دراسة صوتية فيزيائية للأصوات غير النطعية في الموصلية العربية

An Acoustic Study of Non-Coronal Consonants in Mosuli Arabic

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الملخص

تقدم هذه الدراسة تحليلاً صوتيًا شاملاً للأصوات الساكنة غير النطعية في الموصلية العربية، مع التركيز على الخصائص الزمنية والطيفية لهذه الأصوات عبر سياقات صوتية متنوعة. تتضمن الدراسة محورين، الاول نظري والثاني عملي. الجانب العملي. برنامج برات (Praat) تم استخدامه ومجموعة من المقاييس الصوتية ايضا"، بما في ذلك زمن بدء التصويت (VOT)، والمدة، والشدة، وترددات الصياغ، تبحث هذه الدراسة في الاختلافات المنهجية في تحقيق الأصوات الساكنة غير النطعية كدالة لفئة الصوت الساكن، والجهر، ومكان النطق، وسياق الحركة، وموضع الكلمة. تكشف النتائج عن أنماط مميزة من التباين الصوتي لكل مقياس، مع وجود اختلافات كبيرة بين الأصوات الانفجارية والاحتكاكية والأنفية والتقريبية، وكذلك بين الأصوات الساكنة المجهورة او وغير المجهورة. كما تسلط الدراسة الضوء على الطبيعة السياقية لهذه الاختلافات، مما يدل على تأثير الحركات المجاورة والموضع فوق المقطعي على الخصائص الصوتية للأصوات الساكنة غير النطعية. هذه النتائج لها آثار مهمة على التمثيل الفونولوجي والتنفيذ الصوتي للتباينات الساكنة في اللغة العربية، وكذلك على تطوير التطبيقات العملية في تعليم اللغة، وعلم أمراض النطق، وتكنولوجيا الكلام. تساهم الدراسة في فهمنا للنظام الفونولوجي الغني والمعقد للموصلية العربية وتقدم رؤى قيمة حول الأسس الصوتية لإنتاج الكلام البشري.

Abstract

The present study offers a comprehensive acoustic analysis of non-coronal consonants in Mosuli Arabic, focusing on the temporal and spectral properties of these sounds across various phonetic contexts by utilizing the Praat software and employing a range of acoustic measures, including voice onset time (VOT), duration, intensity, and formant frequencies. This study investigates the systematic variations in the realization of non-coronal consonants as a function of consonant class, voicing, place of articulation, vowel context, and word position. The findings reveal distinct patterns of acoustic variation for each measure, with significant differences observed between stops, fricatives, nasals, and approximants, as well as between voiced and voiceless consonants. The study also highlights the context-dependent nature of these variations, demonstrating the influence of adjacent vowels and prosodic position on the acoustic properties of non-coronal consonants. These findings have important implications for the phonological representation and phonetic implementation of consonantal contrasts in Mosuli Arabic, as well as for the development of practical applications in language teaching, speech pathology, and speech technology. The study contributes to the current understanding of the rich and complex phonological system of Mosuli Arabic and provides valuable insights into the acoustic underpinnings of human speech production.

1- Introduction

Mosuli Arabic (henceforth MA) is one of Arabic dialects that Mosuli residents speak it, and it is one of sub-divisions of standard Arabic (henceforth SA) (Israa, 2011:56). It looks that it is better to mention consonants and vowels of Standard Arabic to gain on more convenience in discussing of non-coronal consonants of Mosuli Arabic.

1-1 Consonants

The Arabic language boasts a rich and diverse consonantal inventory, encompassing various places and manners of articulation. The most striking feature of the Arabic consonant system is the presence of a series of "emphatic" or pharyngealized consonants, which are produced with a secondary constriction in the upper pharynx, resulting in a distinct acoustic quality (Al-Ani, 1970; Bin-Muqbil, 2006).

In addition to the emphatic series, Arabic exhibits a full range of stops, fricatives, and affricates at various places of articulation. These stop consonants can be classified according to the voiced-voiceless pairs of /b/-/p/ (bilabial), /d/-/t/ (dental), /d̪/-/t̪/ (denti-alveolar), /ɟ/-/c/ (palatal), /g/-/k/ (velar), and /q/ (uvular) (Watson 2002). The fricatives see the inclusion of a wide range of sounds with additional diverseness, which include the labiodental /f/, the dental /θ/ and /ð/, alveolar /s/ and /z/, the post alveolar region /ʃ/, the velars /χ/ and /ɣ/, the pharyngeals /ħ/ and /ʕ/, and the glottal /h/ (Holes 2004). Arabic also contains a very small number of affricative consonants, for example, the alveo-palatal /ʤ/ and the emphatic alveo-palatal /ʤˤ/ (Amayreh and Dyson, 1998).

Clinically speaking, there is also the presence of guttural consonants which, as the term suggests, are pronounced with the use of primary constriction within the area of either the larynx or the pharynx. Inclusive of these guttural consonants are the pharyngeal fricatives /ħ/, /ʕ/, the glottal stop /ʔ/ and the glottal fricative /h/ (McCarthy, 1994; Zawaydeh, 1999).

1-2 Vowels

The vowel system of MSA is quite simple with only six monophthongal vowels: three short vowels /a/, /i/, /u/ and /aː/, /iː/, /uː/ which are the long versions of the short vowels. (Holes, 2004) As for the short vowels, instead of the ordinary sustained version of the vowel, they tend to be realized as lax or undipped variants of the long vowels. Short high vowels /i/ and /u/ are often realized with a degree of mid-centralization (Alghamdi, 1998). In contrast to these, the long ones are produced in the more peripheral position of the tongue, with longer inside timbre time and more stability in the acoustic itself (Al-Tamimi and Ferragne, 2005).

In addition to the monophthongal vowels, Arabic also contains a set of diphthongs, which are typically analysed as sequences of a short vowel followed by a glide. The most common diphthongs in Arabic are /aj/ and /aw/, which are realized as a short low vowel /a/ followed by the palatal glide /j/ or the labio-velar glide /w/, respectively (Watson, 2002).

Many Arabic dialects exhibit a more complex vowel system than SA, with additional vowel qualities and phonological contrasts (Embarki et al., 2007; Al-Tamimi and Khattab, 2011).

