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Acoustic Correlates of Emphatic Sounds in Palestinian Arabic-speaking Persons with Aphasia

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Abstract

Objective: *The aim of this study was to examine the acoustic characteristics of the emphatic sounds as produced by Palestinian Arabic-speaking persons diagnosed with Broca's aphasia as compared to normal speakers.* ***Method:*** *The acoustic correlates of emphasis in Palestinian Arabic using measurements of voice onset time (VOT), frequency values of F1 and F2 formants, and duration of vowel were investigated. Four subjects diagnosed with Broca's aphasia and four normal speakers residing in the West Bank participated in this study. The emphatic stop /t͡ˤ/ and its plain counterpart /t/ in initial positions presented in monosyllabic words were investigated. The target stops were followed immediately by the vowels /a/, /u/, and /i/. The speech samples were analyzed using PRAAT and Phono lab speech analysis software,. F1 and F2 formants were measured and compared with the data in the literature.* ***Results:*** *The acoustic measurements of the target vowels demonstrated an increase in F1 and a decrease in F2 formant in case of emphatic sounds compared to the plain one. Lowering of F2 formant was found to be a reliable acoustic cue of emphatic sounds. However, F2 formant was generally higher among subjects with Broca's aphasia compared to the control group. The results also revealed that subjects with Broca's aphasia were unable to maintain the acoustic distinction between the emphatic sounds and their plain counterparts.* ***Conclusion:*** *The VOT value of the emphatic voiceless stop /t͡ˤ/ was significantly shorter than that of its plain counterpart /t/ as demonstrated by both the normal speakers and the subjects with Broca's aphasia. The articulatory complexity of the emphatic sounds and therefore the deviated patterns in subjects with Broca's aphasia might suggest motor programming and motor planning deficits.*

1. Introduction

Broca's aphasia is a condition in which the subject experiences loss or impairment of language function that can be observed after damage to the Broca's area, which is located in the left frontal side of the brain, thereby causing dysprosody, low rate of speech, reduced variety of grammatical form, low performance on sentence repetition and auditory comprehension. Subjects with Broca's aphasia show predictable behavioral manifestations due to the central disruption of the syntactic parsing component of the language system coupled with an (theoretically independent) articulatory deficit affecting only the speech output system (Berndt & Caramazza, 1980). Usually occurring after a stroke, the most noticeable characteristics of Broca's aphasia is the subject being unable to form complete meaningful sentences by the omission of "function" words and inflectional morphemes (Kean, 1977). Patients suffering from this type of aphasia experience dysprosody, low rate of speech, reduced variety of grammatical form, low performance on sentence repetition, and auditory comprehension (Kolk & Heeschen, 2007). Moreover, aphasia produces disorders in behavior and may eventually result in serious psychological problems. For example, persons with aphasia often report feeling anxious when using language as communication although the studies related to aphasia and anxiety are scarce (Cahana-Amitay et al., 2011). Therefore, both psychiatrists and clinical psychologists are now being involved to treat patients with aphasia.

Emphasis is a phonetic and phonemic feature that can be characterized in Arabic language as well as other Semitic languages such as Hebrew. Arabic has the following emphatic sounds: /t͡/, /d͡/, /ð͡/, and /s͡/. In fact, *most* Arabic dialects are characterized by features of emphasis; however, they may not necessarily share the same emphatic features such as acoustic and articulatory characteristics (Zawaydeh, 1997).

Studies relating to emphatic sounds report conflicting ideas on the mechanism of emphatic sound production resulting in different terms being used to describe the configurations of the vocal tract during the speech production involving emphatic sounds. For example, the term "pharyngealization" was used to describe the articulatory configuration of emphasis in several Arabic dialects (Wahba, 1993; Al-Tamimi, Alzoubi, & Tarawnah, 2009). Some other studies termed it as

"uvularization" (McCarthy, 1994), "labialization" (Lehn, 1963), "velarization" (Hetzron, 1998), and "glottalization" (Ladefoged, 1971) to describe the same process.

Articulatory, emphatic sounds are distinguished by two types of articulations: primary articulation involving the dental/alveolar region in the vocal tract, and a secondary articulation, where the back of the tongue is involved. Based on these criteria, different studies characterized that constriction of the pharynx belongs to the secondary articulation type. Lehn (1963) proposed that emphasis generally includes "slight retraction, lateral spreading, and concavity of the tongue and raising of its back" (p. 30).

