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# Voice onset time production in Palestinian Arabic-speaking aphasics – preliminary results

**Abstract**: This study represents the first attempt to compare voice onset time (VOT) production between Palestinian Arabic-speaking Broca's aphasics and control subjects. The stimuli consisted of the stop cognates /t/ and /d/, which were presented in simple real words, and were followed immediately by the short vowels (/a/, /u/, /i/). Acoustic analysis revealed that persons with Broca's aphasia could maintain the voicing contrast between the voiced and voiceless stops. This result contradicts findings that have been reported in studies on other languages. Furthermore, this study did not find significant phonetic errors in the VOT production of aphasic speakers. The VOTs were not significantly different between the groups and both the subjects with Broca's aphasia and the control group produced longer VOTs for the voiceless stop /t/ than for the voiced counterpart /d/. In addition, vowel quality had a significant effect on the VOT of the preceding stop consonant, as exhibited by both the control speakers and the aphasic speakers.

**Key words**: Palestinian Arabic, stops, voice onset time (VOT), aphasia.

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## Realizacja czasu odsunięcia dźwięczności (VOT) u palestyńskich użytkowników języka arabskiego dotkniętych afazją - wstępne wyniki

**Abstrakt**: Badania te stanowią pierwszą próbę porównania realizacji czasu odsunięcia dźwięczności (VOT) u palestyńskich użytkowników języka arabskiego dotkniętych afazją Broki z osobami z grupy kontrolnej. Jako bodźce zastosowano zwarte kognaty /t/ i /d/, które były prezentowane w prostych słowach, oraz występowały bezpośrednio po krótkich samogłoskach (/a/, /u/, /i/). Analiza akustyczna wykazała, że osoby z afazją Broki były w stanie utrzymywać kontrast dźwięczności między zwarciami dźwięcznymi i bezdźwięcznymi. Wynik ten przeczy ustaleniom w badaniach na innych językach. Ponadto, badanie to nie wykazało istotnych błędów fonetycznych w produkcji VOT u osób dotkniętych afazją. Wartości VOT nie różniły się istotnie pomiędzy grupami i zarówno osoby z afazją Broca jak i osoby z grupy kontrolnej produkowały dłuższe VOT wymawiając bezdźwięczną spółgłoskę /t/ niż jej dźwięczny odpowiednik /d/. Ponadto, jakość samogłoski miała znaczący wpływ na VOT w poprzedzającej spółgłosce zwartej, jak wykazano na przykładzie osób z grupy kontrolnej oraz osób dotkniętych afazją.

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**Słowa kluczowe**: palestyński Arabski, zwarcie, czas odsunięcia dźwięczności (VOT), afazja.

## Introduction

Voice onset time (VOT) is defined as an interval between the release burst of a stop sound and the beginning of glottal pulsing (Lisker, Abramson, 1964). Specifically, VOT is the duration between a stop release and the onset of a vowel. Many studies found that in stop sounds the duration of the abduction – adduction gesture plays a prominent role in the phonetic distinction of voiced and voiceless stop cognates (Benguerel, et al., 1978; Hirose, Gay, 1972). Abramson (1977) indicated that VOT reflects the timing coordination of supra-laryngeal articulators. In general, VOT is a reliable acoustic cue for the distinction between voiced and voiceless stops in initial and stressed position in various languages (Klatt, 1975; Lehiste, 1970). However, in their study on perceptual switching in Spanish/English bilinguals, Bohn and Flege (1993) found that VOT may not be a sufficient cue for the perception of voicing contrast, as widely claimed. The authors concluded that the acoustic analysis failed to demonstrate acoustic dimensions that would «reliably differentiate the short-lag Spanish /t/ tokens that were predominantly identified as “t” from those that were ambiguous between “t” and “d”» (p. 267).

Functionally, VOTs before the release were considered negative and called “voicing lead”, whereas VOT values after the release were stated as positive and called “voicing lag”. On the other hand, if release and voicing take place simultaneously, the VOT value is zero (MacKay, 1987). Lisker and Abramson (1964) reported that the voiced stop consonants /b/, /d/, and /g/ have relatively short VOTs (-20ms to +20ms), whereas the voiceless stop consonants /p/, /t/, and /k/ have longer VOTs (25ms – 100ms). Acoustic studies have found that the place of articulation can greatly affect VOT values. For example, it has been found that bilabial stops have the shortest VOTs, while alveolar stops tended to have intermediate VOTs, and velar stops have the longest VOTs (Sharmistha, Wooil, 2010). However, in languages such as Japanese, Mandarin and Cantonese, bilabial stops have longer VOTs than alveolar ones (Chen, et al, 2007; Riney, et al., 2007). Furthermore, it has been found that VOTs of voiced and voiceless stop vary with the speaking rate, where VOT decreases as the rate increases at slower rate (Miller, et al., 1984; Baum, Ryan, 1993). In fact, the VOT has been widely used in studies of different languages. For example, Keating, Linke and Huffman (1983) reported

VOT values for 51 languages, while, more recently, Cho and Ladefoged (1999) investigated VOT production in 18 languages.

