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An Acoustic Analysis of Pharyngeal and Emphatic Consonants in Iraqi Arabic

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An Acoustic Analysis of Pharyngeal and Emphatic Consonants in Iraqi Arabic

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Abstract

An Acoustic Analysis of Pharyngeal and Emphatic Consonants in Iraqi Arabic

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Emphatic consonants in Arabic are coronal obstruents with a secondary articulation. The exact place of the secondary constriction is debated, though these consonants are often said to be pharyngealized. The emphatic consonants contrast with plain coronal obstruents and pharyngeal fricatives. Emphatic consonants also affect adjacent and non-adjacent vowels through a process of emphasis spread, usually by F1 raising and F2 lowering. A production experiment in Iraqi Arabic examined the acoustic patterns of plain, emphatic, and pharyngeal consonants and adjacent vowels. Acoustic measurements of the first and second formants of the low vowel /a/ and the high front vowel /i/ before and after the consonant were analyzed, as well as center of gravity of the fricatives. This experiment found that F1 was higher adjacent to pharyngeal and emphatic consonants than adjacent to plain consonants. F2 was lower adjacent to emphatic consonants than adjacent to plain and pharyngeal consonants. These results suggest some similarities in the articulation of pharyngeal and emphatic consonants, but that emphatic consonants have a slightly different constriction for the secondary articulation than the constriction

for pharyngeal consonants. Vowels adjacent to pharyngeal consonants also did not have the characteristic F2 lowering associated with emphatic consonants and emphasis spread. The center of gravity of pharyngeal /ħ/ was lower than the center of gravity for plain /s/ and emphatic /$s^ʕ$/, but there was no difference in the center of gravity values for the plain and emphatic fricatives. Combined with the F2 lowering of vowels adjacent to emphatic consonants, this suggests that the perception of emphatic consonants may be primarily triggered by the adjacent vowel, not the consonant itself. The results of this experiment motivate future analyses of the relationship between the effects of emphatic consonants on adjacent vowels and the perception of emphatic consonants.

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1 Introduction

One typologically unusual feature of Arabic is the class of coronal obstruents with a secondary articulation, which are traditionally called *emphatic* consonants (Watson 2007). There is a debate on the exact nature of the secondary articulation, with some arguing that they are uvularized (Jongman et al 2011, Zawaydeh 1990) while others claim that they are pharyngealized (Davis 1995, Embarki et al 2007, Watson 1999). The emphatic coronals contrast with plain (non-pharyngealized) coronal obstruents with the same primary place, manner, and voicing, as shown by minimal pair /ʕaduː/ "enemy" and /ʕadˤuː/ "member" (Wehr 1994). Recent studies of Iraqi (Hassan and Esling, 2011), Jordanian (Al-Masri and Jongman, 2004; Al-Tamimi and Heselwood, 2011; Jongman et al, 2011; Khattab et al, 2002; Zawaydeh, 1997), Palestinian (Card, 1983), and across Moroccan, Kuwaiti, Jordanian, and Yemini Arabic (Embarki et al, 2007; Embarki et al, 2011) have shown that emphatics affect vowels immediately adjacent to the consonant in a manner that correlates with lower F2 values in comparison to vowels adjacent to plain consonants. Emphatic consonants are also associated with higher F1 values in adjacent vowels, primarily in Jordanian Arabic (Al-Tamimi and Heselwood, 2011; Jongman et al, 2011; Zawaydeh, 1997). For example, in the word for *he fasted* /sˤaːm/ (Erwin, 1969), the low phonemic vowel /a/ is produced as back [sˤɑːm] due to the emphatic consonant, in contrast with the same vowel in [saːm] 'he priced'. The backing is most audible with the low vowel /a/ and many studies have focused on this vowel, but it is unclear if these consonants affect the other vowels similarly. Arabic also has primary pharyngeal consonants that are produced exclusively in the pharynx, without the primary coronal constriction of emphatics. These consonants provide a contrast to emphatic consonants which may share a pharyngeal, but not coronal, place. They are acoustically distinct from emphatic consonants in terms of the Center of Gravity (CoG) of the consonant (Norlin 1983), but they may have similar effects on neighboring vowels as a result of the pharyngeal constriction (Hassan and Esling 2011).

The current study seeks to expand the body of knowledge about emphatic consonants and their effects on adjacent vowels by examining how emphatic consonants affect different adjacent vowels, focusing on short low /a/ and high front /i/. These effects of emphatic consonants will be compared to the effects of plain coronals and pharyngeal fricatives to examine the similarities and differences between pharyngeal and emphatic consonants, which are often claimed to be pharyngealized. Pharyngeal and emphatic consonants are also said to be part of the same phonological class (Watson 2007), and would therefore be expected to have similar effects on adjacent vowels. This paper explores the effects of emphatic consonants on high front /iː/ and low /aː/ in Iraqi Arabic, since this topic has not been extensively studied in this dialect, even though the effects of emphatic consonants are highly audible in regular speech.

This research is a step towards a quantitative account of the effects of pharyngeal and emphatic consonants on neighboring vowels in Iraqi Arabic, leading to a better understanding of coarticulation and assimilation. A production experiment was conducted to examine the acoustics of vowels adjacent to plain, emphatic, and pharyngeal consonants, as well as the CoG of the fricative consonants. The effects of the position of the vowel relative to the consonant, of the manner of the consonant, and of the type of vowel were also examined. In Section 2, I discuss previous research that has been done on these consonants and adjacent vowels. In Section 3, I discuss the methods used in the experiment. In Section 4, I investigated the effects of emphatic consonants, the manner of the target consonant, and the position of the vowel on the F1 and F2 of the adjacent low vowel /a/. In Section 5, I analyze the effects of emphatic consonants and the manner of the consonant on the vowels /a/ and /i/ that preceded the target consonant. In

Section 6, I discuss the effects of plain, emphatic, and pharyngeal fricatives on adjacent vowels. In Section 7, I analyze how the primary and secondary place of articulation affect the CoG of voiceless fricatives to compare the acoustic affects of pharyngealization in these types of consonants. The relationships between the results of these four experiments provide a more complete analysis of plain, emphatic, and pharyngeal consonants on adjacent vowels.

2 Background

2.1 Emphatic Consonants in Different Arabic Dialects

The current experiment examines the effects of emphatic consonants on adjacent vowels in Iraqi Arabic. All dialects of Arabic have a contrast between plain and emphatic consonants, but the number of emphatic phonemes varies by dialect (Watson 2007). Iraqi Arabic has three emphatic consonants /sˤ tˤ ðˤ/ which contrast with plain /s t ð/ (Erwin, 2004; Maamouri, 2013; Qafisheh 1979), as shown in **Table 1**. This dialect also contains the pharyngeal fricatives /ħ/ and /ʕ/, which provide a contrast to plain and emphatic consonants because these sounds may share a pharyngeal place with the emphatic consonants, but lack a coronal constriction.

		Bilabial	Labiodental	Interdental	Plain Coronal	Emphatic	Alveo-Palatal	Velar	Uvular	Pharyngeal	Glottal
Stops	vl vd	(p) b			t d	tˤ dˤ		k g	q		
Fricatives	vl vd		f	θ ð	s z	 ðˤ	ʃ	x ɣ		ħ ʕ	h
Affricates	vl vd						tʃ dʒ				
Nasals	vd	m			n						
Laterals	vd				l	(lˤ)					
Tap	vd				ɾ						
Glides	vd	w					j				

Table 1 Iraqi Consonant Inventory[1] (Maamouri, 2013; Qafisheh, 1979)

This dialect has an audible effect of emphatic consonants, which is more likely to be observable than in other dialects. The current study focuses on the production of vowels adjacent to emphatic consonants /tˤ/ and /sˤ/ and the contrasting plain consonants /t/ and /s/, as well as pharyngeal /ħ/. The study was restricted to one dialect because of the dialectal variation in the

[1] Marginal phonemes are in parentheses

acoustic effects of emphatic consonants on adjacent vowels. Eastern dialects, including Gulf Arabic, have a smaller change between the steady state and transition of a vowel adjacent to an emphatic consonant in comparison to Moroccan Arabic (Embarki et al 2011). Crucially, these differences mean that what is true for one dialect cannot be assumed to be true in another dialect without evidence supporting that conclusion.