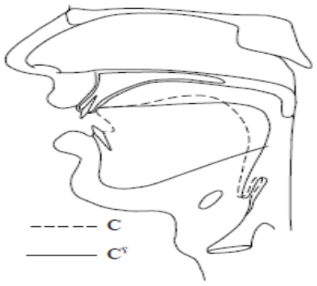

Figure 1. A schematic illustration of the vocal tract shape during the articulation of one of the emphatic Arabic sounds and its plain counterpart. This presentation is based on descriptions in Al-Ani (1970), Ali and Daniloff (1972), Ghazeli (1977), and Muqbil (2006).

According to Ali and Daniloff (1972), during the articulation of Arabic emphatic consonants, "the tongue exhibits a simultaneous slight depression of the palatine dorsum and a rearward movement of the pharyngeal dorsum toward the posterior pharyngeal wall" (Hassan, 2005, p. 127). Furthermore, Ghazeli (1977) observed in a speaker of Tunisian Arabic that emphasis involves retraction of the tongue toward the posterior pharyngeal wall at the level of the second cervical vertebra, which is near the uvula.

In their study of emphatic sounds in Hebrew and Arabic, Laufer and Baer (1988) found that emphatics are produced with a secondary articulation, in which an epiglotto-pharyngeal narrowing is observed. The authors concluded that emphatic articulation in Arabic and Hebrew are found to be more pharyngealized than velarized. Furthermore, in a videofluoroscopic experiment on emphasis in Jordanian Arabic, Al-Tamimi et al. (2009) concluded that emphatic sounds in Jordanian Arabic

are pharyngealized, indicated by both tongue root retraction into the oropharynx and the elevation of the larynx. In contrast, Giannini and Pettorino (1982) found that emphatic sounds are produced with an evident constriction in the lower pharynx rather than the uvula. In general, studies focusing on articulation in Semitic languages suggest that both uvularization and pharyngealization are actively involved in emphasis.

However, the acoustic aspects of emphasis in Arabic have not been frequently analyzed and investigated compared to phonological studies (Al-Masri & Jongman, 2004). Based on a fiberscopic investigation, Zawaydeh (1999) found an articulatory similarity between emphatics, uvular, and pharyngeals, where pharyngeal narrowing dominated. However, the study does not discuss the precise locations of the pharyngeal constrictions. Tamimi, Alzoubi, and Tarawnah (2009) found that tongue-root retraction in the oropharynx is actively involved in the production of emphatic sounds. Few studies have investigated the articulatory and acoustic correlates of emphasis in different varieties of Arabic, where the formant frequencies, particularly F1 and F2, have been mostly investigated. In general, lowering of F2 has been found to be a reliable acoustic cue of emphatics for various Arabic dialects. For example, Al-Ani (1970) reported significant F2 lowering in an emphatic context compared to plain segments. Card (1983) investigated the acoustic features of emphasis in Palestinian Arabic. According to him, a considerable effect of emphasis on F2 values were observed, which were lower than those of the plain environments. Wahba (1993) conducted an acoustic analysis of emphasis in Alexandrian Egyptian Arabic. He concluded that emphasis resulted in a significant lowering of F2 compared to the values of the plain vowels; while no significant difference in F1 values were observed. Similar acoustic findings were reported for Jordanian Arabic. In their study of the acoustic features of emphasis in the northern dialect of Jordanian Arabic, Al-Masri and Jongman (2004) found that emphasis is manifested in a significant lowering of F2 frequency value in the emphatic environment compared to the plain one. Zawaydeh (1999) conducted an acoustic investigation on emphasis in several Arabic dialects and also reported significant F2 lowering in the emphatic vowels compared to the plain environment. Khattab, Al-Tamimi, and Heselwood (2006) investigated the productions of the stop sound /t/ and its emphatic cognate /t͡/ in Jordanian Arabic containing the vowels /i/ and /æ/. They gave evidence regarding the raising of F1 formant and lowering of F2 formant in the emphatic environment.

Moreover, the results showed that the voice onset time (VOT) of emphatic stop consonants was significantly shorter than the VOT of plain stops. Hassan (2005) found that F1 and F2 formants are relatively closer to each other in vowels that are adjacent to emphatic segments than to their plain counterparts.