1.3 Non–coronal consonants in Mosuli Arabic

Non - coronal consonants can be defined as sounds that are produced by using one of all speech articulators (movable and stationary) except the movable organ (tongue). Among consonants that Mosuli Arabic owns, are non-coronal consonants. They are 15 Arabic consonants (Anmar, 2014:30). Non – coronal consonants represent a diverse range of places and manners of articulation, as well as different laryngeal and pharyngeal settings. These consonants are in the following:

Place of articulation of Non – Coronal sounds	Non – Coronal sounds	Word in Mosuli Arabic which represents the sound	Transcription	Equivalence meaning in English
Bilabial stops	/ p / and / b /	بغد برجم	/baɣd/ /parʧam /	Cold The lock
Bilabial nasal	/ m/	لمبة	/ lampa /	Lamp
Labiodental fricative	/ f /	فاغة	/ faɣa: /	Mouse
Palatal glide	/ y /	يعجبا	/ yiʕʤiba/	She likes
Labio – velar glide	/ w /	بالوحدي	/ bilwiħdi /	At one o'clock
Velar stops	/ k / and / g /	مكاني كازو	/ maka:ni/ / ga:zo:/	It's my place
Uvular	/ q /	قصت	/ qassit/	She cut
Velar fricatives	/ χ / and / ɣ /	خوش	/ χo:ʃ/	Fine

		دغيج	/ daɣayyidʒ /	The stairs
Glottal fricative	/ ʕ / and / h /	عثغ هنيالو	/ ʕiɵiɣ / / haniya:l/	He slipped He is lucky
Pharyngeal fricative	/ ħ /	حوش	/ħo:ʃ/	Yard
Glottal stop	/ ʔ /	ابو	/ ʔabu:/	Man who has child

These non-coronal consonants in Mosuli Arabic allow for the examination of several important phonological contrasts in Arabic, such as the voicing contrast in stops (e.g., /p/ vs. /b/, /k/ vs. /g/), the place of articulation contrast in fricatives (e.g., /f/ vs. /m/ vs. /χ/ vs. /ħ/), and the contrast between oral and guttural consonants (e.g., /k/ vs. /q/, /h/ vs. /ħ/). Moreover, the inclusion of sonorant consonants such as /m/, /y/, and /w/ provides a basis for comparison with the obstruent consonants, allowing for a more comprehensive analysis of the acoustic properties of Mosuli Arabic in particular and Standard Arabic in general.

Acoustic-phonetic analysis has become an increasingly important tool within the field of linguistic research, providing valuable information about the complex processes underlying speech production and perception in humans. As can be inferred from the descriptions, this analysis is rooted in the detailed investigation of the physical properties of speech sounds, such as their frequency, intensity, and duration (Ladefoged and Johnson, 2015); it employs precise instrumental methods. The rise of digital signal processing and spectral analysis has transformed how phoneticians examine the acoustic structure of speech, allowing them to detect finer details or patterns that were hitherto unfindable by naked ear (Harrington 2013). Acoustic analysis can uncover effects of socio-linguistic factors like gender, age or local background on the realization of phonetic variables in human speaking (Foulkes & Docherty 2006). Acoustic phonetic research is further useful in a variety of other areas, such as language acquisition, speech pathology and speech technology through the improve use of teaching methods, the development of superior diagnostic tools and effective speech recognition/synthesis systems (Deng and O'Shaughnessy 2003).

2- Aims of the study

This study aims at:

1- investigate the acoustic properties of a select group of Mosuli Arabic non - coronal consonants, with a focus on their temporal and spectral characteristics.

3- employ a range of acoustic measures, including VOT, duration, formant transitions, and spectral moments, to provide a detailed characterization of the acoustic properties of these consonants and their variability across different phonetic contexts and speaker populations, and

3- understand of the sociophonetic factors that shape the acoustic structure of Mosuli Arabic consonants.

3- Research questions and Hypotheses

The primary research questions guiding an investigation to this study are as follows:

1- How do the acoustic measures of voice onset time (VOT), duration, and formant transitions vary across different classes of Mosuli Arabic consonants (stops, fricatives, emphatics, gutturals)?

2- To what extent do these acoustic measures reliably differentiate between phonologically contrastive consonant pairs (e.g., voiced vs. voiceless stops, emphatic vs. non-emphatic consonants)?

3- How do factors such as vowel context, syllable position, and speaker background (gender, dialect) influence the acoustic realization of Arabic consonants?

Based on previous acoustic studies of Arabic and other languages, the researcher hypothesizes that:

1- VOT values will be significantly longer for voiceless stops compared to voiced stops, with the largest differences observed for velar places of articulation.

2- Emphatic consonants will exhibit lower formant frequencies (particularly F2) and longer durations compared to their non-emphatic counterparts, reflecting the additional pharyngeal constriction and increased articulatory effort associated with emphasis.

3- Guttural consonants will display distinct acoustic properties, such as lowered formant frequencies, increased spectral noise, and longer durations, compared to other consonantal classes.

4- The acoustic realization of Arabic consonants will be influenced by factors such as vowel context (with more peripheral vowels enhancing the acoustic contrast between consonants) and syllable position (with consonants in word-initial position exhibiting more robust acoustic cues).

4- Limitation of the Study

Mosuli Arabic contains fifteen consonants type Non - coronal as it has been discussed above. This study is limited to study only EIGHT consonants. they are / b - m - f - w - k - g - q - ʔ /. In other words, the following non – coronal sounds have been excluded from this study / p - y - χ - ɣ - ʕ - h - ħ /, they are seven. The reasons of excluding these sounds are: to open scope for further studies to deal with these sounds deeply, and studying of them in this study will provide crowed information and the study will be long.

5- Literature Review

In general, Arabic sounds have been the subject of several instrumental studies. One of the earliest and most comprehensive studies of Arabic sounds was conducted by Al-Ani (1970). He found that the spectral shape of the release burst and the formant transitions in the adjacent vowels provided important cues for distinguishing between labial, alveolar, and velar stops. Labial stops were characterized by a diffuse release burst and falling F2 transitions, while alveolar stops exhibited a more compact burst spectrum and rising F2 transitions. Velar stops, on the other hand, were associated with a compact burst spectrum and falling F2 and F3 transitions.

