

## VOWEL PRODUCTION IN APHASIA: PRELIMINARY ACOUSTIC FINDINGS FROM ARABIC

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**Abstract.** The present study examined the temporal and spectral characteristics of vowels produced by Palestinian Arabic-speaking individuals with Broca's aphasia compared to healthy speakers. Specifically, vowel duration and formant frequency measures (F1&F2) were made. Eight speakers with Broca's aphasia and eight healthy speakers participated in the study. Repetition was used to elicit the target vowels to minimize language comprehension or reading difficulties by the individuals with Broca's aphasia. The speech sample contains the long vowels (/a:,u:,i:/) embedded in CVC words with nasal initials. Statistical analysis was used to determine any significant differences concerning the formant values (F1/F2) between the speaker groups. Findings showed that speakers with Broca's aphasia produced vowel categories with more variability than healthy speakers. For some, formant frequencies were comparable with those of the healthy speakers, and yet others showed an overlap of phonetic categories. Specifically, F1 and F2 for the vowel /u:/ were higher for individuals with Broca's aphasia compared to normal-speaking individuals, but they were not statistically significant. Furthermore, although speakers with Broca's aphasia produced longer vowel durations than the healthy speakers, they were not significantly different between speaker groups except for the vowel /i:/. Reduced vowel space was also observed in speakers with Broca's aphasia. The vowel ellipses as shown by speakers with Broca's aphasia were larger than those of healthy speakers. Results support previous studies showing abnormal temporal durations and spectral patterns in Broca's aphasia. Findings can contribute to cross-linguistic research on vowel production in aphasia, mainly in understudied languages such as Arabic.

**Keywords:** *Palestinian Arabic-speaking Broca's aphasics, formants of Arabic vowels, vowel duration, acoustic analysis, Broca's aphasia.*

**Гішам Адам. Породження голосних під час афазії: попередні результати досліджень звуків у носіїв арабської мови.**

**Анотація.** У цьому дослідженні порівнювалися темпоральні й спектральні характеристики голосних, що породжувалися носіями палестинської арабської з афазією Брока, та здоровими носіями цієї мови. Зокрема, було зроблено вимірювання тривалості голосних і формантної частоти (F1&F2). У дослідженні взяли участь вісім осіб з афазією Брока та вісім здорових осіб. Повторення використовувалося для виявлення цільових голосних, щоб звести до мінімуму труднощі розуміння мови або читання особами з афазією Брока. Фрагмент мовлення містив довгі голосні (/a:,u:,i:/) у словах, побудованих за принципом пригласний-голосний-приголосний із початковим носовим звуком. Для визначення будь-яких істотних відмінностей щодо значень формант (F1/F2) між групами мовців використовувався статистичний аналіз. Результати засвідчили, що мовці з афазією Брока породжували голосні з більшою варіативністю, ніж здорові мовці. Для деяких формантні частоти були відповідними з частотами здорових мовців, а в інших виявилось взаємонакладення фонетичних категорій. Зокрема, F1 і F2 для голосних /u:/ були вищими, але статистично не значущими в осіб із афазією Брока в порівнянні зі здоровими мовцями. Більше того, хоча у мовців з афазією Брока була довша тривалість голосних, ніж у

здорових мовців, вони не відрізнялися суттєво між групами мовців, за винятком голосного /i:/. Зменшений простір між голосними також спостережено в осіб з афазією. Еліпси голосних, у них були більшими, ніж у здорових мовців. Результати підтверджують попередні дослідження, які показують аномальну часову тривалість і спектральні моделі афазії Брока. Одержані висновки можуть сприяти міжлінгвістичним дослідженням щодо породження голосних під час афазії, головним чином у маловивчених мовах, зокрема арабській.

**Ключові слова:** носії палестинської арабської з афазією Брока, форманти арабських голосних, тривалість голосних, голосовий аналіз, афазія Брока.

## Introduction

Aphasia is a language disorder affecting all language modalities, such as using, speaking, understanding, reading, and writing. Aphasia can be categorized into different types and sub-types, depending on symptom or site of lesion (Garraffa & Fyndanis, 2020).). Table 1. presents the main types of aphasia according to neoclassical and functional system theories. Broca's aphasic speech is widely investigated compared to other types of aphasia (Matchin, 2018).