Regarding energy distribution, Obrecht (1961) reported that plain /s/ and its emphatic counterpart /s¯/ cannot be identified based on their lower frequency cutoffs, which are at about 3,000 Hz and 2,750 Hz as reported by Al-Ani (1970). No such significant differences were reported by Ghazeli (1977), who found that both fricatives /s/ and /s¯/ demonstrate energy at 3,000 Hz. However, Giannini and Pettorino (1982) found that /s/ and /s¯/ exhibit energy concentrations between 3,000 and 4,000 Hz. Norlin (1987) found that emphatic sounds, on average, are characterized by higher energy concentration and lower mean intensity than plain sounds. Concerning duration, Al-Ani (1970) reported no considerable differences between emphatic and plain sounds. In contrast, other investigators reported some differences; for example, that the emphatic sounds were found to be longer before the vowel /a/, while plain sounds were longer before the short vowel /i/ (Giannini & Pettorino, 1982).

In fact, most of the aphysiologists agree that aphasia is impairment in language function and is caused due to brain damage; therefore, it falls within the scope of neurologists. However, by studying language-processing disorders in conditions such as Broca's aphasia, there might be a possibility to address the underlying issues in a multidisciplinary approach. We studied the acoustic characteristics of emphatic sounds in Palestinian Arabic-speaking subjects with Broca's aphasia, and the key contributions of this investigation is to provide a better understanding of emphasis in Arabic, particularly, in the speech of people diagnosed with Broca's aphasia. In addition, apart from contributing to neurolinguistic research, this study may also contribute to the development of clinical applications when evaluating and/or treating Palestinian Arabic-speaking subjects with Broca's aphasia.

2. Objectives of the study

The primary objective of this study is to investigate the acoustic correlates of emphasis in Palestinian Arabic, using VOT measurements, frequency values of the formants F1 and F2, and vowel duration. In fact, as most formal therapy for aphasia is provided by trained speech therapists (language therapy), the scope of this study

involves in identifying the acoustic mechanism of emphatic sounds so that speech therapists utilize such information to benefit the patient and to advance the scientific knowledge regarding aphasia and speech distortion. Furthermore, although several studies have examined the acoustic correlation of emphasis in different Arabic dialects, we did not encounter any research article that examines the acoustic characteristics of emphasis in people diagnosed with Broca's aphasia.

In fact, one of the key contributions of this investigation is to provide a better understanding of emphasis in Arabic, particularly, in the speech of people diagnosed with Broca's aphasia. Therefore, the following are the aims of this study: (1) to examine the acoustic characteristics of the plain/emphatic consonants; (2) to examine whether vowel duration is affected by emphasis; (3) to examine whether F2 will be significantly lower for the vowels adjacent to the emphatic environment compared to plain vowels; (4) to examine the VOT patterns produced by the Palestinian Arabic-speaking subjects with Broca's aphasia and compare them to the control (normal speakers) group; and (5) to explain the aphasic patterns in terms of neurolinguistic research to aphasialogists and neurologists.

The following hypotheses were developed to handle the research questions:

1. There are considerable acoustic differences between emphatic and plain segments for both subjects with Broca's aphasia and normal speakers. More specifically, F1 of emphatic vowels is higher than that of its plain counterparts, while vowels in emphatic environments are characterized by significant F2 lowering compared to the plain environment.

2. Subjects with Broca's aphasia will demonstrate specific acoustic patterns that are incomparable to those of normal speakers, particularly in terms of formant frequencies and VOT values.

3. Emphasis will affect vowel duration in both target and adjacent syllables.

3. Method

A total of eight subjects participated in this study. Among them, four male native speakers of Palestinian Arabic living in the West Bank and diagnosed with Broca's aphasia participated in this study. Their age ranged between 45 and 58 years (mean = 52 years). The diagnosis of Broca's aphasia was based on the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1983) and the Bilingual Aphasia Test (Jordanian Arabic version) (Paradis, 1987). In all these participants,

none reported neurological surgery; neurological disorder; or any previously reported speech, language, or hearing disorders unrelated to the symptoms of aphasia. The subjects were predominantly right-handed and had no significant history of educational problems. The methods used in this study are based on those adopted by Adam (2013).

Four normal speakers (control subjects) participated in this study. Their age and gender was matched with the speakers with Broca's aphasia. The control participants had no history of hearing impairments or speech and language disorders.

Persons with aphasia

Table 1:
Details of the participants. Participant data: (A: person with aphasia; CVA: Cerebro-vascular accident; L: left hemisphere; MPO: months post-onset; M: male).