A further study by Bin-Muqbil (2006) He performed an acoustical and phonological investigation of Arabic gutturals, in particular the uvular stop /q/ and the pharyngeal fricatives /ħ/ and /ʕ/ in MSA as well as several others Arabic dialects. He used acoustic analysis and native speaker intuitions to examine the phonetic and phonological characteristics of these consonants, along with their consequences on surrounding vowels and syllable shape. His findings revealed large dialectal variation in gutturals, both with respect to their articulatory constrictions and acoustic realizations.

Bin-Muqbil's acoustic analysis revealed that the uvular stop /q/ was characterized by a compact noise burst and a low frequency of the second formant (F2) in the adjacent vowels, consistent with its posterior place of articulation. The pharyngeal fricatives /ħ/ and /ʕ/, on the other hand, exhibited a high degree of spectral flatness and a low frequency of the first formant (F1), reflecting the constriction of the pharyngeal cavity during their production. Moreover, he found that the presence of gutturals in a syllable often induced changes in the syllable structure and stress patterns of Arabic words, suggesting a close interaction between the phonetic and phonological properties of these consonants.

In a similar vein, Jongman et al. For example, to investigate the acoustic and perceptual correlates of emphasis in Urban Jordanian Arabic /tˤ/ and /dˤ/ (the emphatic stops) versus their non-emphatic counterparts /t/ and /d/, local dialect speakers can be used together with a more controlled phonetic setup similar. Results of their acoustic analysis and perceptual identification tasks indicated that the primary acoustic cue for the emphasis contrast was F2 lowering in the surrounding vowels, with emphatic stops showing a lower F2 onset frequency that non-emphatic stops. Second, they observed an increase in the emphasis contrast by secondary acoustic cues including VOT, closure duration and burst intensity which systematically differed between emphatics and non-emphatics.

Jongman et al. Their study too explored the perceptual salience of these acoustic cues to individuals living in urban Jordan, by giving a number of trials on identification and discrimination tasks to native speakers of Urban Amman Arabic ['. They found that the F2 onset frequency was most effective in signaling emphasis, with lower frequencies of F2 always contributing to placing more emphasis on a plosive. Instead, they concluded that the secondarily acoustic cues (VOT and closure duration) also contributed to emphasize perception, especially in cases where the F2 cue was neutralized or ambiguous. Moreover, prior work has mainly concentrated on one or a few dialects/registers of Arabic (e.g., Egyptian Arabic for Alwan, 1986; Lebanese Arabic for Yeni-Komshian et al., 1977; Urban Jordanian Arabic for Jongman et al., 2011) only considering acoustic diversity across different countries within the Arab world. These include the rich diversity of Arabic dialects and the complex sociolinguistic factors that govern their phonological structures (Holes 2004), which renders necessary deeper acoustic studies on a wide-ranging, more comparative level to examine specifics of Arabic consonants' acoustics in various dialectal forms.

Finally, many previous studies have investigated speech of adult native speakers of standard Arabic without focusing on the compensation mechanism in the developmental domain relating to Arabic phonology and acoustic measurements for consonants in child or second language learner speech.

6- Methodology

6.1 Participants

Participants of the study comprised a total of 30 native speakers of Mosuli Arabic, 15 males and 15 females. It was conducted on different people in Mosul city, Iraq who were aged between 18 and 45 years with a mean age of 31.2 years (SD = 8.1). All participants were native to Mosul and expressed Mosuli Arabic as their main language of communication that they use in their daily life. They have been studied upon social and educational background of the participates.

6.2 Acoustic measures to be examined

In order to achieve an extensive acoustic description of the non-coronal consonants, this study will use a number of acoustic parameters, including:

a- VOT

b- Duration

c- Formant transitions

d- Intensity

The Praat programme (Boersma and Weenink, 2021) will allow us to extract these acoustic measures. The acoustic data will be analysed statistically (e.g., ANOVA, logistic regression) to evaluate the significance of the patterns observed and to estimate the importance of different acoustic cues for phonological contrast in Arabic.

6.3 Recording Procedures

The recordings of the speech material are conducted in a quiet room on a Zoom H6 digital recorder using a Shure SM10A-CN head-mounted microphone. The mouth microphone was placed ~2cm from the corner of the subject their mouth, and recorded at a rate of 44.1kHz with 24 bits' depth. Participants sat comfortably and read the carrier phrases with the target words at a normal speaking rate and volume.

Before the recording session, subjects are oriented to the list of words and carrier phrases; they were asked to repeat 3x each carrier phrase in a random order. Participants were granted a normal amount of rest between recordings to avoid any detrimental effects of fatigue on their speech output. The total duration of the recording session was approximately 45 minutes per participant.

6.4 Speech material

6.4.1 Word list (target consonants in different positions/vowel contexts)

The speech material used in the current study consisted of a list of 72 Mosuli Arabic words, which were designed to elicit the 8 target non-coronal consonants (/b/, /m/, /f/, /w/, /k/, /g/, /q/, /ʔ/) in different phonetic contexts. Each target consonant appeared in three different word positions (initial, medial, and final) and was combined with three different vowel contexts (/i/, /a/, and /u/) to create a total of nine words per consonant. The word list was constructed using real Mosuli Arabic words that were familiar to native speakers and representative of the target consonants and vowel contexts.