Substitutions, omissions, deletions, and morphosyntactic impairments are mainly characterized by agrammatic speech (Menn & Obler, 1990; Caramazza, 1997; Haley, Ohde & Wertz, 2011; Boye & Bastiaanse, 2018; Ouden et al., 2019; Martínez-Ferreiro et al, 2020). Deficits in the articulatory implementation of the phonetic features were also observed in speakers with Broca's aphasia (Kurowski & Blumstein, 2016; Verhaegen et al., 2019) reflecting timing deficits and articulatory coordination and laryngeal motor control impairments.

Table 1

*Classification of Aphasia According to Neo-Classical (Boston) and Functional System (Luria) Theories Adapted from Johansson (2012, p. 15)*

Dichotomisation	Neo-classical (Boston)	Functional (Luria) systems
Anterior / non-fluent / expressive	Broca's aphasia	Efferent motor aphasia
	Transcortical motor aphasia Global aphasia	Dynamic aphasia
Posterior / fluent / Receptive	Conduction (subcortical) aphasia	Afferent motor aphasia
	Wernicke's aphasia	Acoustic-gnostic (Sensory) aphasia
	Transcortical sensory aphasia	Acoustic-mnemonic aphasia
	Anomic aphasia	Semantic (amnesic) aphasia

## Arabic vowel system

Modern Standard Arabic (MSA) vowel system has three short vowels (/a, i, u/) and three long counterparts (/a:, i:, u:/). Vowel duration in Arabic is phonemic. That is, vowel quantity results in meaning differences such as in the following minimal pair: [mal] bored [ma:l] moved. English vowel system has been extensively studied compared to Arabic. Several acoustic studies on English vowels have established normative data for formant frequencies. Formant frequencies of standard Arabic vowels, in contrast, were generally less studied and documented.

A very few acoustic studies on Arabic vowels in standard Arabic and Arabic dialects have been carried out (Belkaid 1984; Abou Haidar 1994; Al-Anani, 1999; Newman & Verhoeven, 2002; Alotaibi & Hussain, 2009). It must be noted that these acoustic studies generally did not establish a database for standardized formant frequencies of the Arabic vowels due to research methodologies differences and dialectal and regional linguistic features. Furthermore, these studies were not aiming to study Arabic vowels' acoustic characteristics in individuals with impaired speech and for clinical purposes generally. The current study is thus a step towards filling this gap.

The purpose of the present study was to examine acoustic characteristics of vowels in Palestinian Arabic-speaking individuals with Broca's aphasia compared to healthy speakers. This study has two main research questions:

1. What are the temporal features of vowels produced by speakers with Broca's aphasia compared to healthy speakers?
2. What are the spectral characteristics (F1&F2) of vowels produced by speakers with Broca's aphasia compared to healthy speakers?

We hypothesized that some, if not all, of the acoustic measures of vowel duration and formant frequencies (F1& F2) will be significantly different between the speaker groups.

## Temporal and spectral studies

Several studies have addressed the consonantal errors in speakers with Broca's aphasia (Menn & Obler, 1990; Fyndanis et al., 2018; Aziz et al., 2020), assuming that the vowel system is relatively intact in Broca's aphasia. However, the literature on vowel production in aphasia has reported several findings. Haley, Ohde, and Wertz (2001) documented a high frequency of vowel errors in speakers with apraxia of speech with coexisting aphasia. The authors reported distortion and substitution vowel errors.

Keller (1978) examined in a detailed study vowel production and substitution patterns in the speech of five English-speaking Broca's aphasics. The analysis revealed that Broca's aphasics selectively impaired vowel height, and the substituted vowels closely matched the target vowels with the tendency of tongue body lowering.

In investigating vowel durations in speakers with Broca's aphasia, Schirmer (2004) found that those durations were significantly longer for speakers with Broca's aphasia than healthy speakers. In contrast, Gandour and Dardarananda (1984) found that Broca's aphasics' durational patterns are comparable to those of the healthy speakers.