2.2 Vowels Adjacent to Plain and Emphatic Consonants

Research on emphatic consonants has focused on the differences between the formants of vowels adjacent to emphatic consonants and of vowels adjacent to plain coronal consonants. The F2 values of vowels adjacent to emphatic consonants have been found to be lower throughout the duration of the vowel, including at the midpoint, than in vowels adjacent to plain coronal obstruents in most dialects, including Iraqi (Hassan and Esling 2011), Jordanian (Al-Masri and Jongman, 2004; Al-Tamini and Heselwood, 2011; Embarki et al, 2007; Embarki et al, 2011; Jongman et al, 2011; Khattab et al, 2002; Zawaydeh, 1997), Moroccan (Embarki et al, 2007; Embarki et al, 2011), and Palestinian (Card 1983) Arabic. Lower F2 values are the most well-studied cue of emphatic and pharyngeal consonants, because their acoustic effects on adjacent vowels suggest that they are produced with constriction around the pharynx (Jongman et al 2017).

Vowels adjacent to emphatic consonants are also reported to have higher F1 values than vowels adjacent to plain coronals, but this distinction has not been found as consistently as F2 lowering in vowels adjacent to emphatics. In Jordanian Arabic, Al-Tamini and Heselwood (2011) found higher F1 values in vowels adjacent to emphatic consonants, while Khattab et al (2002) did not. In the same dialect, Jongman et al (2011) found effects of F1 at the midpoint of the vowel and the onset of the vowel from the emphatic consonant, but not at the offset away from the emphatic consonant. Within Iraqi Arabic, F1 was not previously found to be significantly lower adjacent to emphatic consonants (Hassan and Esling 2011), but the variation among dialects and the contrast with pharyngeals supported analyzing F1 in the current study (see Section 2.3).

Previous work has also found that the manner of the consonant can effect the extent of the effects of that consonant on adjacent vowels. Jongman et al (2011) found lower F2 values in vowels adjacent to emphatic stops than in vowels adjacent to emphatic fricatives, suggesting that the effect of emphatic consonants on neighboring vowels was more pronounced with emphatic stops than with emphatic fricatives. The corresponding plain coronals did not vary in their effects on the neighboring vowels. The emphatic voiceless fricative /sˤ/ has been found to have the least amount of pharyngeal constriction (Al-Tamimi and Heselwood 2011) which may contribute to this difference. The differences found in these studies support the examination of the effect of consonant manner on vowel formants in the current study. Coupled with acoustic analyses of the emphatic consonants themselves, examining these effects will improve our understanding of the articulation of emphatic consonants.

The vowel quality affects the formant structures of vowels adjacent to emphatic consonants, due to inherent differences in formants between vowels (Jongman et al, 2011; Peterson and Barney, 1952). Iraqi Arabic has five vowel qualities, with long and short vowels (**Figure 1**). High front /i/ has a low F1 and a high F2, while back /u/ has a low F1 but also a low F2. Low /a/ has a higher F1 than /i/ or /u/, but intermediate F2 values. However, the quality of a vowel may limit the effects of emphatic consonants on vowel formants. Jongman et al (2011) found that F1 values of /a/ adjacent to emphatic consonants were significantly higher than the F1 of /a/ adjacent to plain consonants. The F1 of /i/ adjacent to emphatic consonants was not significantly higher than the F1 of /i/ adjacent to plain consonants. This pattern suggests that the F1 of the high vowel /i/ was not affected by emphasis. The F2 of /a/ and /i/ adjacent to emphatic consonants were both lower than the same vowels adjacent to plain consonants.

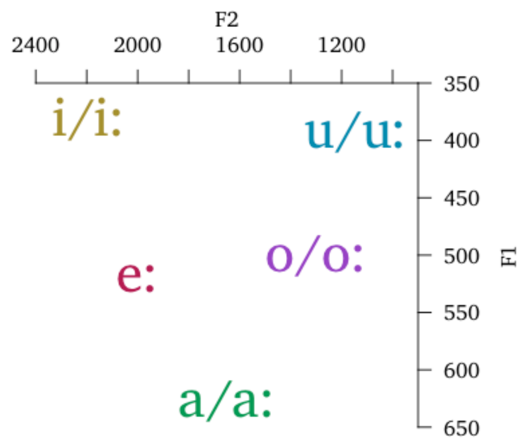

Figure 1 Iraqi Vowel Inventory (Qafisheh 1979)

The position of the vowel relative to the emphatic consonant may also restrict the effects of the consonant. Al-Masri and Jongman (2004) found that F2 values of vowels following emphatic consonants were lower than the F2 of vowels following plain consonants by approximately 500 Hertz. There was a smaller difference of 150 Hertz between the F2 values of vowels preceding the plain and emphatic consonants. This result suggests directional effects of emphatic consonants on adjacent vowels. Understanding the potential directionality effects can support a future quantitative analysis of emphasis spread in Iraqi Arabic.

2.3 Vowels Adjacent to Pharyngeal Consonants

One of the controversies about emphatic consonants is their exact place of secondary articulation. Directly comparing the effects of plain, emphatic, and pharyngeal consonants will demonstrate similarities and differences in their effects on adjacent vowels, helping to clarify similarities and differences in articulation. By studying the primary pharyngeals and emphatic consonants, which have been said to be pharyngealized (Davis 1995, Embarki et al 2007, Watson 1999), it is possible to compare the effects of primary and secondary pharyngeal constriction on adjacent vowels. The effects of pharyngeal consonants on adjacent vowels provide a useful contrast to emphatic consonants because they are pharyngeal but lack a coronal constriction. Al-Tamini and Heselwood (2011) and Butcher and Ahmed (1987) report higher F1 values in vowels adjacent to pharyngeal consonants than adjacent to non-emphatic consonants, while F2 values in vowels adjacent to pharyngeals are lower. The F1 raising and F2 lowering in vowels adjacent to pharyngeal consonants is similar to the pattern observed with emphatic consonants and contributes to the perception of pharyngeal fricatives (Alwan 1989). This effect varied somewhat by type of vowel and position of the vowel relative to the consonant. Butcher and Ahmed (1987) found low F2 values in front vowels adjacent to pharyngeals, but high F2 values in back vowels adjacent to the same consonants. Hassan and Esling (2011) found that pharyngeals affect the vowel following, but not preceding, the consonant. If, as claimed by Watson (2007), pharyngeals are within the class of emphatics in Arabic phonological processes, it would be expected that they would have similar effects on neighboring vowels as emphatic consonants. If they are not part of the same phonological class, however, the true pharyngeals may have a different pattern of effects on adjacent vowels, to the extent that vowels adjacent to pharyngeals may be similar to vowels adjacent to plain consonants.

2.4 Center of Gravity of Voiceless Fricatives

As phonemic fricative contrasts, one would expect that plain, emphatic, and pharyngeal consonants are acoustically different within the consonant itself, in addition to any effects on adjacent vowels. It is easiest to examine consonant differences in fricatives, which are distinguished by Center of Gravity (CoG) in most languages (Gordon 2002). Cross-linguistically, consonants that are produced further back in the vocal tract have lower CoG values during the frication. Pharyngeal fricatives are produced in the the pharynx with no oral constriction, suggesting that they will have a lower CoG than both plain and emphatic consonants. In Cairene Arabic, Norlin (1983) found that the CoG of emphatic fricatives was lower than the CoG for plain fricatives. This measure will relate the effects of emphatic consonants on vowels to the production of these consonants.

2.5 Goals of the Current Experiment

This experiment sought to examine the effects of plain, emphatic, and pharyngeal consonants on adjacent vowels. The experiment measured the effects on /a/ and /i/, in order to compare how different vowel qualities were affected by the target consonants. Stops and fricatives were used to understand effects of consonant manner, and vowels both before and after the target consonant were recorded to examine the effects of the position of the vowel relative to the consonant.

3 Methods

3.1 Participants

Five native speakers of Iraqi Arabic, two female and three male, participated in this experiment. All were affiliated with the University of Texas (Austin). The speakers ranged in age from 32 to 41, with an average age of 37. They grew up in Iraq and came to the US to study and all spoke English. One participant also spoke Kurdish.

3.2 Stimuli

Each participant read 24 words in one session, with a subset of words being used for each comparison. The target consonants were the plain coronals /s t/, emphatic coronals /sˤ tˤ/, or pharyngeal fricatives /ħ ʕ[2]/. The plain and emphatic consonants contrasted in their secondary, but not primary, articulation. The voiceless pharyngeal was chosen as a contrast to the voiceless plain and emphatic fricative. All consonants are represented in the orthography. The target words contained these consonants intervocalically with one of two vowels patterns. The words were all lexical items of Arabic that contained the target sequence with a CVCVC pattern and stress on the first syllable. Two short vowels, /a/ and /i/, were selected based on their different heights and high frequency in the language. The most effective way to record /a/ and /i/ in the same position was by using targeted segments that had one of two vowel patterns. An /iCa/ pattern, as in /sitˤaɾ/ "to dazzle", is a verbal form of certain roots and occurs unmarked for the masculine singular past. The /aCi/ pattern, as in /xatˤiɾ/ "dangerous", is a nominal form of certain verbs. There were two words for each target consonant and vowel pattern combination.