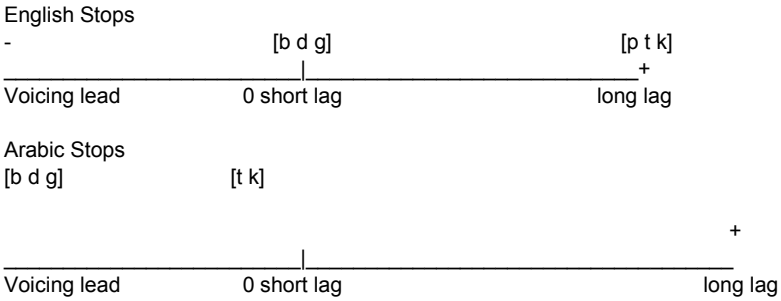


Fig. 1. VOT distributions in Arabic and English

VOT data has been gathered for several neurogenic communication disorders, including aphasia (Blumstein, et al., 1977; Blumstein, et al., 1980; Gandour, Dardarananda, 1984; Baum, et al., 1990; Provost, Arsenault, 1995; Ryalls, et al., 1997; Katz, 2000; Seung-Rho Lee, et al., 2011). Aphasia is defined as a language disorder that results from an acquired brain injury, characterised by sound substitutions or distortions, especially due to timing deficits (Blumstein, et al., 1977; Van der Haegen, et al., 2012).

In fact, several studies have argued that speech errors of individuals with Broca's aphasia were phonetic, while Wernicke's aphasics mistargeted phonemes (Sidiropoulos, et al., 2010). Luria (1966) indicated that phonetic errors reflect articulatory distortions of the target sound. Blumstein et al. (1977) examined VOT productions in speech of English speakers with aphasia and concluded that people with Broca's aphasia have a deficit that typically related to articulatory implementation level. This reflects impairments in the programming of the speech organs, resulting in sound distortion. In contrast, speech patterns of people with Wernicke's aphasia suggest phonemic selection deficits, whereby the sound produced is completely different from the target (Hewlett, 1985).

A distinction, thus, is made between phonetic and phonemic errors, based on the range of VOT values, specifically as people with Broca's aphasia show problems with sounds that require complex planning and coordination of two independent articulators, affecting consequently the timing of VOT (Katz, 2000). Thus, the distinction between both types of deficit is determined by comparing the VOT values produced by people

with aphasia to those of typical speakers. As an example of the two error types, Blumstein (1980) reported that the normal VOT range of the English voiced stop [b] is from -105 to +15 msec and the normal VOT range of its voiceless counterpart [p] is from +35 to +105 msec. Accordingly, a phonemic error occurs when the VOT of the voiced [b] is greater than +35 msec, falling, consequently, in the VOT range of [p], whereas a range between +15 and +35 msec classified as phonetic/articulatory error (review Blumstein, et al., 1977; Ryan, 1993; Blumstein, 1995; Katz, 2000). However, one way that the VOT productions of persons with aphasia matched typical productions was that both people with Broca's aphasia and Wernicke's aphasia were able to produce velar stops with longer VOT values compared to labial and alveolar stop consonants (Baum, Ryan, 1993).

People with Broca's aphasia display a considerable overlap in VOT distribution and usually have a longer VOT duration compared to typical speakers (Baum, Ryan, 1993; Blumstein, 1980). However, other studies have found that Broca's aphasics can maintain the phonetic distinction between stops (Itoh, et al., 1982; Tuller, 1984). Furthermore, as was reported for Broca's aphasia, studies conducted on patients with apraxia demonstrated overlapping patterns between voiced and voiceless stops and showed that their VOTs were longer than those of typical speakers. For example, results obtained by Gandour and Dardarananda (1984) indicated that subjects with apraxia produced a longer voicing lag than typical speakers. However, Shewan, Leeper and Booth (1984) found that subjects with Broca's aphasia produced a short VOT lead and lag.

In fact, VOT has been widely investigated both in normal and English-speaking aphasics. Thus, the above mentioned results and conclusions have been mostly based on investigation of English. However, cross-language studies reported notable differences and clearly exhibit that languages have a wide range of different VOT categories and ranges (Lisker, Abramson, 1964; Cho, Ladefoged, 1999). For example, in their study on Polish speakers Keating, Mikos and Ganong (1981) found that their speakers produce VOT patterns that are incomparable to those of English speakers. The authors concluded that Polish speakers are more likely not to produce distinct categories of VOT values. Thus, by assuming that phonetic rules are determined by language specific principles rather than universal rules (Cho, Ladefoged, 1999) then the patterns shown by people with aphasia concerning VOT production tend to be variable and depend on the spoken language.