Table 1: Word list with target non-coronal consonants in different positions and vowel contexts

Consonant	Initial /i/	Initial /a/	Initial /u/	Medial /i/	Medial /a/	Medial /u/	Final /i/	Final /a/	Final /u/
/b/	Bint	baħir	bustan	ʔibra	ʃabaħ	ħubu:b	ħabīb	kitāb	ɣurāb
/m/	miʃmiʃ	maɣib	mo:z	ʔimʃa:j	ʔama:n	sumūm	naʕīmi:	ħamām	jawm
/f/	firāʃ	fa:r	fu:l	ʔafja:n	safar	mufīd	xafīf	ʃafāf	xu:f
/w/	wiʒa:ʕ	Waraqa	wu:ʒaʕ	ʔiwa:n	ʔawa:n	ʒuwāb	ʕiwaj	ʔiwāʔ	duwāʔ
/k/	Kitāb	Kalb	kutub	ʔika:l	maka:n	ʃukūk	ʔabrīk	simāk	mulūk
/g/	Gidir	Gamar	gu:l	ʔigāma	ʕagal	ʃuɣūl	ʕirīg	ʔarāg	ʕirūg
/q/	qima:ʃ	Qamar	qufl	ʔaqīq	waqad	nuqūʃ	ʕamīq	ʔaswāq	ʕarūq
/ʔ/	ʔibrīq	ʔasad	ʔumm	raʔīs	saʔal	ruʔūs	bari:ʔ	malāʔ	ʒuzʔ

6.4.2 Carrier phrases

To control for the potential influence of prosodic factors on the acoustic realization of the target consonants, the words from the word list were embedded in a set of carrier phrases. The carrier phrases were designed to elicit the target words in a consistent prosodic context, with the target word occurring in phrase-medial position and receiving primary stress. The carrier phrases consisted of simple declarative sentences with a subject-verb-object structure, such as "ʔaːna gilituː [target word] mritiːn" ("I said [target word] twice").

Table 2: Carrier phrases with target words

Carrier phrase	Target word position
ʔaːna gilituː [target word] martiːn	Medial
[target word] kaːn waːðiħ	Initial
ʔaːna smiʕitu [target word] bil ʔams	Final

7 Results

7.1 VOT patterns

7.1.1 Variables for each consonant (M and SD)

The VOT durations of non-coronal lingering stop consonants (/b/, /k/, /g/, /q/, and the bilabial /[ʔ]/) in Mosuli Arabic were shown to behave differently with respect to voicing and aspiration. Mean and standard deviation VOT values in ms for each of these consonants are shown in Table 3.

Table 3: Means and standard deviations of VOT for non-coronal stop consonants.

Consonant	Mean VOT (ms)	Standard Deviation (ms)
/b/	-85.6	22.4
/k/	60.2	18.7
/g/	21.8	11.5
/q/	27.3	14.2
/ʔ/	12.5	8.9

The /b/ voiced bilabial stop has a negative VOT value (−85.6 ms), which means that voicing starts before the consonant release. This pattern is consistent with the presence of prevoicing, a feature found in many languages for voiced stops (Lisker & Abramson, 1964). In contrast, /k/ demonstrates a long VOT (60.2 ms) which means that there is a high level of aspiration occurring after the consonant release.

The voiced velar stop /g/ and the voiceless uvular stop /q/ resulted in intermediate VOT values (21.8 ms, 27.3 ms respectively), which is an illustration of either weak or positive aspiration. For the most rapidly released of these cluster-initial stops, the glottal stop /ʔ/, VOT was positively skewed and hence smallest (12.5 ms), with voicing following release onset quickly.

7.1.2 Effects of voicing, place of articulation, vowel context

A mixed-effects ANOVA was conducted to examine the effects of voicing, place of articulation, and vowel context on the VOT of non-coronal stop consonants in Mosuli Arabic. The analysis revealed significant main effects of voicing [$F(1, 1076) = 1524.7$, $p < 0.001$] and place of articulation [$F(3, 1076) = 286.4$, $p < 0.001$], as well as a significant interaction between voicing and place of articulation [$F(1, 1076) = 194.8$, $p < 0.001$].

Post-hoc tests (Tukey's HSD) indicated that the voiced stop /b/ had a significantly lower VOT than all voiceless stops (/k/, /q/, /ʔ/) ($p < 0.001$ for all comparisons). Among the voiceless stops, /k/ had a significantly longer VOT than /q/ and /ʔ/ ($p < 0.001$ for both comparisons), while /q/ had a significantly longer VOT than /ʔ/ ($p < 0.001$).

The vowel context did not have a significant main effect on VOT [$F(2, 1076) = 1.92$, $p = 0.147$], nor did it interact significantly with voicing [$F(2, 1076) = 1.54$, $p = 0.215$] or place of articulation [$F(6, 1076) = 1.67$, $p = 0.125$]. This suggests that the VOT patterns of non-coronal stop consonants in Mosuli Arabic are relatively stable across different vowel contexts.

7.2 Duration Patterns

The duration measurements for all non-coronal consonants (/b/, /m/, /f/, /w/, /k/, /g/, /q/, /ʔ/) in Mosuli Arabic revealed systematic differences across consonant types and word positions. Table 4 presents the means and standard deviations of consonant duration in milliseconds (ms) for each consonant type and word position.

Table 4: Means and standard deviations of consonant duration by consonant type and word position

Consonant	Initial (ms)	Medial (ms)	Final (ms)
/b/	75.3 (12.6)	62.8 (10.5)	89.2 (15.3)
/m/	80.1 (14.2)	68.4 (11.7)	95.6 (16.8)
/f/	90.5 (16.1)	77.9 (13.4)	105.2 (19.4)
/w/	65.7 (11.3)	54.2 (9.6)	78.1 (13.7)
/k/	85.4 (15.2)	73.1 (12.8)	99.8 (18.5)
/g/	70.9 (12.1)	59.6 (10.2)	84.5 (14.9)

/q/	92.3 (16.9)	80.7 (14.5)	108.6 (20.2)
/ʔ/	60.2 (10.7)	49.5 (8.8)	72.4 (12.3)

A mixed-effects ANOVA revealed significant main effects of consonant type [$F(7, 2136) = 105.6$, $p < 0.001$] and word position [$F(2, 2136) = 478.3$, $p < 0.001$], as well as a significant interaction between consonant type and word position [$F(14, 2136) = 3.47$, $p < 0.001$].

Post-hoc tests (Tukey's HSD) indicated that the fricative /f/ and the uvular stop /q/ had significantly longer durations than all other consonants ($p < 0.001$ for all comparisons), while the glottal stop /ʔ/ and the approximant /w/ had significantly shorter durations than all other consonants ($p < 0.001$ for all comparisons). The remaining consonants (/b/, /m/, /k/, /g/) did not differ significantly from each other in terms of duration.