Subject	Age	Etiology	MPO	Gender
A.B	49	CVA-L	13	M
D.S	55	CVA-L	22	M
W.D	58	CVA-L	70	M
O.Z	47	CVA-L	90	M

The speech stimuli consisted of the emphatic stop /t¯/ and its plain counterpart /t/ in initial positions presented in monosyllabic words, as shown in Table 2. Monosyllabic real words, except one, were selected to avoid the difficulties with long words experienced by subjects with Broca's aphasia (Haley & Martin, 2010). The pseudo word was phonetically and phonologically licensed in Palestinian Arabic.

Table 2:
Stimuli. /t¯/ is the emphatic sound while /t/ is the plain counterpart

Consonant		
Vowel	/t¯/ </t/	Meaning
i	t¯ib	Medicine
	tib	pseudo word
u	t¯ub	to attack
	tub	to show penitence
a	t¯ab	to have a problem
	tab	to condemn

The target stops were followed immediately by the vowels /a/, /u/, and /i/. During the recording, the participants were instructed to read out the stimulus words loud, using the carrier phrase including the expression "ʔi ħki" ("Say") five times at a normal speaking rate. The stimulus words were printed on 3 × 5 index cards and presented to the subjects randomly to avoid a learning effect. The subjects' responses were recorded using a high-quality microphone (Sony F-V220) positioned approximately 15 cm from the participants' mouth. All the participants were allowed practice time to become familiarized with the experiment. In total, 240 speech samples (8 speakers × 2 stops × 3 vowels × 5 repetitions) were digitized at a sampling rate of 22,050 Hz and were saved as WAVE files on a notebook (Sony VAIO, SVT13112FXS). Fifteen VOT measurements for the emphatic /t¯/ and its plain counterpart /t/ (five for each of the vowels /a/, /u/, and /i/) were taken for each participant. The same procedures were carried out for the control group. Vowel duration was measured in ms and selected from the steady sate of the vowel to the offset of the vowel.

VOT is measured in milliseconds (ms) from the beginning of the release burst to the first periodic cycle of the following vowel. It is rounded up to the nearest 5-ms mark. A spectrogram is used for measuring voicing, which can be read from the voicing bar at the bottom of the instrument. Voicing that preceded the release of the stop was stated as a negative value while voicing after the release burst was assigned a positive value (Lisker & Abramson, 1964). The recording equipment and microphone were identical for both groups. Phonolab (Metoui, 1995) and PRAAT speech analysis

software (Boersma & Weenink, 2008) were used to measure the acoustic correlations, including the VOT and vowel durations. For the target vowels, F1and F2 formants were measured at onset, midpoint, and offset of the vowel.

4. Results

The statistical analysis was performed with SPSS 13.0 by Independent Samples T-test. The results in this study demonstrate a main effect of emphasis on VOT durations. The mean VOT of the plain voiceless stop /t/ was 53 ms, whereas the mean VOT of the voiceless emphatic /t̄/ was 26 ms. This difference was statistically significant [$F(1, 17) = 115.32$, $p = 0.001$]. The difference between plain and emphatic VOT was found to be significant for both subjects with aphasia and normal speakers.

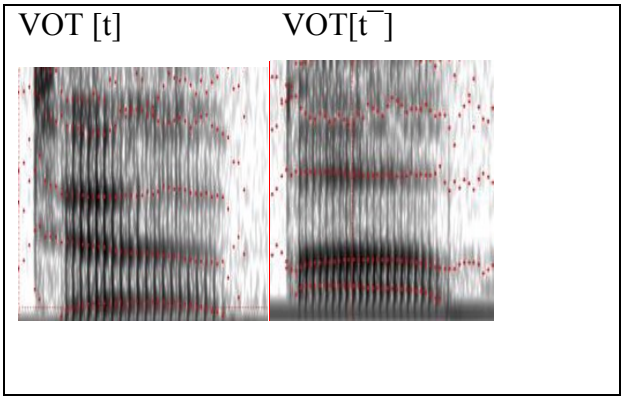

Figure 2.VOT of the voiceless plain stop /t/ and the emphatic voiceless stop /t̄/

The results show that the duration of the emphatic and plain consonants under study was not significantly different in the normal speakers [$F(1, 240) = 0.277$, $p = 0.581$]. However, subjects with Broca's aphasia made the plain stop /t/ longer than its emphatic counterpart [$F(1, 240) = 5.799$, $p = 0.014$].