[2] The voiced pharyngeal fricative was elicited but was not used in the analysis because of its voicing difference with the other fricatives.

Within the word, the initial and final consonants were restricted to non-pharyngeal obstruents and approximants, because non-target pharyngeals or emphatics may affect vowels throughout the word through emphasis spread (Watson 1999). The voiceless uvular stop [q] was excluded because it can affect the formants in a manner similar to emphatics, especially the second formant (Watson, 2007; Zawaydeh, 1997). Nasals and laryngeals were excluded because of potential effects of these consonants on adjacent vowels. Clusters and geminates were avoided as well, so that all words had the same CVCVC pattern. Given these restrictions and the meaningful words in Arabic that contained these target consonants, the word-initial and word-final consonants consisted of the set of [ɾ l θ f s ʃ ʒ x ɣ b d k].

The target words were embedded in meaningful sentences (found in the Appendix), shown in (1), because the same orthographic representation can correspond with different words and short vowels depending on context. The target word was never utterance-initial or utterance-final to avoid the prosodic effects of these positions. These sentences were composed by the author and edited by a native Arabic speaker.

1. ʒamaːl al-maɾa **sitˤaɾ** al-ɾiʒaːl
   beauty DEF-woman dazzled DEF-man
   "The beauty of the woman dazzled the man."

3.3 Experimental Procedures

Recordings were done in a sound-treated room dedicated for this purpose in the Phonetics Lab at the University of Texas at Austin. The participant wore a Shure SM10A head-mounted microphone. Materials were recorded using a MOTU UltraLite-MK3 Hybrid recorder at a sampling rate of 44100 Hertz.

The participants were presented with sentences in written Arabic on a computer. Each sentence was presented individually on a slideshow, with one sentence for each of 24 target words. They were instructed to read each sentence silently and then say the sentence out loud. They could repeat a sentence if they felt that they made an error, and the last token would be used. The participants controlled the speed of the slide show by pressing a button to advance to the next sentence, and were allowed to rest between blocks. All sentences were randomly ordered within blocks. There were nine test blocks for 9 repetitions of each word, resulting in 216 recordings. Five participants completed the experiment, for a total of 1080 words, each with two target vowels.

3.5 Tokens of Data

There were a total of 2160 target vowels recorded. Only 1441 tokens were included in the analysis. One sentence was left off of the powerpoint for one repetition, so it has one less token than the other words (5). Recordings that were unclear (4) or where the speaker misread the target word (9) were culled from the final analysis. Tokens were also excluded for partial or complete devoicing (701 tokens excluded). This was unexpected and unreported previously in the literature, and primarily affected /i/ and for vowels in the unstressed position. All partially or completely voiceless tokens were excluded because it was impossible to accurately measure F1. Omitting this many data points made it impossible to compare the two vowels /a/ and /i/ both preceding and following the consonants. The examination of the data was restructured to allow for analysis of the better-recorded tokens (see Section 8) by using the data in three comparisons.

Each comparison focused on a different subset of words, though the data in the comparisons overlapped. Comparison 1 examined the low vowel /a/ before and after the target consonants [s t sˤ tˤ]. Comparison 2 examined /a/ or /i/ in the first syllable in words containing [s t sˤ tˤ]. Comparison 3 focused on the low vowel /a/ where it preceded the voiceless plain alveolar fricative /s/, the voiceless emphatic alveolar fricative /sˤ/, and the voiceless pharyngeal fricative /ħ/. Comparison 4 measured the CoG of these fricatives.

3.4 Measurements

Recordings were segmented into the target VCV sequences using the spectrogram and waveform produced by Praat (Boersma and Weenink 2016) with annotated text grids. After obstruents, the onset of the vowel was defined by the end of the release burst from stops (immediately after the burst at all frequencies) and the end of frication for fricatives where the waveform became periodic and regular, in contrast to the random waveform of the fricative. Before obstruents, the offset of the vowels was defined as the beginning of the voiceless period of stops and the beginning of frication of fricatives, which in both cases corresponded with the end of visible formants in the higher frequencies. For /ɾ/ and /l/, each vowel was considered to start after the lower intensity of the approximate, where the formants resumed their regular pattern. A vowel preceding /l/ or /ɾ/ was considered to stop immediately before this point. For the pharyngeal fricatives, onset and offset were defined by the point where the intensity of the vowel decreased. For the CoG measurements, the fricative was considered to be the area between the two vowels.

The formant measurements for F1 and F2 are from the PRAAT LPC burg analysis (Boersma and Weenink 2016) of formant values. A Praat script was used to extract these measurements at the midpoint in the target vowels. For points where the algorithm did not detect or mislabeled the formants, they were measured by hand from the spectrogram. The CoG was also measured with a Praat script that examined the target fricative. The original design of the study included three measurement points, at the onset, midpoint, and offset. However, due to the difficulty of measuring short vowels, only the midpoint was examined.

4 Comparison One- Positional Effects of Plain and Emphatic Consonants

Comparison One examined the effects of plain and emphatic consonants on the formants of the adjacent low vowel /a/. This comparison also examined the relationship to formant values between the position of the vowel relative to the target consonant and the role of the manner of the target consonant and how they affect formants.

4.1 Hypotheses

I expected that F1 values would be higher in vowels adjacent to emphatic consonants than in vowels adjacent to plain consonants. I expected that F2 values will be lower in vowels adjacent to emphatic consonants than in vowels adjacent to plain consonants. I expected an interaction between the type of consonant and the position of the vowel. Specifically, I predicted that F1 would be higher and F2 would be lower in vowels following an emphatic consonant than in vowels preceding the emphatic consonants. I also expected that vowels adjacent to emphatic fricatives would have higher F1 values than vowels adjacent to emphatic stops, while vowels adjacent to emphatic fricatives would have lower F2 values than vowels adjacent to emphatic stops.

4.2 Results

The data was analyzed in R (R Core Team, 2016; RStudio, Team 2015) using a mixed model analysis (Bates et al 2015, Singmann et al 2016). The mixed model was run using a Kenward-Rogers test in *afex: Analysis of Factorical Experiments* (Singmann et al 2016), which calculated p values for all fixed effects and interactions in a given model. The fixed effects for the mixed model for F1 and F2 were TYPE (plain or emphatic), MANNER (stop and fricative), and

POSITION (before or after the consonant). The full model converged for F2, with the random intercept of WORD and the random slopes of TYPE, MANNER, and POSITION by SUBJECT. The full model failed to converge for F1, so a more restricted set of random slopes were used by excluding the random slope of MANNER, thus the random slopes used in the model for F1 were only TYPE and POSITION by SUBJECT (see Barr et al 2013).