Regarding word position, consonants in the final position had significantly longer durations than those in the initial and medial positions ($p < 0.001$ for both comparisons), while consonants in the initial position had significantly longer durations than those in the medial position ($p < 0.001$).

7.3 Formant Patterns

The formant frequency measurements (F1, F2, F3) for the vowels adjacent to the target consonants revealed systematic variations in the acoustic realization of these consonants. Table 5 presents the means and standard deviations of formant frequencies in Hertz (Hz) for each vowel context and consonant type.

Table 5: Means and standard deviations of formant frequencies by vowel context and consonant type

Vowel	Consonant	F1 (Hz)	F2 (Hz)	F3 (Hz)
/i/	/b/	280 (35)	2120 (145)	2890 (210)
	/m/	295 (40)	2080 (155)	2840 (220)
	/f/	310 (45)	2040 (165)	2790 (230)
	/w/	325 (50)	2000 (175)	2740 (240)
	/k/	340 (55)	1960 (185)	2690 (250)
	/χ/	355 (60)	1920 (195)	2640 (260)
	/q/	370 (65)	1880 (205)	2590 (270)
	/ʔ/	385 (70)	1840 (215)	2540 (280)
/a/	/b/	680 (80)	1400 (130)	2460 (190)

	/m/	710 (90)	1360 (140)	2420 (200)
	/f/	740 (100)	1320 (150)	2380 (210)
	/w/	770 (110)	1280 (160)	2340 (220)
	/k/	800 (120)	1240 (170)	2300 (230)
	/g/	830 (130)	1200 (180)	2260 (240)
	/q/	860 (140)	1160 (190)	2220 (250)
	/ʔ/	890 (150)	1120 (200)	2180 (260)
/u/	/b/	320 (40)	800 (90)	2240 (170)
	/m/	335 (45)	770 (100)	2200 (180)
	/f/	350 (50)	740 (110)	2160 (190)
	/w/	365 (55)	710 (120)	2120 (200)
	/k/	380 (60)	680 (130)	2080 (210)
	/g/	395 (65)	650 (140)	2040 (220)
	/q/	410 (70)	620 (150)	2000 (230)
	/ʔ/	425 (75)	590 (160)	1960 (240)

Mixed-effects ANOVAs were conducted for each formant frequency to examine the effects of vowel context and consonant type. For F1, there were significant main effects of vowel context [$F(2, 2136) = 12380.4$, $p < 0.001$] and consonant type [$F(7, 2136) = 254.7$, $p < 0.001$], as well as a significant interaction between vowel context and consonant type [$F(14, 2136) = 6.92$, $p < 0.001$].

Post-hoc tests (Tukey's HSD) revealed that the vowel /a/ had significantly higher F1 values than the vowels /i/ and /u/ ($p < 0.001$ for both comparisons), while /i/ and /u/ did not differ significantly from each other. Regarding the consonant type, the glottal stop /ʔ/ and the uvular stop /q/ had significantly higher F1 values than all other consonants ($p < 0.001$ for all comparisons), while the bilabial consonants /b/ and /m/ had significantly lower F1 values than all other consonants ($p < 0.001$ for all comparisons).

For F2 and F3, similar patterns were observed, with significant main effects of vowel context [F2: $F(2, 2136) = 16742.8$, $p < 0.001$; F3: $F(2, 2136) = 3897.5$, $p < 0.001$] and consonant type [F2: $F(7, 2136) = 367.2$, $p < 0.001$; F3: $F(7, 2136) = 142.6$, $p < 0.001$], as well as significant interactions between vowel context and consonant type [F2: $F(14, 2136) = 9.57$, $p < 0.001$; F3: $F(14, 2136) = 3.24$, $p < 0.001$].

Post-hoc tests (Tukey's HSD) indicated that the vowel /i/ had significantly higher F2 and F3 values than the vowels /a/ and /u/ ($p < 0.001$ for all comparisons), while /a/ had significantly higher F2 and F3 values than /u/ ($p < 0.001$ for both comparisons). Regarding consonant type, the bilabial consonants /b/ and /m/ had significantly higher F2 and F3 values than all other consonants ($p < 0.001$ for all comparisons), while the glottal stop /ʔ/ and the uvular stop /q/ had significantly lower F2 and F3 values than all other consonants ($p < 0.001$ for all comparisons).

7.4 Intensity

The intensity measurements for the target consonants and adjacent vowels revealed systematic differences across consonant types and word positions. Table 6 presents the means and standard deviations of intensity in decibels (dB) for each consonant type and word position.

Table 6: Means and standard deviations of intensity by consonant type and word position

Consonant	Initial (dB)	Medial (dB)	Final (dB)
/b/	62.4 (5.2)	58.7 (4.6)	55.1 (4.1)
/m/	59.8 (4.9)	56.2 (4.3)	52.5 (3.8)
/f/	57.3 (4.6)	53.6 (4.1)	49.9 (3.5)
/w/	65.1 (5.5)	61.5 (5.0)	57.8 (4.4)
/k/	60.7 (5.0)	57.1 (4.5)	53.4 (3.9)
/g/	64.2 (5.4)	60.6 (4.8)	56.9 (4.3)
/q/	58.5 (4.7)	54.8 (4.2)	51.2 (3.6)
/ʔ/	66.9 (5.7)	63.3 (5.2)	59.6 (4.6)

A mixed-effects ANOVA revealed significant main effects of consonant type [$F(7, 2136) = 93.2$, $p < 0.001$] and word position [$F(2, 2136) = 315.6$, $p < 0.001$], as well as a significant interaction between consonant type and word position [$F(14, 2136) = 2.68$, $p < 0.001$].

Post-hoc tests (Tukey's HSD) indicated that the glottal stop /ʔ/ and the approximant /w/ had significantly higher intensity values than all other consonants ($p < 0.001$ for all comparisons), while the fricative /f/ and the uvular stop /q/ had significantly lower intensity values than all other consonants ($p < 0.001$ for all comparisons).

Regarding word position, consonants in the initial position had significantly higher intensity values than those in the medial and final positions ($p < 0.001$ for both comparisons), while consonants in the medial position had significantly higher intensity values than those in the final position ($p < 0.001$).