Results of studies examining VOT production by individuals with aphasia speaking other languages, such as Thai (Gandour, Dardarananda, 1984) and French (Ryalls, et al., 1995) are variable. Gandour

and Dardarananda (1984) found that patients with Broca's could not maintain the voicing contrast with respect to VOT range and they exhibited ranges of VOT overlap. These findings are similar to those of Blumstein et al.'s (1977). Ryalls et al. (1995) examined VOT production in French-speaking Broca's aphasics and compared the results with those of the control group. The researchers concluded that, similar to the typical speakers, patients with Broca's aphasia were able to maintain the voicing contrast by exhibiting discrete VOT ranges and distributions.

Studies examining VOT production have focused mainly on English, as previously discussed, and only a few attempts have been made to examine VOT patterns in Arabic (Flege, Port, 1981; Khattab, 2000; Port, Mitleb, 1980; Yeni-Komshing, 1977). As expected, research on VOT, for instance, suggests that similar stops across different languages may have quite different timing correlates and patterns (Lehiste, 1970; Kohler, 1979). Differences between VOT ranges of stops in Arabic and English have been reported. Khattab (2000) found that the VOT range for Arabic voiceless stops occurs nearly within the general range of English voiced stops, while voiced Arabic stops and English voiceless stops located at the end of the continuum, as clearly shown in Fig.1. In other words, the voiced Arabic stops /b/ and /d/, for example, are characterized by negative VOT "voicing lead", while the voiceless stops /t/ and /k/ fall in the short – lag VOT range. In their study of voicing in Lebanese Arabic, Yeni-Komshian, Caramazza and Preston (1977) found that the stops /b/ and /d/ are produced with voicing lead, while the stops /t/and /k/ are characterised by a short voicing lag.

Studying VOT in PA, a language less documented and investigated, is interesting because it reflects specific set of acoustic features. For example, it has been found that voicing contrast in Arabic stops appears to differ from that of English (Yeni-Komshian, et al., 1977). In fact, capturing such cross-language temporal and timing differences could improve the understanding of mechanisms underlying Broca's aphasia.

The current study was therefore designed (1) to examine VOT patterns produced by Palestinian Arabic-speaking Broca's aphasics and compare them to those of a control group; (2) to relate the observed aphasic patterns to the underlying deficit of Broca's aphasia; and (3) to examine whether the patterns of the errors are comparable to the errors found in other languages, such as English.

The following hypotheses were formulated for this research study:

1. There are VOT duration differences between the stops /t/ and /d/ as produced by the control subjects and persons with aphasia.
2. Palestinian Arabic-speaking Broca's aphasics will not be able to maintain the voicing contrast between stop sounds.

3. Patients with Broca's aphasia would have phonetic impairments when producing stops.

## Method

#### Participants

Four male native speakers of Palestinian Arabic living in the West Bank participated in this study. They were aged between 45 and 70 (mean = 52 years). The participants were diagnosed with Broca's aphasia based on the Boston Diagnostic Aphasia Examination (Goodglass, Kaplan, 1983) and the Bilingual Aphasia Test (Jordanian Arabic version) (Paradis, 1987). In all cases, there was no reported neurological surgery; neurological disease; or reported previous speech, language, or hearing disorders unrelated to the aphasic symptoms. The subjects were predominantly right handed and had no significant history of educational problems.

Four control subjects, who were age and gender matched with the speakers with Broca's aphasia, participated in the study. The control participants had no history of hearing impairments or speech and language disorders.

Table 1. Details of the participants*

| Persons with aphasia | | | | |
|---|---|---|---|---|
| **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 |

* Participant data: A – person with aphasia; CVA – Cerebro vascular accident; L – left hemisphere; MPO – months post onset; M – male.

#### Stimuli and Measurements

The speech stimuli consisted of the stops /t/ and /d/ in initial positions presented in monosyllabic real words, as shown in Table 2. Monosyllabic words were selected to avoid difficulties with long words experienced by subjects with Broca's aphasia (Haley, Martin, 2010). The target stops were followed immediately by the vowels /a/, /u/ and /i/. During the recording, the participants were instructed to read the stimulus words out loud, using the carrier phrase using the expression "ʔi ħki" ("Say") 5 times at a normal speaking rate. The stimulus words were presented to the subjects

randomly to avoid a learning effect, and they were printed on 3×5 index cards. The subjects' responses were recorded using a high-quality microphone (Sony F-V220) positioned approximately 15 cm from the participants' mouths. All of 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 22050 Hz, and they were saved as WAVE files on a notebook (Sony VAIO, SVT13112FXS). Fifteen VOT measurements for the voiceless /t/ and the voiced /d/ (five for each of the vowels /a/, /u/, /i/) were recorded for each participant. The same procedures were carried out for the control group.