Some acoustic studies showed that vowel formant frequency and the related vowel space measures are crucial to vowel discrimination tasks for healthy speakers and individuals with impaired speech (Liu et al, 2005; Tsao et. al., 2006) as they provide reliable acoustic clues about vowels accuracy production (Chodroff & Wilson, 2020). The vowel space is traditionally plotted as the triangular organization showing the first two formants F1 and F2. The acoustic investigations use the vowel space to quantify the articulatory configuration and function (Ferguson & Kewley-Port, 2007).

Haley, Bays and Ohde (2001) examined the acoustic and perceptual correlates of vowel quality in speakers with aphasia and apraxia of speech (AOS). Twenty speakers with and without apraxia of speech and ten healthy speakers participated in the study. F1 and F2 were measured at the midpoint of the vowel segment. Their acoustic analysis showed that the formant patterns of speakers with Broca's aphasia were deviated from those of the healthy speakers and varied across the aphasic and apraxic speakers. The results also showed that F1 and F2 values were abnormally variable across the groups. The authors generally documented vowel articulation impairments in many aphasic and apraxic participants, reflecting articulatory positioning deficits for vowel production.

In a repetition task, Ziegler and Hoole (1989) reported F1 and F2 measures in an acoustic and perceptual analysis for the vowels [i] and [i:]. Two aphasic patients, one has Broca's aphasia, and the second has Wernicke's aphasia, together with a healthy speaker and a dysarthric control, participated in the study. The aphasic group demonstrated a higher degree of spectral overlap between the target vowels compared to the healthy speakers. Additionally, the formant frequencies for the vowels produced by the speaker with Broca's aphasia were distributed relatively in a greater range compared to the speaker with Wernicke's aphasia.

## **Method**

### **Participants**

Eight Arabic-Palestinian speakers diagnosed with Broca's aphasia participated in the present study (6 male speakers and two female speakers). They were native speakers of Palestinian Arabic and all diagnosed with mild to moderate Broca's aphasia (Paradis & Libben, 1987). Each participant underwent a standardized aphasia assessment based on both formal and informal tests and clinical reports. The selected subjects were right-handed and had been suffering from a single left hemisphere lesion for at least six months before testing. They showed typical effortful, non-

fluent, telegraphic speech features, producing simplified and short utterances. They also had problems with free and bound grammatical morphemes.

The age of the participants ranged from 47 to 70 years. The time post-onset ranged from 13 to 210 months, and their number of years of education ranged from 5 to 14 years. Hearing was normal with no evidence of dysarthria or visual impairments. Table 2 presents the details of Broca’s participants. Eight healthy speakers of Palestinian Arabic matching the speakers with Broca’s aphasia for age and gender served as the control group.

Table 2  
*Data of the Participants with Agrammatism*

Subject	Gender	Age	Education (years)	Handedness Hemiplegia	m.p.o	Handedness
A1	M	69	12	Right	112	Right
A2	M	76	9	Right	30	Right
A3	M	48	13	Right	42	Right
A4	M	47	8	Right	34	Right
A5	M	53	14	Right	120	Right
A6	M	66	10	Right	13	Right
A7	F	69	11	Right	210	Right
A8	F	70	5	Right	70	Right
Means		60.25	10.25		78.87	

Participant data: (A: agrammatic speaker; CVA: Cerebro vascular accident; L: left hemisphere; MPO: months post onset; M: male, Edu: Education).

### Speech sample

The speech sample includes the target long vowels (/a:/, /u:/, /i:/) embedded in CV disyllabic words with nasal initials (/m, n/). Acoustically, vowels can be easily determined by using nasals, and the coarticulatory effects can be minimized. The stimuli include real words whenever possible; otherwise, nonsense words matching the same structure of the given real words were provided, as shown in table 2. For the target vowel initiation, a carrier sentence has been used. The stimuli have been written on a card and presented to the participants.

Each participant was asked to repeat after the examiner the token 3 times at normal pitch and loudness as much as possible. The aphasic subjects have produced 144 vowel tokens (6 words x 3 repetitions x 8 subjects). Methodologically, the study uses repetition to elicit the target vowels to minimize possible language comprehension, and reading difficulties may occur by the aphasic speakers (Kempler & Van Lancker, 2002).