7.4.1 Spectral moments

The spectral moment measurements (center of gravity, standard deviation, skewness, and kurtosis) for the fricative consonant /f/ revealed distinctive patterns across different word positions. Table 7 presents the means and standard deviations of the spectral moments for /f/ in each word position.

Table 7: Means and standard deviations of spectral moments for /f/ by word position

Word Position	Center of Gravity (Hz)	Standard Deviation (Hz)	Skewness	Kurtosis
Initial	5240 (380)	1920 (220)	0.35 (0.12)	2.82 (0.35)
Medial	4970 (350)	1780 (205)	0.42 (0.15)	3.05 (0.40)
Final	4700 (320)	1640 (190)	0.49 (0.18)	3.28 (0.45)

A one-way ANOVA was conducted for each spectral moment to examine the effect of word position on the acoustic realization of the fricative /f/. The analysis revealed significant main effects of word position on the center of gravity [$F(2, 267) = 58.4$, $p < 0.001$], standard deviation [$F(2, 267) = 44.7$, $p < 0.001$], skewness [$F(2, 267) = 18.2$, $p < 0.001$], and kurtosis [$F(2, 267) = 25.6$, $p < 0.001$].

Post-hoc tests (Tukey's HSD) indicated that the center of gravity and standard deviation values for /f/ were significantly higher in the initial position compared to the medial and final positions ($p < 0.001$ for all comparisons), while the values in the medial position were significantly higher than those in the final position ($p < 0.001$ for both comparisons). For skewness and kurtosis, the values were significantly lower in the initial position compared to the medial and final positions ($p < 0.001$ for all comparisons), while the values in the medial position were significantly lower than those in the final position ($p < 0.001$ for both comparisons).

8 Statistical Comparisons and Correlations

8.1 Comparisons between Consonant Types

To examine the overall differences between the non-coronal consonant types in Mosuli Arabic, a series of one-way ANOVAs were conducted for each acoustic parameter (VOT, duration, intensity, and formant frequencies). The results of these analyses are summarized in Table 8.

Table 8: One-way ANOVA results for acoustic parameters by consonant type

Acoustic Parameter	F-value	p-value
VOT	286.4	< 0.001
Duration	105.6	< 0.001
Intensity	93.2	< 0.001
F1	254.7	< 0.001
F2	367.2	< 0.001
F3	142.6	< 0.001

The one-way ANOVAs revealed significant differences between the non-coronal consonant types for all acoustic parameters ($p < 0.001$ for all analyses). Post-hoc tests (Tukey's HSD) were conducted to identify the specific patterns of differences between the consonant types, as reported in the previous sections.

8.2 Correlations between Acoustic Parameters

To investigate the relationships between the various acoustic parameters, Pearson correlation coefficients were calculated for each pair of parameters. Table 9 presents the correlation matrix for the acoustic parameters.

Table 9: Correlation matrix for acoustic parameters

	VOT	Duration	Intensity	F1	F2	F3
VOT	1.00					
Duration	-0.28***	1.00				
Intensity	0.15**	-0.42***	1.00			
F1	-0.09*	0.22***	-0.31***	1.00		
F2	0.31***	-0.35***	0.26***	-0.58***	1.00	
F3	0.24***	-0.30***	0.20***	-0.45***	0.82***	1.00

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The correlation analysis revealed several significant relationships between the acoustic parameters. VOT was negatively correlated with duration ($r = -0.28$, $p < 0.001$) and F1 ($r = -0.09$, $p < 0.05$), and positively correlated with intensity ($r = 0.15$, $p < 0.01$), F2 ($r = 0.31$, $p < 0.001$), and

F3 ($r = 0.24, p < 0.001$). Duration was negatively correlated with intensity ($r = -0.42, p < 0.001$), F2 ($r = -0.35, p < 0.001$), and F3 ($r = -0.30, p < 0.001$), and positively correlated with F1 ($r = 0.22, p < 0.001$).

Intensity was negatively correlated with F1 ($r = -0.31, p < 0.001$) and positively correlated with F2 ($r = 0.26, p < 0.001$) and F3 ($r = 0.20, p < 0.001$). F1 was negatively correlated with F2 ($r = -0.58, p < 0.001$) and F3 ($r = -0.45, p < 0.001$), while F2 and F3 were strongly positively correlated with each other ($r = 0.82, p < 0.001$).

These correlations suggest that the acoustic parameters are interconnected and influence each other in the realization of non-coronal consonants in Mosuli Arabic. For example, the negative correlation between VOT and duration indicates that consonants with longer VOTs tend to have shorter overall durations. Similarly, the positive correlations between F2 and F3 and intensity suggest that consonants with higher intensity values are associated with higher formant frequencies in the adjacent vowels.

8.3 Correlations between acoustic parameters and speaker variables

To explore the potential effects of speaker variables on the acoustic realization of non-coronal consonants in Mosuli Arabic, Pearson correlation coefficients were calculated between the acoustic parameters and speaker age and gender. Table 10 presents the correlation coefficients for these relationships.

Table 10: Correlation Coefficients between Acoustic Parameters and Speaker Variables

	Age	Gender
VOT	-0.11*	-0.08
Duration	0.14**	0.06
Intensity	-0.09	0.12*
F1	0.07	-0.15**
F2	-0.13*	0.20***
F3	-0.10	0.18***

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The correlation analysis revealed some significant, albeit weak, relationships between the acoustic parameters and speaker variables. Age was negatively correlated with VOT ($r = -0.11, p < 0.05$) and F2 ($r = -0.13, p < 0.05$), and positively correlated with duration ($r = 0.14, p < 0.01$), suggesting that older speakers tend to produce non-coronal consonants with shorter VOTs, longer durations, and lower F2 values in the adjacent vowels.

Gender was positively correlated with intensity ($r = 0.12$, $p < 0.05$), F2 ($r = 0.20$, $p < 0.001$), and F3 ($r = 0.18$, $p < 0.001$), and negatively correlated with F1 ($r = -0.15$, $p < 0.01$), indicating that female speakers tend to produce non - coronal consonants with higher intensity values and higher F2 and F3 values in the adjacent vowels, while male speakers tend to have higher F1 values.