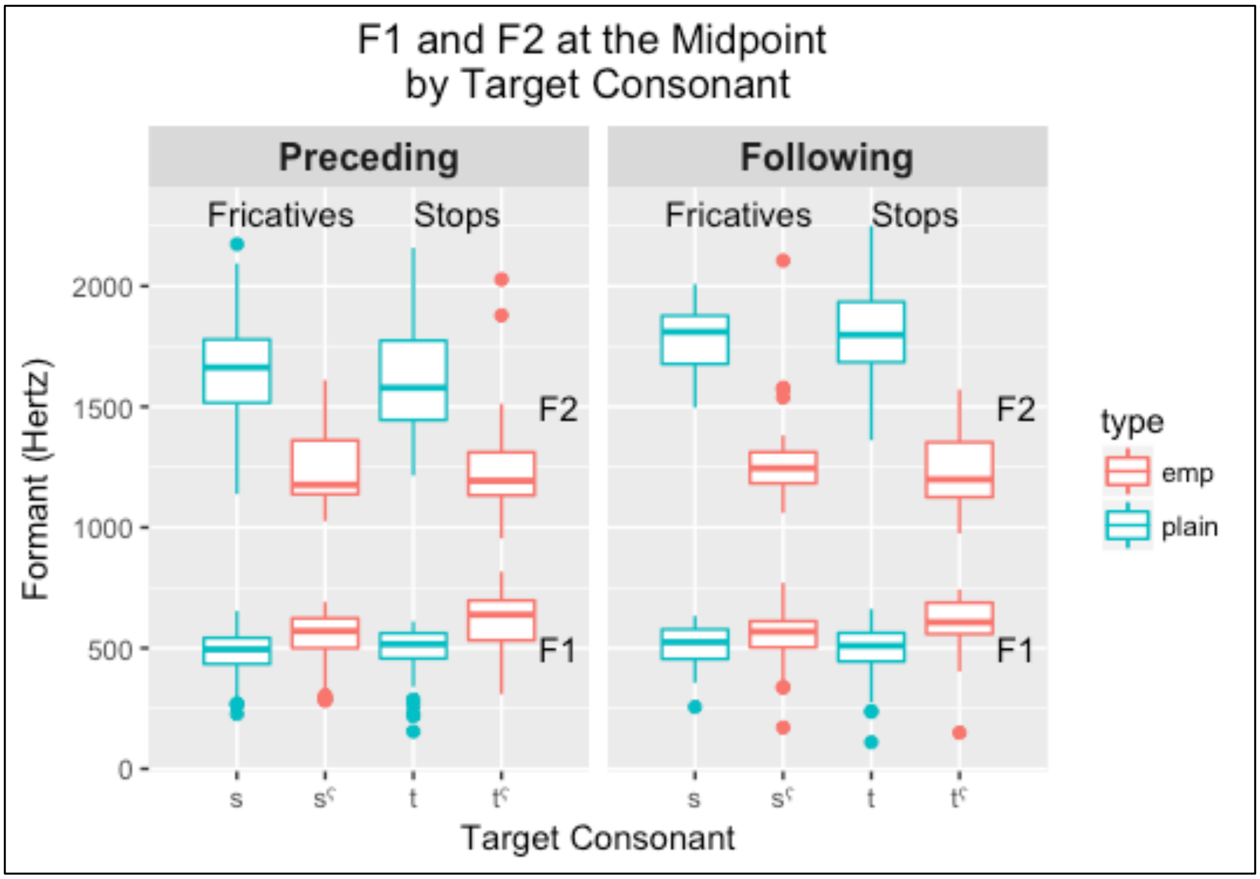

Figure 2 Comparison 1 Boxplot of F1 and F2

Figure 2 presents the distribution of F1 and F2 values for /a/ before and after the four target consonants. The formant values are separated by the TYPE and MANNER of the target consonant. For F1, there were significant main effects of TYPE (F(1, 11.56) = 7.63, p = .02) and MANNER (F(1, 8.02) = 7.56, p = .03). Vowels adjacent to emphatic consonants had a higher F1 than vowels adjacent to plain consonants. Vowels adjacent to stops had a higher F1 than vowels adjacent to fricatives. There were no significant interactions. For F2, there was a significant effect of TYPE (F(1, 9.33) = 13.82, p = .004). Vowels adjacent to emphatic consonants had a lower F2 than vowels adjacent to plain consonants. The F2 differences by manner and position were not significant. **Table 2** shows the p values for the models described above

Fixed Effects	F1	F2
TYPE	**F(1, 11.56) = 7.63, p = .02**	**F(1, 9.33) = 13.82, p = .004**
MANNER	**F(1, 8.02) = 7.56, p = .03**	F(1, 10.93) = 0.00, p = .95
POSITION	F(1, 10.91) = 0.04, p = .85	F(1, 9.81) = 0.62, p = .45
TYPE * MANNER	F(1, 8.03) = 1.41, p = .27	F(1, 10.54) = 0.06, p = .81
TYPE * POSITION	F(1, 10.40) = 0.96, p = .35	F(1, 9.56) = 0.38, p = .55
MANNER * POSITION	F(1, 9.89) = 0.02, p = .89	F(1, 13.52) = 0.64, p = .44
TYPE * MANNER * POSITION	F(1, 10.30) = 1.13, p = .31	F(1, 13.66) = 0.67, p = .43

Table 2 Statistical Results for Comparison 1 [3]

4.3 Discussion

The differences between vowels adjacent to emphatic and plain consonants were significant for F1 and F2. F1 was higher in vowels adjacent to emphatic consonants in comparison to the F1 of vowels adjacent to plain consonants, supporting the hypothesis and consistent with previous research in other dialects (Al-Tamimi and Heselwood, 2011; Jongman et al, 2011; Zawaydeh, 1997). F2 was lower for vowels adjacent to emphatic consonants in comparison adjacent to plain consonants, which supported the hypothesis and was consistent with previous work for Iraqi Arabic (Hassan and Esling 2011) and other dialects (Al-Masri and Jongman, 2004; Al-Tamini and Heselwood, 2011; Card, 1983; Embarki et al, 2007; Embarki et al, 2011; Jongman et al, 2011; Khattab et al, 2002; Zawaydeh, 1997).

The MANNER of the target consonant also had a significant effect on the F1 values at the midpoint of a neighboring vowel, but it did not interact with TYPE as was expected. This failure may be a result of measuring short vowels or problems with the stimuli and should be examined more closely before strong conclusions are drawn. It is unlikely that there is a broad effect of

[3] Values that were statistically significant at $p < 0.05$ are bolded

manner on vowels at the midpoint independently of TYPE. This experiment did not support the hypothesis because F2 was not significantly affected by MANNER.

There was no significant effect of POSITION, nor did POSITION affect the steady state of the vowel in a regular manner, contrasting with Al-Masri and Jongman's findings that emphatic consonants have a larger effect on vowels following a target consonant than preceding it (2004). Neither hypothesis about the effect of POSITION were supported because there was no significant effect of POSITION on F1 or F2.

Comparison One demonstrated that F1 is raised and F2 is lowered in vowels adjacent to emphatic consonants. These results also tell us that the consonant manner affected F1 midpoint, similar to the findings of Jongman et al (2011). F1 was affected by the consonant MANNER, but did not interact with TYPE. POSITION did not affect either F1 or F2. These results were consistent with previous research done on both Iraqi Arabic and other dialects for the low vowel /a/.

5 Comparison 2- Effects of Emphatic Consonants on High Front /i/ and Low /a/

Comparison 1 did not address the relationship between emphatic consonants and different vowels. Comparison 2 examined this by comparing the effects of emphatic and plain consonants on two vowels: low /a/ and high front /i/. It is expected that high front /i/ will have lower F1 values and higher F2 values than the low vowel /a/, and that the F1 of /i/ will not be higher next to emphatic consonants like the F1 of /a/. F2 is expected to be lower for both vowels adjacent to emphatic consonants. As in Comparison 1, vowels were measured at the midpoint, but only vowels before the target consonants were examined because of the number of voiceless vowels in the unstressed position which could not be measured (see Section 8).

5.1 Hypotheses

I expected higher F1 values and lower F2 values in vowels adjacent to emphatic consonants. I expected an interaction between the effects of emphatic consonants and type of vowel, specifically that the F1 of low /a/ would be higher adjacent to emphatic consonants than adjacent to plain consonants. No significant difference was expected for F1 values for the high front vowel /i/ between vowels adjacent to emphatic and plain consonants. I expected that F2 would be lower in vowels adjacent to emphatic consonants than adjacent to plain consonants for both /a/ and /i/. As in Experiment 1, it was expected that there would be an interaction between manner and type of consonant in which vowels adjacent to emphatic fricatives had higher F1 and lower F2 values than vowels adjacent to emphatic stops. I did not expect significant F1 and F2 differences in vowels adjacent to plain stops and fricatives. Given the regular differences in formant values between different vowels, I also expected that the F1 values of /i/ will be lower than the F1 values of /a/, while the F2 values of /i/ will be higher than the F2 values of /a/.

5.2 Results

The statistical model was identical to the model in Comparison 1 except that it had the fixed effect of VOWEL, with two levels: high front /i/ and low /a/, instead of POSITION, with interactions with the other fixed effects. The fully maximal model had the random intercept of WORD and the random slopes of TYPE, VOWEL, and MANNER by SUBJECT. However, the full model failed to converge for F1 and F2, so the random slope of MANNER was removed. The model converged with the random intercept of WORD and random slopes of TYPE and VOWEL by SUBJECT, so this model was used for both F1 and F2.

Figure 3 graphs F1 and F2 values for each vowel based on the following consonant. There were higher F1 values and lower F2 values preceding emphatic consonants. F2 is higher for /i/ than /a/, while F1 is lower for /i/ than /a/. For the high front /i/, F2 was higher preceding stops than fricatives for both plain and emphatic consonants. However, the F1 and F2 values for /a/ and /i/ are not as different as would be expected, given two vowels that differ in height and backness.