The recordings were done in a quiet room using a high-quality microphone positioned around 15 centimeters from the participants' mouth. PRAAT program was used to extract the formant frequencies (F1, F2) automatically (Boersma & Weenink, 2020) and manually corrected at the midpoint of the vowels, using Phono-Lab (Metoui, 1995). Formants were measured 10 times in each vowel, and the data were recorded using a sampling rate of 16 Hz at 16 bits. The formants' values of the healthy speakers served as a point of reference. ANOVA statistical analysis was conducted to determine possible significant differences in the formant values (F1/F2) between the speaker groups. The correlation between the vowel formants F1 and F2 was tested using independent sample t-tests.

Table 3

*The Stimuli in a Nasal Context*

Target Vowels	Target consonant /m/	Target consonant /n/
/a:/	/ma:l/	/na:l/
/u:/	/mu:l/	/nu:l/
/i:/	/mi:l/	/ni:l/

## Results

*Formant frequencies.* Tables 4 and 5 present the mean F1 and F2 values of the long vowels (/a:, u:, i:/) across the nasal consonants /m/ and /n/ and between the speaker groups (Speakers with Broca's aphasia vs. Healthy speakers). Mann-Whitney U-test was used to compare F1 and F2 values across and within the groups (Speakers with Broca's aphasia vs. Healthy speakers).

Table 4

*Mean F1 and F2 (Hz) Values of Both the Groups Across Different Nasal Consonants /m/ and /n/*

Vowels	/m/		/n/					
	Group I (Healthy speakers)	Group 2 (Broca's aphasics)	Group I (Healthy speakers)	Group 2 (Broca's aphasics)				
	F1	F2	F1	F2	F1	F2	F1	F2
/a:/	760.70	1212.31	838.07	1271.75	762.72	1339.97	819.51	1318.72
/u:/	366.75	823.94	432.12	930.66	365.33	1047.53	391.79	1048.71
/i:/	414.72	2584.37	415.18	2126.97	321.59	2256.28	345.70	2334.37

Table 5  
*Mean F1 and F2 (Hz) of Vowels Between the Speaker Groups*

Vowels	Group 1 (Healthy speakers)		Group 2 (Broca's aphasics)	
	F1	F2	F1	F2
/a:/	761.71	1276.14	828.79	1295.235
/u:/	366.04	935.735	411.955	989.685
/i:/	368.155	2420.325	380.44	2230.67

The speaker groups displayed a statistically significant distinction between vowel targets. Tests of fixed effects showed that F1, ( $F(1,14)= 8.52, p=.001$ ), but not F2, ( $F(1,14) = 1.12, p=.33$ ) was significantly different for (/a:,u:, i:/) targets among healthy speakers. The same result was observed in the Broca's aphasic group, where a significant difference between /a:/, /u:/ and /i:/ was found for F1, ( $F(1,14)=5.31, p=.004$ ), but not F2, ( $F(1,14)= 1.07, p= .38$ ).

As shown in table 6, the Mann-Whitney U-test results revealed that the F1 values of vowel /a:/ in individuals with Broca's aphasia were statistically significant ( $Z=-3.267, p=.001$ ) than normal speaking subjects. In contrast, there was no significant difference between speakers with Broca's aphasics and normal speaking individuals for F2. i.e., F2 values were similar between both the groups. For the vowel /u:/, both F1 and F2 were higher in individuals with Broca's aphasia than normal-speaking individuals. But these findings were not statistically significant. The F1 of vowel /i:/ was similar between Broca's aphasics and normal speaking subjects, i.e., no significant difference between the groups on F1 values. However, for F2, it was higher in normal speaking subjects than in individuals with Broca's aphasia, which was statistically significant at .05 level ( $Z=-3.126, p= .012$ ).

Table 6  
*The Values of Mann-Whitney U-test for the Vowels /a:, u:,i:) Following the Nasals /m/ and /n/*

Vowels	Group I (Normal)		Group 2 (Broca's aphasics)	
	F1	F2	F1	F2
/a:/	-2.894 (p= .037)	-.714 (p= .627)	-3.267 (p=.001)	-.672 (p= .664)
/u:/	-1.156 (p= .139)	-1.548 (p= .097)	-2.351 (p=.056)	-2.232 (p= .054)
/i:/	-1.956 (p= .063)	-3.126 (p= .012)	-1.864 (p=.078)	-2.945 (p= .023)

\* Significant difference between means at  $P <.05$  or less utilizing the Mann-Whitney U-test (z -store correction for tied ranks).