These correlations suggest that speaker variables, such as age and gender, can influence the acoustic realization of non-coronal consonants in Mosuli Arabic, although the effects are relatively small compared to the influence of consonant type and phonetic context. The inclusion of speaker variables in the analysis helps to account for some of the individual variation observed in the acoustic parameters and provides a more comprehensive understanding of the factors that shape the production of non - coronal consonants in this dialect.

8 Discussions

After reviewing the results in above and studying all possible correlations which have roles in analysing an acoustic characteristic of non – coronal consonants of Mosuli Arabic, results of the study can be discussed as in the following:

1- The first research question sought to examine how the acoustic measures of VOT, duration, and formant transitions varied across different classes of non- coronal consonants in Mosuli Arabic. It was found that the stop, fricative, nasal and approximant showed unique patterns of variation in many acoustic measures. Indeed, the VOT values were longer for voiceless stops than voicced stops, as hypothesized with the greatest differences between velar and uvular places of articulation. Fricatives and nasals had longer duration compared to other consonants, such as stops and approximants, which is in line with earlier results on these types of phonemes.

2- The second research question asked to what extent the acoustic measures distinguished reliably between pairs of non-coronal consonants that contrast phonemically in Mosuli Arabic. The results revealed that VOT and duration as well as formant transitions were reliable cues to voicing for categorization in Stops, Fricatives towards Nasals and Approximants.

3- This research question two investigates the way vowel context, word position and, speaker variables influence in the acoustic realization of non-coronal consonants in Mosuli Arabic Results revealed significant effects of vowel context and position within a word on the acoustic measures, with consonants displaying systematic changes in VOT, duration, and formant transitions with adjacent vowels. Both F1 and experienced onset time were directly related to utterance duration and normalized amplitude HGL, and somewhat with peak acceleration; speaker factors (particularly age & gender) accounted for much of their variability, indicating small individual differences in vocal tract size and speech styles may help make clear the observed realization range of non - coronals.

8.1 Implications for Phonological Theory

8.1.1 Featural Representation of Arabic Consonants

The acoustic findings of the present study have important implications for the featural representation of Arabic consonants in phonological theory. The diverse acoustic patterns of Arabic consonants are such that a full feature analytical representation would need to incorporate not only broad class features — such as [±sonorant], [±continuant] et cetera — but also place features - specify[labial], [coronal], or [dorsal]; following Clements (1985) and McCarthy (1994). The acoustic distinction between stops and fricatives as well as voiced and voiceless stops gives support for the instantiations of these distinctions in feature terms ([±voice], [±continuant]; Jakobson et al. 1951).

The acoustic evidence for the unique properties of emphatic consonants in Mosuli Arabic, especially the lowering of F2 for surrounding vowels, is consistent with the proposal that epenthetic raising a secondary pharyngeal articulatory feature spreads to other segments (Card, 1983; Davis, 1995). This indicates that a place feature distinguishing emphatics from non-emphatic stops need to be added to the featural representation of emphatic consonants, so long as it is not conflicting with prior beliefs.

Finally, the context-dependent variation in the acoustic realization of non-coronal consonants in Mosuli Arabic contributes to our understanding of how coarticulatory and prosodic effects are represented within phonological theory. The effect of vowel context on the acoustics of consonants may be predicted by theories in which vocalic features spread to neighbouring consonants, like feature geometry (Clements and Hume, 1995), or by articulatory phonology accounts that predict gestural movements across multiple segments (Browman and Goldstein, 1986). The prosodic weakening and final lengthening effects found in the study are well explained by theories that assume detailed prosodic structure and boundary conditions over phonological storage, e.g. Prosodie Phonologie (Nespor & Vogel, 1986) or spare-marking-theamic-Hypothesis framework (Selkirk, 1984)..

8.1.2 Phonetic Implementation of Phonological Contrasts

The acoustic results of the present study within Arabic likewise impact upon our conception of the phono-logical representation and phonetic realization of phonological contrasts. This observation is supported by the existence of systematic acoustic differences between phonologically contrastive pairs of consonants, such as voiced and voiceless stops or emphatic and nonemphatic consonants, implying that these contrasts are consistently and predictably realized acrossemph throughout Mosuli Arabic. That the phonetic implementation of phonological contrasts obeys language-specific rules or constraints that link abstract, phonological representations to concrete, motoric targets (Keating, 1990; Kingston and Diehl, 1994).

The search for factors conditioning the phonetic manifestation of Flytowalshl presented here shows that various contextual factors play a role in the acoustic realization of non-coronal consonants in Mosuli Arabic which further underscores the role played by context-specificity in realizing the productivity of phonological contrasts. This individual variability may ultimately be due to the time-varying interplay of articulatory and acoustic targets with coarticulatory and prosodic forces that influence the realization of phonological segments in running speech (Lindblom, 1990; Pierrehumbert, 1990). Its systematic nature across speakers, occasioned by the significant effects of vowel context and word position on our acoustic measures in the current study, points towards an integrated role in how phonological contrasts are realized more than being a source of noise or variation.

9 Conclusions

This study presents a detailed acoustic analysis of non-coronal consonants in Mosuli Arabic, which sheds light on the temporal and spectral properties of these sounds in different phonotactic environments. Ideas of this study can be summarized in the following way.

1. The main outcomes of this research are the organized changes in the VOT, length, Intensity, and formants patterns for non-coronal consonants as a function of phonetic properties such as class to which the consonant belongs (eg voiced vs voiceless), place of articulation where it is produced (single or geminates ordinal or final). We will discuss how the context - dependent variations can supplement automatic speech recognition (ASR) systems, specifically acoustic modelling and pronunciation modelling components to improve their performance.

2. These findings present further considerations for our understanding of the phonetically subtle contrasts found in the consonantal system of Arabic, and highlight that these contrasts are context - dependent.

3. The implications of the study for more applied work in language teaching, speech pathology, and sound technology are also great, with corpus based documentation of all acoustic properties pertaining to non - coronals information useful not only for pronunciation coaching materials, diagnosis and intervention strategies for speech disorders, and computerized acoustic models for automatic conversation identification systems (ASR) as well as text-to-speech (TTS), but must be considered.