The F1 formant production by normal speakers for vowels in onset positions in plain environments was 442 Hz and for vowels adjacent to emphatic sounds was 508 Hz, $p < 0.001$. In the subjects with Broca's aphasia, however, F1 values for vowels in onset positions in plain environments were 586 Hz and for vowels adjacent to emphatic sounds was 642 Hz, $p < 0.001$.

Furthermore, the acoustic analysis shows that vowel duration was not influenced by emphasis in the normal speakers. Accordingly, mean vowel duration

was 60 ms for vowels in a plain environment and 58 ms for vowels in an emphatic environment for normal speakers. In contrast, subjects with Broca's aphasia exhibited longer duration for vowels in a plain environment than in an emphatic environment (85 and 72 ms, respectively). In addition, in the energy production during speech by normal speakers, the energy concentration in the emphatic stop burst of /t͡/ was lower than in /t/, (3,900 and 4,210 Hz, respectively). In contrast, energy productions by subjects with Broca's aphasia were characterized by lower energy concentrations at 3,700 Hz.

F2 formant measurements across all the data show that F2 value is consistently lower in emphatic than in plain environments. This agrees with the findings reported by other studies several Arabic dialects (Al-Ani, 1970; Ghazeli, 1977; Laufer & Baer, 1988; Zawaydeh, 1999).

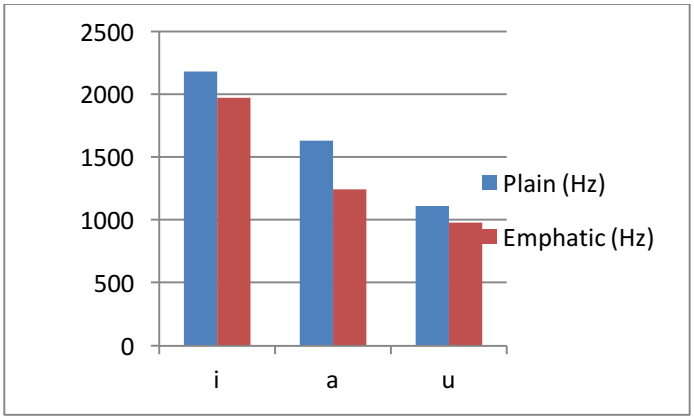

Figure 3. F2 by vowel quality in plain and emphatic environments as produced by the normal speakers.

As shown by the normal speakers, average F2 value was 980 Hz in emphatic environments and 1,315 Hz in plain ones. In contrast, subjects with Broca's aphasia exhibited an average F2 value of 1,460 Hz in emphatic environments and 1,510 Hz in plain environments. The results show that the lowering in F2 value is significantly greater in emphatics as produced by the normal speakers (335 Hz) compared to those of the subjects with Broca's aphasia (50 Hz). Furthermore, lowering of F2 value is much higher for the short vowel /a/ compared to other vowels /i/ and /u/ as shown by the normal speakers. However, the subjects with aphasia tend to show the opposite pattern by demonstrating higher F2 decrease for the short back vowel /u/ compared to other vowels, that is, /i/ and /a/.

Interestingly, F1 value tended to be raised in all the vowels under study. In contrast, the degree of F2 lowering was less for the subjects with aphasia than for the

normal speakers, indicating that the subjects with aphasia produced emphatic sounds with more limited acoustic cues than the normal speakers. In general, the patterns demonstrated by subjects with aphasia are characterized by higher F2 values for vowels adjacent to the emphatic environment than their plain counterparts.

5. **Discussion**

The results of this study clearly show that VOT is a reliable acoustic cue for emphasis in Palestinian Arabic. The results indicate that the VOT of the emphatic voiceless stop /t͡/ was significantly shorter than that of its plain counterpart /t/ as demonstrated by the normal speakers and the subjects with aphasia. This is in accordance with other studies conducted on Arabic dialects. For example, in their study on Jordanian Arabic, Khattab et al. (2006) found that the VOT of the stop /t͡/ was significantly shorter than that of the stop /t/. In fact, the shorter VOT of emphatic stops is an acoustic attribute related to articulatory configurations required for the production of emphatic sounds, resulting in considerable pharyngeal constriction (Lehn, 1963).