*Vowel duration.* Figure 1 presents the average durations (ms) of the three long vowels (/a:,u:,i:/) for speakers with Broca's aphasia and healthy speakers. Although Broca's aphasics produced longer durations for all three vowels than the healthy speakers, the ANOVA analysis showed no significant differences among the speaker groups for the vowels /a:/ and /u:/ except for the vowel /i:/ being significantly longer for speakers with Broca's aphasia relative to the healthy speakers.

Figure 1

*Box Plot of Mean Vowel Duration (Ms) for the Vowels /A:, U:,I:/ As Produced by the Healthy Speakers and Speakers with Broca's Aphasia*



*Vowel space.* Figure 2 illustrates the acoustic vowel space of Broca's aphasics and healthy speakers. When comparing Broca's aphasics' findings to healthy speakers, differences between the groups were observed. More specifically, the front vowel /i:/ is more backed in Broca's aphasics than healthy speakers. Vowel backness is associated with F2 lowering, indicating reduced tongue advancement. Interestingly, Broca's aphasics produced /u:/ more fronted compared to the healthy speakers. Also, the acoustic vowel space showed that Broca's aphasics had the vowel categories approximately in the same regions of the vowel space in healthy speakers. Furthermore, unlike the healthy speakers, /a:/ was lower in the acoustic space in Broca's aphasics speech. Furthermore, speakers with Broca's aphasia produced (/i:, u:/) lower in the acoustic space than the healthy speakers whose (/i:, u:/) were located much higher.

As shown in Fig. 2, Broca's aphasics demonstrated a relatively reduced acoustic area compared to healthy speakers. The vowel ellipses of all vowel understudies in Broca's aphasics were noticeably larger than the healthy speakers, as can be seen in Fig. 3. Among the three vowels, Broca's aphasics produced the vowel /u:/ with the

largest ellipse areas relative to the healthy speakers, suggesting tongue positioning deviations.

Figure 2  
*The Acoustic Vowel Space of Broca's Aphasics and the Healthy Speakers*