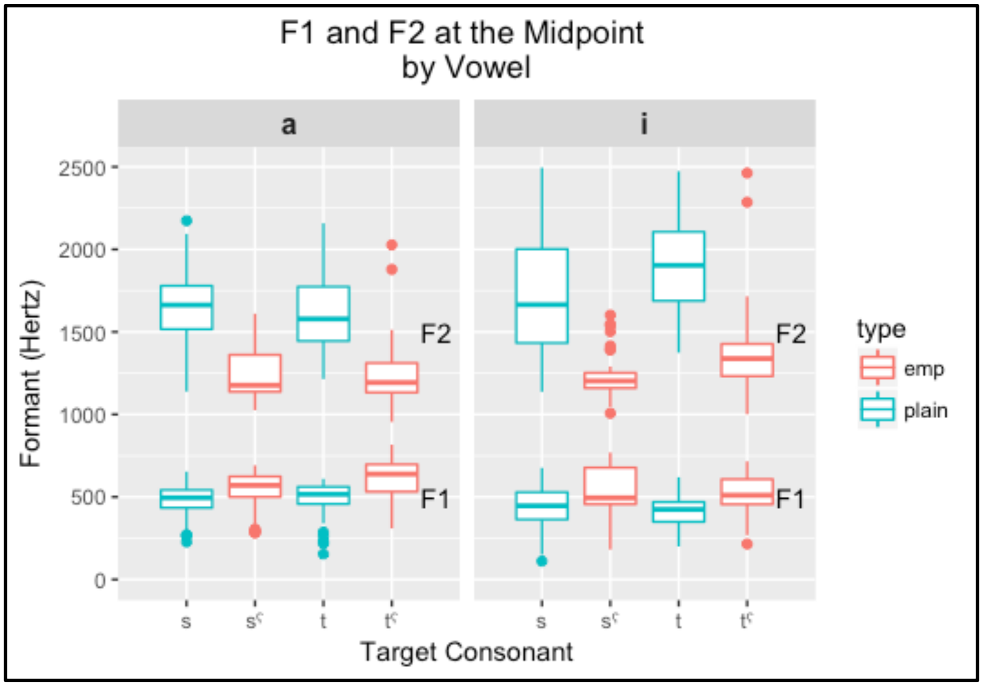

Figure 3 Comparison 2 Boxplot of F1 and F2

Figure 4 shows the distribution of the low vowel /a/ and the high front /i/ plotted by F1 and F2, which have overlapping F1 and F2 values. A subject-by-subject breakdown demonstrated that some speakers did not distinguish /a/ and /i/ in environments adjacent to both plain and emphatic consonants, while other speakers had a distinction between /a/ and /i/ in both environments. The lack of distinction between the vowels limits the conclusions that can be drawn about how emphatic consonants affect different short vowels.

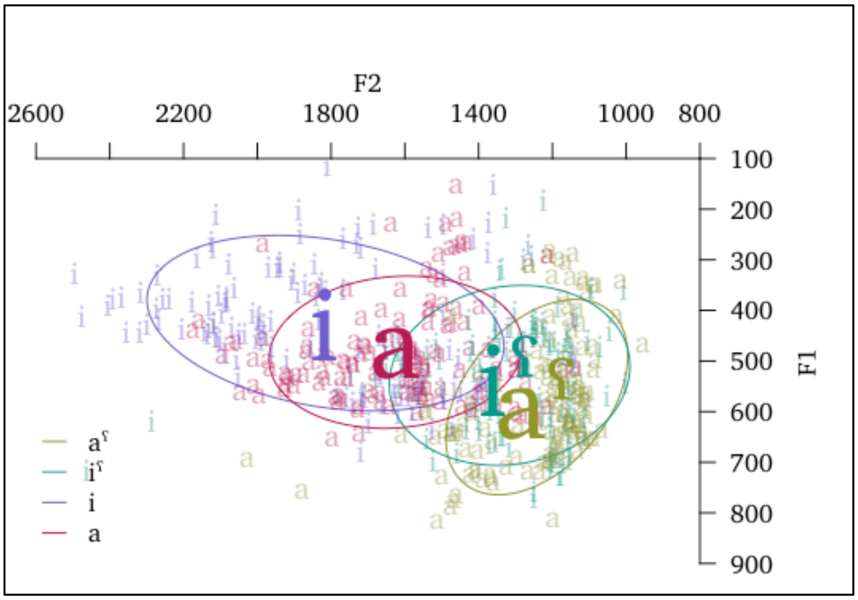

Figure 4 Comparison 2 Vowel Plot

There was a significant main effect of TYPE at F1 ($F(1, 9.83) = 5.18$, $p = .0465$), with vowels adjacent to plain consonants having lower F1 values than vowels adjacent to emphatic consonants. The factor of TYPE was also significant for F2 ($F(1, 9.01) = 7.33$, $p = .02$), where F2 was higher in vowels adjacent to plain consonants than in vowels adjacent to emphatic consonants. There was not a significant effect of VOWEL for either F1 or F2, nor was there an interaction between VOWEL and TYPE for F1 or F2, as shown in **Table 3**. There was a marginally significant effect of MANNER on F1 ($F(1, 8.46) = 4.25$, $p = .07$), but it did not interact with TYPE.

Fixed Effects	F1	F2
TYPE (plain)	**F(1, 9.83) = 5.18, p = 0.0465**	**F(1, 9.01) = 7.33, p = .02**
MANNER (stop)	F(1, 8.46) = 4.25, p = .07	F(1, 8.53) = 0.00, p = .99
VOWEL (i)	F(1, 12.54) = 0.32, p = .58	F(1, 8.74) = 0.01, p = .94
TYPE*MANNER (plain*stop)	F(1, 8.82) = 0.72, p = .42	F(1, 9.13) = 0.02, p = .89
TYPE*VOWEL (plain*i)	F(1, 8.98) = 0.31, p = .59	F(1, 8.61) = 0.00, p = .96
MANNER*VOWEL (stop*i)	F(1, 8.71) = 3.08, p = .11	F(1, 8.57) = 0.13, p = .73
TYPE*MANNER*VOWEL (plain*stop*i)	F(1, 9.36) = 0.44, p = .52	F(1, 9.96) = 0.03, p = .88

Table 3 Statistical Results for Comparison 2[4]

[4] Values that are significant at $p<0.05$ bolded

5.3 Discussion

The main results of Comparison 2 indicate that the two vowels /a/ and /i/ were affected similarly when adjacent to emphatic consonants. F1 was higher and F2 was lower in vowels adjacent to emphatic consonants, supporting. There was no interaction between TYPE and VOWEL for F1 or F2, failing to support the hypothesis that /i/ would be less affected by emphatic consonants that /a/. The lack of an interaction supported the hypothesis that both vowels would be equally affected by emphasis for F2. This would suggest that both vowels are affected similarly by emphatic consonants but this conclusion is not fully supported because the two vowels were not consistently different (see Section 8). Given that formant values distinguish vowels (Peterson and Barney 1952), it was expected that F1 would be lower in /i/ than in /a/ and F2 would be higher in /i/ than in /a/, but these predictions were not supported. The lack of a clear distinction between vowels indicates that different subjects were producing different vowels, so this experiment did not successfully analyze the potential for differences in the effect of emphatic consonants on different vowels.

6 Comparison 3- The Effect of Plain, Emphatic, and Pharyngeal Fricatives on Adjacent Vowels

The first two comparisons focused on the contrast between coronal plain and emphatic consonants. Arabic also has pharyngeal fricatives, thus Comparison 3 examined the differences between vowels adjacent to voiceless plain coronal, emphatic coronal, and pharyngeal fricatives. Emphatic coronals are similar to plain coronals in their primary coronal articulatory and may be similar to pharyngeal consonants in their secondary articulation. The contrast between these three groups may show similarities in their phonological effects on adjacent vowels, from which inferences about articulation can be made.

6.1 Hypotheses

I expected that F1 would be lowest in vowels adjacent to plain /s/ and highest in vowels adjacent to pharyngeal /ħ/, while emphatic /sˤ/ would have intermediate values. I expected that F2 values would be lowest adjacent to emphatic /sˤ/ and highest adjacent to plain /s/, with pharyngeal /ħ/ having intermediate F2 values. I also expected a significant effect of POSITION, in which the lowering of F2 and raising of F1 adjacent to emphatic consonants would be larger following an emphatic consonant.

6.2 Results

The statistical analysis was a mixed model similar to the previous comparisons. The factor of TYPE had three levels: PLAIN, EMPHATIC, and PHARYNGEAL. The factor of POSITION was also included with two levels: BEFORE and AFTER. The models also included the interactions. For the full model, the maximum random effects structures had the random intercept of WORD and the random slopes of TYPE and POSITION by SUBJECT. The full model was used for F2, but failed to converge for F1, necessitating a limited random slope structure of TYPE by SUBJECT, excluding POSITION. The same statistical model was used for pairwise comparisons, but the levels for TYPE was restricted to two of the three levels, with the same dependent and independent variables and random effects structures. The full random effects structures were used for the pairwise comparisons of F1 s*sˤ, s*ħ, and all F2 pairwise comparisons. The limited random effects structure was used for F1 sˤ*ħ because the full model failed to converge. The graph below shows the mean and standard deviation of F1 and F2 for vowels adjacent to plain, emphatic, and pharyngeal voiceless fricatives.

