1 is raised significantly when neighbouring the emphatics. However, when a scatter plot of the /iː/ tokens for all the speakers with a discriminant line as in Figure 3 is observed, the F1 of /iː/ demonstrates less contribution to the classification of the emphatics and non-emphatics. In the case of /uː/, F1 has equal contribution with F2 in categorizing the emphatics and non-emphatics as in Figure 4.

The acoustic findings of this study could be mapped to the behaviour of the tongue dorsum and tongue root. For example, it might be expected that the greater lowering of F2 in /aː/ be mapped to the substantial backing of the tongue dorsum in emphatic contexts. Backing of /iː/ is significant, but limited since

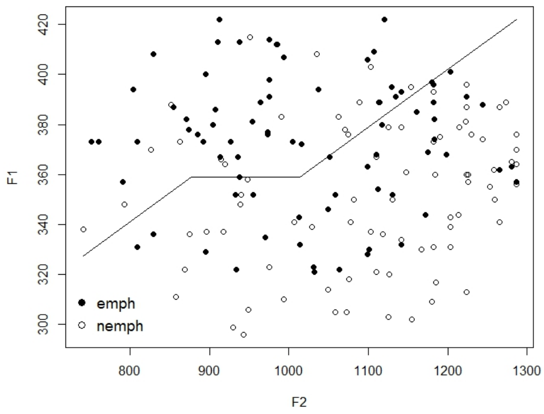

Figure 4: *Scatter plot of F1 and F2 of /uː/ with a discriminant line in the emphatic (emph) and non-emphatic (nmph) environments .*

the high front vowel requires fronting of the tongue body. Such a gesture is antagonistic to the tongue dorsum retraction. With regard to /uː/, the tongue body movement required for this vowel and emphatics are similar as both require tongue dorsum retraction. Hence, the effect of emphatics on this vowel would be less pronounced than in other vowels. Considering the relative rise of F1, it indicates the involvement of tongue root retraction, and such an activity would not be salient and consistent during the articulation of the emphatics. We expect that the tongue root retraction has no role in categorizing the emphatic and non-emphatics in case of the low vowel. In case of the high front vowel, tongue dorsum retraction exhibits more contribution to the classification of this vowel in the emphatic and non-emphatic conditions. Finally, based on the scatter plot, the categorization of the high back vowel in both conditions indicate the involvement of both gestures: tongue dorsum retraction and tongue root retraction.

A recent study [6] reports emphatic stops have a greater effect on adjacent vowels compared to the emphatic fricatives. However, the results of this study show no significant difference between the long vowels when preceded or followed by the emphatic stop and emphatic fricative. While [6] shows that the emphatics in word-final position have a greater effect on the vowels than the emphatics word-initially, the results of this study show that the position of the emphatics initially or finally in the monosyllabic words has a similar effect on adjacent vowels. This acoustic study partially supports the suggestions of [7] that the vowels in the emphatic context undergo two processes: uvularization and pharyngealization. According to [7], only the low vowel undergoes uvularization; however, the current acoustic study shows that the articulation of the vowels /iː/ and /uː/ in the emphatic environment involves consistent tongue dorsum retraction. With respect to pharngealization, [7] reports that only short vowels are pharyngealized, but the current study suggests that long vowels undergo pharyngealization when adjacent to the emphatics.

5. Conclusion

Emphatics are characterized with acoustic effects that are different from the non-emphatics. Lowering F2 and raising F1 are the acoustic attributes of these sounds and based on the behaviour of these two formants, the acoustic results suggest that these sounds are articulated with the tongue dorsum and tongue root retraction. These sounds are categorized well by tongue dorsum retraction represented by the consistent lowering of F2 for all the adjacent vowels. Although F3 may provide valuable information about the articulation of the emphatics, it was not investigated in this study. While [18] reports that F3 is not affected by emphasis, [6] suggests that a raised F3 in the emphatic context indicates that these sounds are uvularized. The third formant of the vowels preceded by the emphatics, uvular and pharyngeal consonants will be discussed in future research. The acoustic results will be then mapped to the tongue dorsum/root retraction of these sound groups using ultrasound.

6. References

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