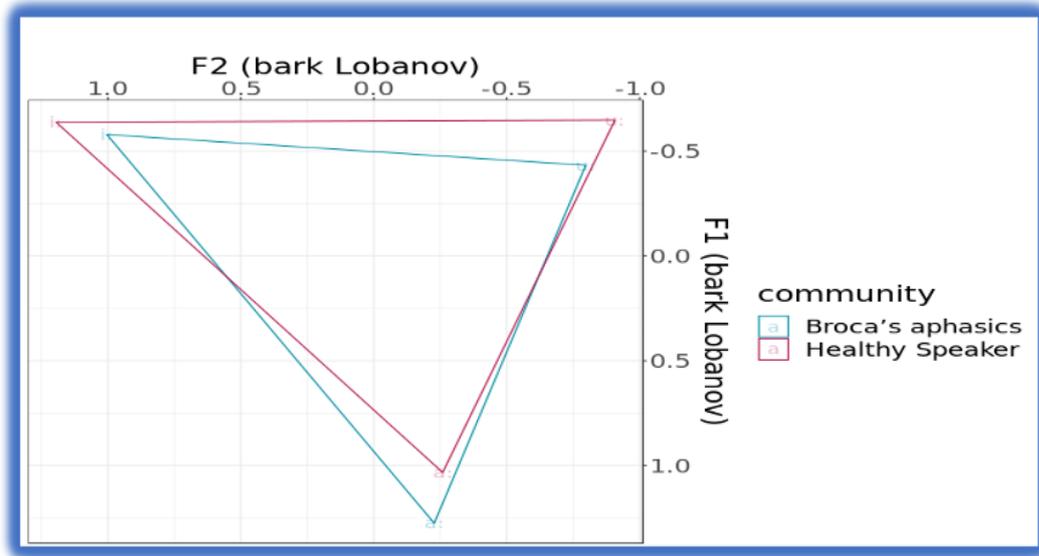
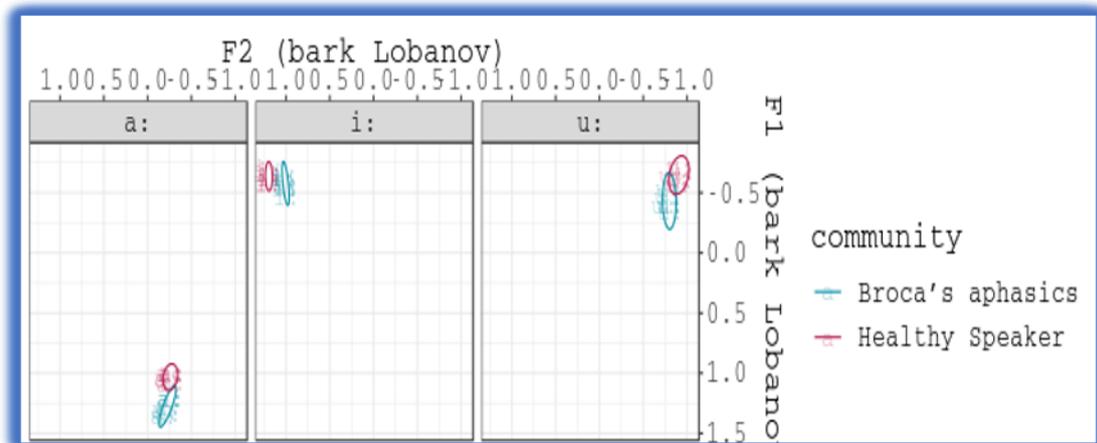
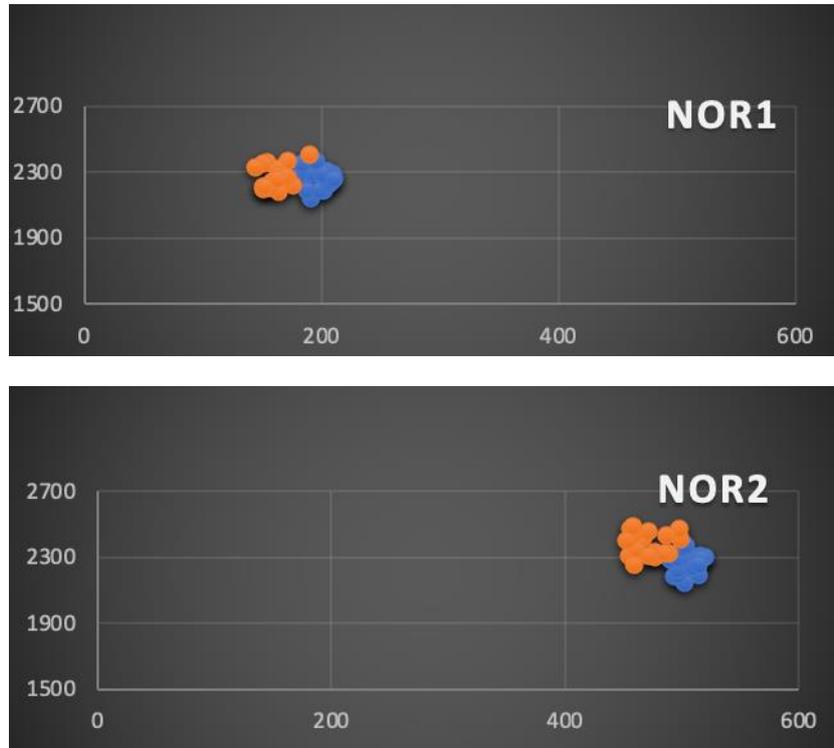


Figure 3  
*The Acoustic Vowel Space of Broca's Aphasics and the Healthy Speakers*