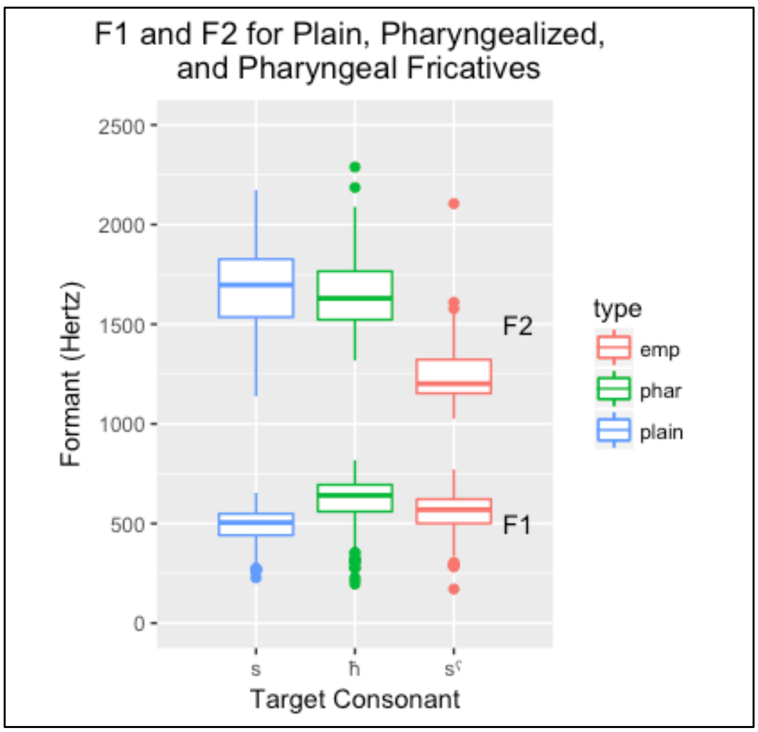

Figure 5 Comparison 3 Boxplot of Plain, Pharyngeal, and Emphatic Fricatives

Vowels adjacent to emphatic /sˤ/ and pharyngeal /ħ/ had higher F1 values than vowels adjacent to plain /s/. Pharyngeal /ħ/ also had higher F1 values than emphatic /sˤ/. For F1, there was a significant main effect of TYPE for the more limited, converged model (F(2, 6.66) = 8.57, p

= .01). However, TYPE was only significant for the pairwise comparison between plain /s/ and emphatic /sˤ/ (F(1, 5.51) = 6.74, p = .04) and between plain /s/ and pharyngeal /ħ/ (F(1, 6.67) = 18.29, p = .004). TYPE was not significant for the pairwise comparison between /ħ/ and /sˤ/ (F(1, 4.18) = 2.86, p = .16). The full model and pairwise comparisons are shown in **Table 4**.

Fixed Effects	Full Model	s*sˤ	s*ħ	sˤ*ħ
TYPE	**F(2, 6.66) = 8.57, p = .01**	**F(1, 5.51) = 6.74, p = .04**	**F(1, 6.67) = 18.29, p = .004**	F(1, 4.18) = 2.86, p = .16
POSITION	F(1, 4.97) = 1.24, p = .32	F(1, 5.51) = 1.44, p = .28	F(1, 5.59) = 0.90, p = .38	F(1, 3.63) = 1.13, p = .35
TYPE*POSITION	F(2, 6.63) = 0.53, p = .61	F(1, 4.85) = 0.68, p = .45	F(1, 4.92) = 0.23, p =.65	F(1, 4.39) = 0.59, p = .48

Table 4 Statistical Results for Comparison 3 F1

Vowels adjacent to emphatic /sˤ/ had the lowest F2 values, while vowels adjacent to /s/ had only slightly higher F2 values than the vowels adjacent to pharyngeal /ħ/. For F2, there was a significant main effect of TYPE for the full model (F(2, 7.28) = 14.31, p = .003). For the pairwise comparison, a different pattern emerged than occurred for F1. There was a significant main effect of TYPE for the pairwise comparison between plain /s/ and emphatic /sˤ/(F(1, 4.46) = 17.44, p = .01) and between emphatic /sˤ/ and pharyngeal /ħ/ (F(1, 8.38) = 52.86, p<.0001), but not for /s/ and /ħ/ (F(1, 4.79) = 0.00, p = .95). The p values are shown in **Table 5**. There was no effect of POSITION on F1 or F2, mirroring what was found in Comparison 1.

Fixed Effects	Full Model	s*sˤ	s*ħ	sˤ*ħ
TYPE	**F(2, 7.28) = 14.31, p = .003**	**F(1, 4.46) = 17.44, p = .01**	F(1, 4.79) = 0.00, p = .95	**F(1, 8.38) = 52.86, p<.0001**
POSITION	F(1, 7.33) = 1.38, p = .28	F(1, 5.40) = 0.00, p = .99	F(1, 4.58) = 0.96, p = .38	F(1, 6.47) = 4.33, p = .08
TYPE*POSITION	F(2, 6.68) = 1.30, p = .33	F(1, 4.80) = 0.39, p = .56	F(1, 4.37) = 0.58, p = .49	F(1, 4.76) = 10.43, p = .02

Table 5 Statistical Results for Comparison 3 F2

6.3 Discussion

The F1 values of vowels adjacent to plain /s/ were lower than the F1 values of vowels adjacent to emphatic /sˤ/ and pharyngeal /ħ/, supporting the hypothesis that F1 would be lowest adjacent to plain /s/. The F1 values of vowels adjacent to emphatic /sˤ/ and pharyngeal /ħ/ were not statistically distinct, suggesting similarities in articulation which resulted in similar acoustic patterns. These results support the conclusion that the secondary articulation of the emphatic consonant is similar to pharyngealization because of the similarities between the effects of pharyngeal and emphatic consonants on the F1 values of adjacent vowels.

The pattern of F2 values was different from the pattern observed in F1 values. Vowels adjacent to emphatic /sˤ/ had lower F2 values than vowels adjacent to /s/ and /ħ/, as was expected. Vowels adjacent to plain /s/ had the highest values, though they were not significantly different from the F2 of vowels adjacent to pharyngeal /ħ/. This pattern suggests that the lowering of F2 is restricted to vowels adjacent to emphatic consonants with secondary, not primary, pharyngealization because pharyngeal /ħ/ did not have the F2 lowering characteristic of vowels adjacent to emphatic consonants. It is possible that either this is a phonological process only triggered by emphatic consonants or it is a coarticulatory process caused by differences in the articulation of pharyngeals and emphatics.

Vowels adjacent to the plain fricative /s/ were distinct from vowels adjacent to emphatic /sˤ/ and pharyngeal /ħ/ for F1. A different pattern was observed for F2, where vowels adjacent to emphatic /sˤ/ were distinct from vowels adjacent to plain /s/ and pharyngeal /ħ/ for F2. Importantly, emphatic consonants have different effects on neighboring vowels than pharyngeal consonants and plain consonants. These results lead to the examination of the acoustic differences between these fricatives in Comparison Four, since the differences in articulation of the consonant may contribute to the effects on adjacent vowels.

7 Comparison Four- Center of Gravity of Voiceless Fricatives

Consonantal effects on adjacent vowels are often a result of the articulation of the consonant. This comparison focuses on the acoustics of the fricative consonants, which likely contribute to the effects of fricatives on adjacent vowels. The CoG of a fricative is a result of its place of articulation (Nittrouer 2002) and may aid in distinguishing plain and emphatic fricatives. Norlin (1983) found that emphatic fricatives have a lower CoG compared to plain fricatives, which is expected given that fricatives produced in the front of the mouth will have higher CoG values than fricatives produced in the back of the mouth (Gordon 2002). Pharyngeals, which only have a constriction in the pharynx, are expected to have a much lower CoG.

7.1 Hypotheses

This comparison analyzed the CoG of the plain, emphatic, and pharyngeal fricatives. Based on Norlin (1983) and Gordon (2002), it was expected that the CoG for plain /s/ would be higher than the CoG for emphatic /sˤ/, which would in turn be higher than the CoG of pharyngeal /ħ/.