In general, the acoustic analysis reveals that vowels in the emphatic environment are characterized by a significant F2 lowering and a noticeable F1 raising, indicating a great effect of emphasis on vowels. These findings, specifically the F2 lowering, are in accordance with those reported by other investigators (Al-Masri & Jongman, 2004; Khattab et al., 2006; Wahba, 1993).

Our results clearly show that subjects with Broca's aphasia are unable to maintain the acoustic distinction between the emphatic sounds and their plain counterparts, expressed mainly by higher F2 values compared to those of the normal speakers. Furthermore, due to the secondary back articulation, the F1 and F2 formants, as displayed by the normal speakers, are much closer to each other than those of subjects with Broca's aphasia.

The fact that subjects with Broca's aphasia produced the emphatic sounds with longer VOT durations than the normal speakers may suggest motor abnormalities related to articulatory configurations involved in the production of emphatic sounds, resulting in slowed transitions from one constriction to the next.

The results of this study show that subjects with Broca's aphasia are unable to implement the acoustic distinction between the emphatic /t͡/ and its plain counterpart /t/. That is, these patients cannot coordinate the articulatory configurations required to

implement the acoustic patterns contributing to emphatic sounds. Consequently, it seems that subjects with Broca's aphasia demonstrate articulatory limitations in terms of tongue movement in the right direction, causing the emphatic sound to be produced at the same place of articulation as the plain counterpart /t/.

De-emphasizing emphasis indicates that subjects with Broca's aphasia are unable to implement the back secondary articulation to an adequate degree, reflecting motor deficits. In fact, controlling and coordinating the articulatory movements is an integral process, where several neuro-motoric mechanisms and several types of information are coded and processed to execute appropriate speech movements. The articulatory complexity of the emphatic sounds and therefore the deviated patterns of subjects with Broca's aphasia, shed light on the nature of the underlying deficits in Broca's aphasia. For example, motor programming and motor planning deficits. The findings of this study are in accordance with several studies that have demonstrated that subjects with Broca's aphasia have impairments at the level of selection and planning of speech sounds (Blumstein, 1973; Dunlop & Marquardt, 1977; Trost & Canter, 1974). It has been found that the speech of subjects with Broca's aphasia is generally characterized by movement transition abnormalities within and between speech sounds, leading to temporal abnormalities, including timing and sequencing abnormalities, as well as problems in initiating and conducting accurate vocal tract configuration for the target sound (Square, Roy, & Martin, 1997). Accordingly, de-emphasizing emphasis refers to deficits in the timing and coordination of the two independent articulators and articulation processes, particularly where both primary and secondary articulators are involved in the production of emphatic sounds. Taken together, the acoustic analysis reveals that people diagnosed with aphasia have articulatory positioning deficiencies, mainly in their attempts to produce emphatic sounds, demonstrating speech-timing deficiencies.

6. **Conclusion**

This paper has addressed the acoustic features of emphatic sounds as produced by Palestinian Arabic-speaking persons with aphasia and normal speakers using VOT measurements, frequency values of the formants F1 and F2, and vowel duration. Subjects with Broca's aphasia are unable to implement the acoustic distinction between the emphatic and their plain counterparts. That is, these patients cannot coordinate the articulatory configurations required to implement the acoustic patterns

contributing to emphatic sounds. Consequently, it seems that subjects with Broca's aphasia demonstrate articulatory limitations in terms of tongue movement in the right direction, causing the emphatic sound to be produced at the same place of articulation as the plain counterpart. Subjects with Broca's aphasia demonstrated higher F2 values compared to those of normal speakers, suggesting difficulty in the acoustic distinction between the emphatic /t͡/ and its plain counterpart /t/. De-emphasizing emphasis sheds light on the nature of Broca's aphasia, indicating difficulties in implementing back secondary articulation to an adequate degree. The results demonstrated that vowels adjacent to emphatic segments are not significantly longer in duration than their plain counterparts. This finding is true for both the normal speakers and the subjects with aphasia. In addition, in the energy productions of the normal speakers, the energy concentration in the emphatic stop burst of /t͡/ is lower than /t/ compared to the patterns demonstrated by subjects with Broca's aphasia. In accordance with several studies, VOT of the emphatic voiceless stop /t͡/ was significantly shorter than the VOT of its plain counterpart /t/ as demonstrated by both the normal speakers and the subjects with aphasia. In addition, the results may have clinical applications, particularly by developing assessment approaches and therapy programs for Palestinian Arabic-speaking subjects with Broca's aphasia.

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