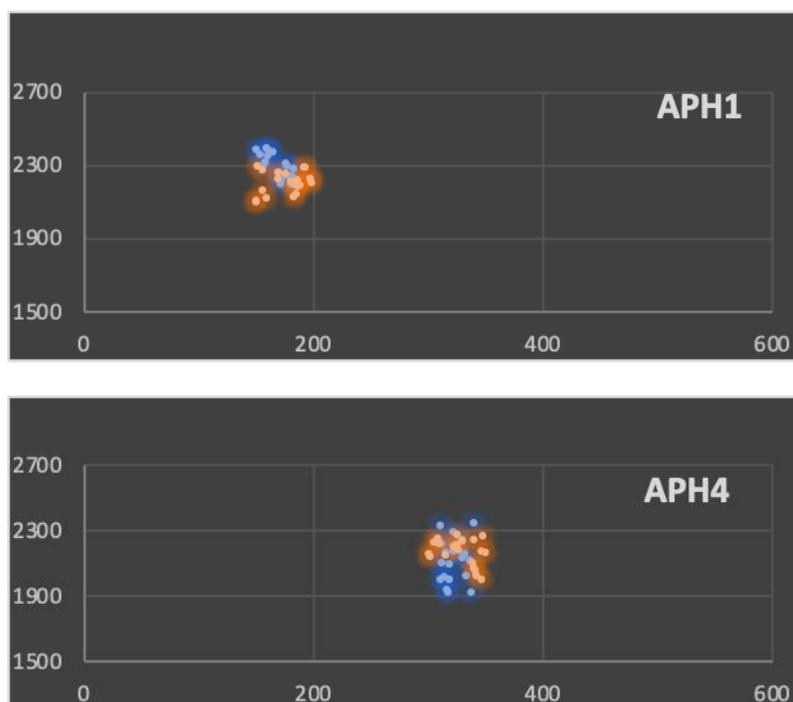
Furthermore, individual formant spaces showed notable variations regarding vowel placement patterns with most vowel distribution variability and overlap for all speakers with Broca's aphasia except for the participant APH6, as shown in Fig. 4. In contrast, the healthy speakers showed no overlap while producing the target vowel categories, as presented in Fig. 4. The findings generally revealed differences between Broca's aphasics and the healthy speakers concerning vowel height and vowel frontness/backness.

Figure 4  
*F1 and F2 Frequencies for Normal Speakers (NOR)*



Colored diamonds and circles represent the target vowels. There is no distribution overlap for healthy speakers NOR1 and NOR2.

Figure 5  
*F1 and F2 Frequencies for Speakers Diagnosed with Aphasia (APH)*





Colored diamonds and circles represent the target vowels. There is a distribution overlap for the speakers with Broca’s aphasia APH1, APH4 and APH7 with the exception of APH6.

## Discussion

The present study was aimed to examine vowel production in Arabic-speaking individuals with Broca’s aphasics compared to healthy speakers, focusing on vowel duration and formant frequencies. The findings showed that speakers with Broca’s aphasia had longer vowel durations compared to healthy speakers, but no statistically significant differences were observed, except /i:/ being longer by speakers with Broca’s aphasia. These results are consistent with previous studies (Baum & Pell, 1997; Baum & Boyczuk, 1999; Schirmer, 2004; Seddoh, 2008).

Such excessive prolongations indicate temporal impairments and motor planning deficits. They may also suggest inadequate tactile feedback during vowel production compared to consonants. Therefore, this may make Broca’s aphasics are uncertain about the articulatory configurations and tongue movements required for producing vowels accurately and intelligibly (Williams & Seaver, 1986). The fact that slow speech also characterized Broca’s aphasia supports such abnormal temporal durations, indicating self-monitoring problems and motor speech planning deficits. It is also interesting to note that our speakers with Broca’s aphasia successfully followed the same durational pattern demonstrated by the control group, namely by producing the high vowels with shorter durations than the low vowels. Similar findings were also reported by Gandour and Dardarananda (1984).

The results also showed that speakers with Broca's aphasia had significantly higher F1 values than healthy speakers. The present study results are consistent with previous studies reporting deviated formant patterns in speakers with Broca's aphasia compared to healthy speakers (Keller, 1975; Ziegler & Hoole, 1989; Haley et al., 2001). Additionally, our findings generally support the common consensus that formant frequencies can predict severity and variability among speakers with Broca's aphasia (Ryalls, 1986; Liu et al., 2005; Tsao et al., 2006).