7.2 Results

The fixed effects for the full mixed model were TYPE and VOWEL PATTERN and their interaction. The fixed effect of TYPE had three levels: plain /s/, emphatic /sˤ/, and pharyngeal /ħ/. The fixed effect of VOWEL PATTERN had two levels: the vowel pattern a-i and the vowel pattern i-a, since the adjacent vowels may have affected the CoG of the fricative. The effect of WORD was included as a random intercept, while the random effects of TYPE and VOWEL PATTERN by SUBJECT were included as random slopes. The pairwise comparisons had identical structures, except that the fixed effect of TYPE only had two of the three levels in each pairwise comparison. The full model converged for the three-way and pairwise comparisons.

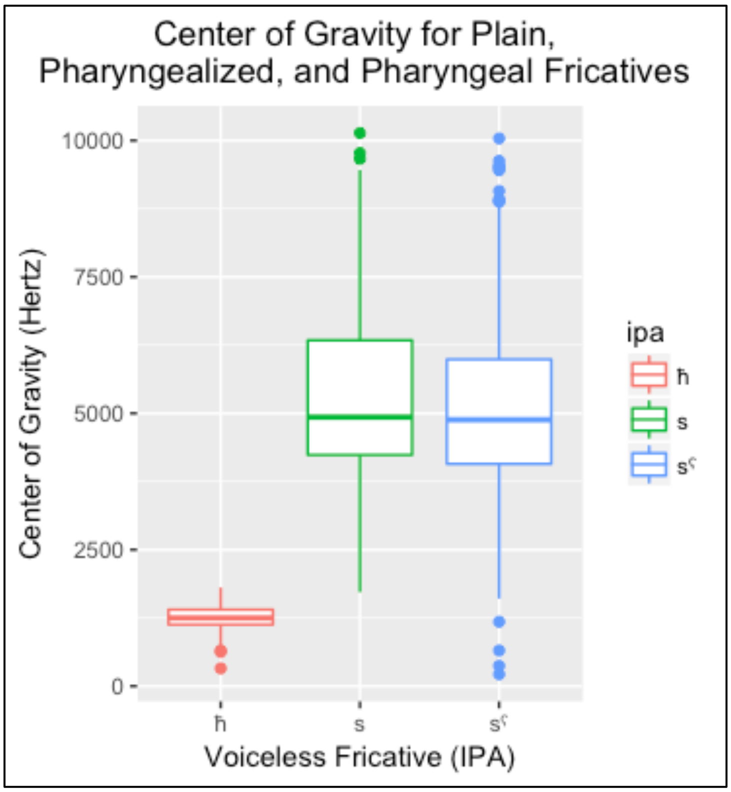

Figure 6 Comparison 4 Boxplot of Center of Gravity

Figure 6 shows that pharyngeal /ħ/ has lower CoG values than plain /s/ and emphatic /sˤ/. There was a significant main effect of TYPE for the CoG ($F(2, 6.05) = 360.00$, $p < .0001$). The pairwise comparisons by TYPE did not show a significant effect of TYPE between plain /s/ and emphatic /sˤ/. There was a significant effect of TYPE in the pairwise comparison between emphatic /sˤ/ and pharyngeal /ħ/ ($F(1, 4.05) = 682.09$, $p < .0001$) and between plain /s/ and pharyngeal /ħ/ ($F(1, 4.03) = 488.09$, $p < .0001$). The pharyngeal fricative /ħ/ has a lower CoG than the coronal fricatives /s/ and /sˤ/. There was no statistically significant difference between the center of gravity for /s/ and /sˤ/, as shown in **Table 6**.

Fixed Effects	Full Model	s*sˤ	sˤ*ħ	s*ħ
TYPE	**F(2, 5.51) = 17.16, p = .004**	F(1, 4.23) = 2.61, p = .18	**F(1, 4.14) = 21.01, p = .009**	**F(1, 4.14) = 27.94, p = .006**
VOWEL PATTERN	F(1, 5.45) = 1.85, p = .23	F(1, 3.50) = 1.24, p = .34	F(1, 3.93) = 2.81, p = .17	F(1, 16.06) = 0.19, p = .67
TYPE*VOWEL PATTERN	F(2, 6.03) = 0.55, p= .60	F(1, 4.00) = 0.68, p = .46	F(1, 4.02) = 0.83, p = .41	F(1, 341.18) = 0.14, p = .71

Table 6 Statistical Results for Comparison 4

7.3 Discussion

Pharyngeal /ħ/ had a lower CoG than plain /s/ and emphatic /sˤ/, as was expected. However, this comparison failed to support the hypothesis that emphatic /sˤ/ would be significantly lower than plain /s/, contrasting with Norlin (1983). This difference may be due to dialectal variation, but it suggests that, in Iraqi Arabic, emphatic consonants are signaled primarily through the formants of adjacent vowels, since they do not differ from similar voiceless coronal fricatives in terms of CoG. Together, Comparison 3 and 4 suggest that the phonological difference between the formant values at the midpoint of the neighboring vowels, in particular the second formant, are the strongest cues to the perception of the emphatic consonant. The CoG alone could likely not cue this distinction.

8 General Discussion

The primary goal of this experiment was to examine how plain, emphatic, and pharyngeal consonants affect the formant values of adjacent vowels. For the first three comparisons, the type of target consonant significantly affected F1 and F2 values. F2 was lower in vowels adjacent to emphatic consonants than in vowels adjacent to plain (Comparison 1, 2, and 3) or pharyngeal (Comparison 3) consonants. The lower F2 values confirm that this characteristic correlate of emphatic consonants occurs in Iraqi Arabic, as it was found consistently in the different comparisons. However, pharyngeal consonants were not associated with significant F2 lowering in adjacent vowels.

The F1 differences were present, but were not as robust as the F2 differences. F1 was lower adjacent to plain consonants than to emphatic (Comparison 1, 2, and 3) or pharyngeal (Comparison 3) consonants. The F1 results contrast with Hassan and Esling's (2011) findings in Iraqi Arabic, where a significant F1 difference was not found, though the results here were consistent with other analyses of different dialects. Pharyngeal and emphatic consonants had similar effects on F1 values of adjacent vowels, with lower F1 values in vowels adjacent to /sˤ/ and /ħ/ than in vowels adjacent to /s/ (Comparison 3). The effects of emphatic consonants on adjacent vowels suggests that emphatic consonants have similar, but not identical, articulation to pharyngeal consonants. For F1, pharyngeal and emphatic consonants had similar effects on adjacent vowels. However, for F2, pharyngeal consonants did not correlate with F2 lowering like the emphatic consonants.

The position of the vowel relative to the emphatic consonant did not affect the degree of F1 lowering or F2 raising (Comparison 1 and 3), contrasting with previous studies (Al-Masri and Jongman 2004). The manner of the target consonant affected F1 values in Comparison 1, where vowels adjacent to stops had higher F1 values than vowels adjacent to fricatives. This result was not replicated in Comparison 2 and F2 values were not affected by MANNER in either. If the effect was the result of acoustic differences between coronal stops and fricatives, that difference only occurred with the low vowel /a/ in Comparison 1 and not with high front /i/ in Comparison 2. The variation by MANNER was not robust, thus contrasting with Embarki (2007) and Jongman et al's (2011) findings that vowels adjacent to emphatic /sˤ/ had higher F2 values than vowels adjacent to other emphatic consonants. The interaction of MANNER and TYPE observed in other dialects did not occur in this study of Iraqi Arabic.

The differences in the CoG values, especially the lack of a distinction between emphatic and plain coronal consonants, contrast with Norlin's (1983) findings in Egyptian Arabic. It is possible that the primary way that speakers distinguish /s/ and /sˤ/ is through higher F1 and lower F2 in vowels adjacent to emphatic consonants. This hypothesis can be examined more closely through a perception experiment that cross-splices these vowels and consonants to examine how the vowel affects perception of plain and emphatic consonants.

The type of consonant did not interact with the different vowels (Comparison 2), suggesting that both vowels were similar affected by emphatic consonants. However, the two vowels were expected to have an effect on F1 and F2 as a result of differences in articulation (Jongman et al, 2011; Peterson and Barney, 1952). This hypothesis was not supported, suggesting that the participants did not produce the targeted vowels. A future experiment can control the elicited vowel more successfully by using the more salient long vowels, which are also present in the writing system.

A large number of vowels were excluded from the analysis because they were voiceless. Vowels were more likely to be voiceless when they occurred after the target in the second, unstressed, syllable. The high vowel /i/ had a higher rate of voiceless vowels than /a/. Vowels adjacent to emphatic consonants were more likely to be voiceless than vowels adjacent to plain consonants. Vowels adjacent to coronal fricatives were slightly more likely to be voiceless than vowels adjacent to coronal stops. However, voiceless vowels were rarely adjacent to the pharyngeal fricative. This pattern was not the main interest of the experiment, but it was an unexpected complication. The voiceless vowels affected the number of tokens used, which prevented an analysis of how position affects high vowels. A future experiment could overcome this problem by using tokens with both /a/ and /i/ in stressed positions, since stressed vowels were less likely to be voiceless. A clearer analysis of the effects of emphatic consonants on different vowels should examine long vowels, which are less likely to be devoiced because they draw stress (Watson 2007) and are written orthographically, which would increase the likelihood of eliciting the desired vowel.