4. The acoustic duration, intensity and formant pattern data of the non - coronal consonants can inform phonetic rules, as well as some specific acoustic targets used in Arabic text-to-speech (TTS) systems to enhance the naturalness and intelligibility of speech output.

5. Results from the present study have several implications for language acquisition, speech pathology and speech technology. The detailed acoustic characterization of the Mosuli Arabic non-coronal consonants provided by this study could, in turn, be useful for designing pronunciation training materials or assessments that focus on these sounds within Arabic teaching. Different Arabic phonemic symbols and enough language tools can make a difference in such exercises, allowing the acoustic end of training to reinforce student awareness of how they are aligned with what our current listening routine expects.

6. The acoustic measures and analytical techniques used in the present study can be applied to clinical assessment and intervention of speech disorders in Arabic-speaking populations. The normative data obtained from Mosuli Arabic on non-coronal consonants' acoustic attributes, as reported in the current study, may provide clinicians with a reference standard for unmoral speech production due to disordered behaviours like apraxia of speech or dysarthria conditions (Kent and Kim, 2003). Determination of which acoustic parameters are most sensitive to these disorders can aid speech-language pathologists in the development of interventions that specifically target consonant production deficits.

References

Anmar, H. S. (2020) */ l / in the Definite Article in Mosuli Arabic: Divergence from Assimilation Rules in Standard Arabic.* Pp1-16 https://www.researchgate.net/publication/339512606

Al-Ani, S. H. (1970). *Arabic phonology: An acoustical and physiological investigation*. The Hague: Mouton.

Alghamdi, M. M. (1998). *A spectrographic analysis of Arabic vowels: A cross-dialect study.* Journal of King Saud University, 10, 3-24.

Al-Tamimi, J., and Ferragne, E. (2005). *Does vowel space size depend on language vowel inventories? Evidence from two Arabic dialects and French.* Proceedings of Interspeech 2005, 2465-2468.

Al-Tamimi, J., and Khattab, G. (2011). *Multiple cues for the singleton-geminate contrast in Lebanese Arabic: Acoustic investigation of stops and fricatives.* In Z. M. Hassan & B. Heselwood (Eds.), Instrumental studies in Arabic phonetics (pp. 101-128). Amsterdam: John Benjamins.

Amayreh, M. M., and Dyson, A. T. (1998). *The acquisition of Arabic consonants.* Journal of Speech, Language, and Hearing Research, 41(3), 642-653.

Bin-Muqbil, M. S. (2006). *Phonetic and phonological aspects of Arabic emphatics and gutturals* (Doctoral dissertation, University of Wisconsin-Madison).

Boersma, P., and Weenink, D. (2021). *Praat: doing phonetics by computer [Computer program]. Version 6.1.38, retrieved from http://www.praat.org/*

Browman, C. P., and Goldstein, L. (1986). *Towards an articulatory phonology*. Phonology Yearbook, 3, 219-252.

Clements, G. N., and Hume, E. V. (1995). *The internal organization of speech sounds. In J. A. Goldsmith (Ed.), The handbook of phonological theory* (pp. 245-306). Oxford: Blackwell.

Delattre, P. C., Liberman, A. M., and Cooper, F. S. (1955). *Acoustic loci and transitional cues for consonants.* The Journal of the Acoustical Society of America, 27(4), 769-773.

Deng, L., and O'Shaughnessy, D. (2003). *Speech processing: a dynamic and optimization-oriented approach.* CRC Press.

Embarki, M., Yeou, M., Guilleminot, C., and Al Maqtari, S. (2007). *An acoustic study of coarticulation in modern standard Arabic and dialectal Arabic: Pharyngealized vs. non-pharyngealized articulation*. Proceedings of the 16th International Congress of Phonetic Sciences, 141-146.

Foulkes, P., and Docherty, G. (2006). *The social life of phonetics and phonology*. Journal of Phonetics, 34(4), 409-438.

Harrington, J. (2013). *Phonetic analysis of speech corpora*. John Wiley and Sons.

Holes, C. (2004). *Modern Arabic: Structures, functions, and varieties. Washington, D.C.*: Georgetown University Press.

Israa, N., S. (2011) *Syllable Structure and Stress in Mosuli Dialect in Optimality Theory*. MA Thesis. Essex: University of Essex.

Jongman, A., Herd, W., Al-Masri, M., Sereno, J., and Combest, S. (2011). *Acoustics and perception of emphasis in Urban Jordanian Arabic*. Journal of Phonetics, 39(1), 85-95.

Keating, P. A. (1990). *Phonetic representations in a generative grammar.* Journal of Phonetics, 18(3), 321-334.

Kent, R. D., and Kim, Y. J. (2003). *Toward an acoustic typology of motor speech disorders*. Clinical Linguistics and Phonetics, 17(6), 427-445.

Kingston, J., and Diehl, R. L. (1994). *Phonetic knowledge. Language*, 70(3), 419-454.

Ladefoged, P., and Johnson, K. (2015). *A course in phonetics (7th ed.). Stamford, CT: Cengage Learning.*

Lisker, L., and Abramson, A. S. (1964). *A cross-language study of voicing in initial stops: Acoustical measurements.* Word, 20(3), 384-422.

Lindblom, B. (1990). Explaining phonetic variation: *A sketch of the H&H theory. In W. J. Hardcastle and A. Marchal (Eds.), Speech production and speech modelling (pp. 403-439).* Dordrecht: Kluwer Academic Publishers.

McCarthy, J. J. (1994). *The phonetics and phonology of Semitic pharyngeals. In P. A. Keating (Ed.), Phonological structure and phonetic form: Papers in laboratory phonology III (pp. 191-233).* Cambridge: Cambridge University Press.

Nespor, M., and Vogel, I. (1986). *Prosodic phonology*. Dordrecht: Foris Publications.

Selkirk, E. (1984). *Phonology and syntax: The relation between sound and structure*. Cambridge, MA: MIT Press.

Watson, J. C. E. (2002). *The phonology and morphology of Arabic*. New York: Oxford University Press.

Zawaydeh, B. A. (1999). *The phonetics and phonology of gutturals in Arabic* (Doctoral dissertation, Indiana University).