Some studies have found a positive correlation between F1 values and gender, with F1 values being higher in female speakers than male speakers (Kim et al., 2011; Lee et al., 2016). However, gender distribution between our Broca's aphasia speakers was not equal, where only two females participated in the study (2/8 females, see table 2). So, it is unlikely that this asymmetric gender distribution drives high F1 values. Therefore, although we view this gender imbalance as a limitation of the current study, there is no substantial evidence that this may have affected the results introduced here. However, higher F1 values generally suggest an articulatory setting with more oral cavity opening and lowered mandible (Lee et al., 2016).

The vowel acoustic spaces and ellipses areas (Figures 2 and 3) showed that speakers with Broca's aphasia displayed more dispersions in the back vowels than the front vowels (Figures 2 and 3). As mentioned earlier, the acoustic features of vowel formant frequencies indicate tongue placement. The results suggest that speakers with Broca's aphasia showed imprecise articulatory positioning of tongue height and advancement, indicating vowel fronting and backing.

The inspection of the acoustic vowel space in our speakers with Broca's aphasia showed a reduced vowel acoustic area and more centralized vowels than the healthy speakers, indicating tongue positioning constraints, confirming previous findings (Ryalls, 1986). The acoustic analysis also suggests that Broca's aphasia speakers in the present study are less intelligible due to their relatively reduced size of vowel space as compared to the healthy speakers. Such results provide strong evidence to previous findings indicating that the acoustic vowel space can serve as an index for vowel accuracy and speech intelligibility (Kim et al., 2011; Karlsson & van Doorn, 2012).

Speakers with aphasia in the present study also reported variability of formant frequencies. The results also revealed acoustic overlaps between the vowel categories in Broca's aphasia, as shown in figure 5. These findings are consistent with those reported by Haley et al. (2010). Acoustic overlap may suggest a relative lack of formant differentiation, imprecise articulatory configurations, and more vowel centralization (Mefferd & Green, 2010; Karlsson & van Doorn, 2012). A closer inspection of the vowel ellipses areas also showed that our participants with Broca's aphasia demonstrate greater dispersions in the high vowels /u:/ and /i:/ than in the low vowel /a:/ (Figures 2 and 5).

Taken together, the results of the present study would give more insight into the vowel acoustic characteristics of individuals with Broca's aphasia and expand our understanding of the underlying nature of Broca's aphasia. The results also suggest that vowels should become an integral part of speech therapy approaches and design.

For example, a speech therapist should include those vowels with more remarkable acoustic overlaps in their training and therapy activities to help patients to identify the differences between vowel pair affected by this acoustic overlap.

### **Limitations of the Study**

The present study is limited by several aspects, including the number of participants, stimuli, and analysis scope. First, the sample size, which included eight individuals (six males and two females) with Broca's aphasia, was relatively small. Including more female speakers can also help determine the gender effect on formant frequencies and vowel durations, allowing for more comparisons between speaker groups.

Secondly, the speech stimuli are relatively small as it includes three vowels (/a:,u:,i). This number of vowels may not allow for general conclusions regarding vowel production in Arabic-speaking individuals with Broca's aphasics. However, the present study's findings are preliminary, and further research is needed to gain better understanding of vowel deficits in Broca's aphasia. Finally, the analysis did not address the formant trajectory and how formants change in time, which was found to be crucial for vowel duration (Liss & Weismer, 1992).

### **Conclusion**

The present paper examined the acoustic features of vowel production in Palestinian Arabic-speakers with Broca's aphasics compared to healthy speakers. The findings showed speakers with Broca's aphasia produced all vowel categories with more variability compared to the healthy speakers. The results also revealed significantly higher F1 values for speakers with Broca's aphasics than the healthy speakers. Reduced vowel acoustic spaces and overlaps were noted in the speakers with Broca's aphasia. Such acoustic variability might reflect articulatory inconsistency and tongue positioning constraints.

Furthermore, although speakers with Broca's aphasia produced longer vowel durations than the healthy speakers, they were not significantly different between speaker groups. The present findings support previous studies concerning abnormal temporal and spectral patterns in Broca's aphasia. Acoustic measures of vowels can help speech therapists develop speech training programs to enhance speakers' speech intelligibility with Broca's aphasia.

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