The differences in effects on adjacent vowels suggest that emphatic and pharyngeal consonants have different acoustic properties. To examine the acoustic effects of pharyngeal and emphatic consonants on adjacent vowels, future experiments should measure F1 and F2 at several points within the vowel to trace the changes in vowel formants over time, based on proximity to the target consonant. This analysis can determine if the F1 raising and F2 lowering of vowels adjacent to emphatic consonants is a phonetic result of coarticulation or if this is a measurable effect of a phonological process in which emphatic consonants lower adjacent vowels. If, for example, the F2 of a vowel adjacent to an emphatic consonant is lower throughout the vowel in comparison to a vowel adjacent to a plain consonant, this would suggest a phonological process instead of simple coarticulation. If vowels adjacent to emphatic and pharyngeal consonants are affected differently, it would suggest that emphatic consonants are a natural class that does not include pharyngeal consonants (see Bessell 1998 for a similar analysis in Interior Salish).

The data presented here provides a foundation for additional research on the phonological process of emphasis spread, in which the emphatic consonants discussed here affect non-adjacent vowels and consonants within the same word (Davis 1995, Watson 1999). Understanding this process requires an empirical foundation in which the effects of emphatic consonants on adjacent and non-adjacent vowels are compared. The effect of emphatic consonants on different vowel qualities is important, since Davis (1995) claimed that the phonological pattern of emphasis spread is restricted by high front /i/ in Palestinian Arabic. However, Zawaydeh (1997) found that high segments do not block emphasis spread in the same dialect. The directionality effects also have bearing on this topic. Both Davis (1995) and Watson (1999) claim that vowels preceding emphatic consonants are more likely to be affected by emphasis spread than vowels after emphatic consonants. It was assumed that asymmetries in emphasis spread patterns (Davis, 1995; Watson, 1999; Zawaydeh, 1997) were the result of differences in the effects the vowel relative to the target consonant. However, these results did not support this analysis of asymmetries for Iraqi Arabic. It is possible that these asymmetries in emphasis spread do not exist in Iraqi Arabic or that the asymmetries of direction only occur in non-adjacent vowels, which are generally affected by emphasis spread. The relationship between different vowels and the effect of emphasis is poorly understood, thus the analysis of different vowels, as was intended here, should be continued in future studies.

8.1 Conclusion

This experiment demonstrated the differences between plain, emphatic, and pharyngeal consonants at the midpoint of adjacent vowels. Primarily, vowels adjacent to emphatic consonants had lower F2 values than vowels adjacent to plain and pharyngeal consonants. F1 was higher in vowels adjacent to emphatic and pharyngeal consonants than in vowels adjacent to plain consonants. A clear understanding of the phonetic effects of plain, emphatic, and emphatic consonants on adjacent vowels paves the way for analysis of emphasis spread by measuring the formants in vowels to identify if a vowel is affected by emphasis, in which case it would have the lower F2 and higher F1 values characteristic of vowels adjacent to emphatic consonants. This type of analysis can clarify if the effect of emphatic consonants decreases relative to the distance away from the emphatic consonant and if certain segments prevent emphasis spread. A corresponding perception study will examine how these acoustic cues are perceived by speakers. This is especially critical given that plain and emphatic fricatives were not acoustically different, at least by the measure of CoG.

Appendix

Stimuli (the transcription, gloss, translation, and Arabic text used, sorted by target consonant)

1) Plain Coronal Stop /t/

a) al-mulaːzm qaːd **ɾatil** al-dʒinuːd li-fuːq al-til
The-lieutenant led column the-soldiers to-top the-hill
The lieutenant led the column of soldiers to the top of the hill
الملازم قاد رتل الجنود لفوق التل.

b) Al-mara maː tuħibb **fatil** ʃaʕaɾ bint-haː
The-woman neg. likes braiding hair daughter-her
The woman does not like braiding her daughter’s hair.
المرة ما تحب فتل شعر بنتها.

c) al-dʒundiː **fitak** b-il-bajt
the-soldier destroyed in-the-house
The soldier destroyed the house.
الجندي فتك بالبيت.

d) al-duktuːɾ **bitaɾ** iːd al-ɾiʒaːl
the-doctor cut.off hand the-man
The doctor cut off the hand of the man.
الدكتور بتر يد الرجال.

2) Emphatic Coronal Stop /tˤ/

a) huwa ɾamaː **satˤil** al-maj b-il-biːɾ
he dropped bucket the-water in-the-well
He dropped the bucket of water in the well.
هو رمى سطل المي بالبير.

b) ʃaft mudʒɾim **xatˤiɾ** b-il-bɑːsˤ
saw criminal dangerous in-the-bus
I saw a dangerous criminal on the bus.
شفت مجرم خطر بالباص.

c) dʒamaːl al-maɾa **sitˤaɾ** al-ɾidʒaːl
beauty the-woman dazzles the-man
Her beauty dazzled the man.
جمال المرة سطر الرجال.

d) huwa **ʃitˤab** ʔakθaɾ al-aːʃiːʔ al-muwdʒuːda
he crossed.out most the-things the-present
He crossed out most of the things on the list.
هو شطب أكثر الاشياء الموجودة.

3) Plain Coronal Fricative /s/

a) al-walid baka: bisibub **fasix** al-kataf
the-boy cried due.to dislocation the-shoulder
The boy cried because of a dislocation of the shoulder
الولد بكى بسبب فسخ الكتف.

b) al-walid samaʕ **kasir** al-dʒisaɾ
the-boy heard breaking the-bridge
The boy heard the break of the bridge.
الولد سمع كسر الجسر.

c) huwa **dʒisaɾ** jatˤlub min-hu al-fulu:s
he dared ask from-him the-money
He dared to ask him for the money
هو جسر يطلب منه الفلوس.

d) al-walid **ɣasil** ʔi:d-hu bi-maj ħa:ɾ
the-boy washed hands-his in-water hot
The boy washed his hands in hot water
الولد غسل إيده بمي حار.

4) Emphatic Coronal Fricative /sˤ/

a) qabl **fasˤil** al-diɾa:sa sa:fɾit li-fɾansa:
before season the-studying I.traveled in-France
Before the school season I was traveling in France.
قبل فصل الدراسة سافرت لفرنسا.

b) al-ʕa:mal xalasˤ **rasˤif** al-ʃa:ɾiʕ
the-worker finished paving the-street
The worker finished paving the road.
العامل خلص رصف الشار ع.

c) huwa **risˤad** al-dʒow
he watched the-weather
He watched the weather
هو رصد الجو.

d) huwa **ɣisˤab** al-ridʒa:l jiftaħ al-ba:b
he forced the-man opens the-door
He forced the man to open the door.
هو غصب الرجال يفتح الباب.

5) Voiceless Pharyngeal Fricative /ħ/

a) tiʃu:f **saħil** sija:ɾatu-ha: min al-ʃuba:k
watches dragging car-her from the-window
She watches the dragging of her car from the window.
تشوف سحل سيارتها من الشباك.

b) al-baqɾa tuħibb **laħis** ɾa:s ʕadʒil-ha:
the-cow likes licking head calf-her

The cow likes licking her calf's head.
البقرة تحب لحس راس عجلها.

c) huwa **ɾiħal** min hal-mintˤaqa
he moved.away from the-area
He moved away from that area.
هو رحل من هالمنطقة.

d) ʔaːbuː-k **biħaθ** ʕan-ik
father-yours looked for-you
Your father was looking for you.
أبوك بحث عنك.

6) Voiced Pharyngeal Fricative /ʕ/

a) al-ħakuːma manaʕat **ʃaʕil** al-naːɾ b-il-sˤajf
the-government banned lighter the-fire in-the-summer
The government banned lighting fires during the summer.
الحكومة منعت شعل النار بالصيف.

b) huwa juʕːkiː min **ɾaʕiʃ** bi-ʔiːd-hu
he suffers from trembling in-hand-his
He suffers from trembling of his hand.
هو يعاني من رعش بيده.

c) al-muʕalam **biʕaθ** al-ɾisaːla min al-madɾaːsa
the-teacher sent the-letter from the-school
The teacher sent a letter from the school.
المعلم بعث الرسالة من المدراسة.

d) al-radʒaːl **siʕad** ħaɾamt-u
the-man made.happy wife-his
The man made his wife happy.
الرجال سعد حرمته.

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