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 millisecond mark. A spectrogram is used for measuring voicing, by referring to the voicing bar at the bottom of the spectrogram. Voicing precedes the release of the stop was stated as negative values and voicing after the release burst was assigned positive values (Lisker, Abramson, 1964). VOT stimuli, recording equipment, and microphone were identical for both groups. Phonolab (Metoui, 1995) and PRAAT software (Boersma, Weenink, 2008) were used to measure the VOT duration.

Table 2. Stimuli

| Consonant | |
|---|---|
| **Vowel** | **T<D** |
| i | tib |
| | dib |
| u | tub |
| | dub |
| a | tab |
| | dab |

## Results

Tables 3 and 4 present the VOT duration values of the stops /t/ and /d/ for both the typical speakers and the participants with Broca's aphasia. For the statistical analysis we perform the *t- test* for average VOTs by group, as well as average standard deviation VOT difference. Such test is sub-

ject to find out the effect of group for average VOTs. We compared the typical speakers and subjects with Broca's aphasia with recorded mean and standard deviation (SD) of VOTs (ms) for the stops /t/ and /d/. The results clearly show that there is no significant differences of the two groups ($p<0.05$). Conforming to results of the typical speakers, the subjects with aphasia had a higher VOT value for the stop /t/ compared to the stop /d/. The VOT average for /t/ produced by control subjects was 56 ms, whereas it was 72 ms for the stop /t/ as produced by the patients with Broca's aphasia. Grouping these VOT differences across the place of articulation, which was identical for the /t/ and /d/stops, the subjects with Broca's aphasia exhibited a higher average difference compared to the control speakers. The patients with Broca's aphasia demonstrated longer VOT duration when compared to the control group.

Table 3. Means and standard deviations (SD) of VOTs (ms) for the stop /t/ in typical speakers and subjects with aphasia

| **Stop /t/** | **Typical speakers** | **Aphasic speakers** |
|---|---|---|
| Mean | 56 | 72 |
| SD | 17.33 | 28 |
| *p-value* (p=0.69>0.05) | | |

Table 4. Means and standard deviations (SD) of VOTs (ms) for the stop /d/ in typical speakers and subjects with aphasia

| **Stop /d/** | **Typical speakers** | **Aphasic speakers** |
|---|---|---|
| Mean | 14 | 17 |
| SD | 7.80 | 11.5 |
| *p-value* (p=0.30>0.05) | | |

VOT productions of patients with Broca's aphasia were analysed with respect to phonetic and phonemic errors. Table 6 presents the percentage of the phonetic errors versus the phonemic ones. Following Blumstein et al. (1977) a phonemic error is determined by a VOT value belonging to the normal range of the corresponding consonant. In contrast, a phonetic error was defined by a VOT value that lies between the normal VOT range for both voiced and voiceless stops (Gandour, Dardarananda, 1984). Interestingly, as seen in Table 5, for the subjects with Broca's aphasia in the present study, the results indicated that an average of 86% of the VOT

productions were produced correctly, while phonetic errors occurred only 9% of the time and phonemic errors occurred 5%. To summarize, somewhat contrary to the results reported for other languages, Palestinian Arabic-speaking Broca's aphasics have intact VOT categories.

Table 5. Error classification (percentage) of the VOT productions

| | **Correct%** | **Phonetic%** | **Phonemic%** |
|---|---|---|---|
| Control | 100 | 0 | 0 |
| Aphasics | 86 | 9 | 5 |

## Discussion

The purpose of this study was to examine the VOT patterns produced by Palestinian Arabic-speaking Broca's aphasics and to compare the results to the results of the control group. We predicted that Palestinian Arabic-speaking aphasics would show deficits in maintaining the voicing contrast between the sop cognates, as reported in other languages. We also predicted that paints with Broca's aphasia would have phonetic impairments when producing stops. Four subjects diagnosed with Broca's aphasia and four control subjects participated in this study. The results showed, as expected, that VOT is a reliable acoustic cue that distinguishes voiceless from voiced Arabic stops. This finding is in accordance with results reported in studies of other languages (Lisker, Abramson, 1964; Cho, Ladefoged, 1999). The typical speakers maintain the voicing contrast between the voiceless stop /t/ and its voiced counterpart /d/. Thus, they showed a full voicing lead for the voiced stops and a voicing lag for the voiceless stops, indicating full control of time programming for the production of the target phonemes. Furthermore, among the control group, no overlapping values were observed between the places of articulation of the stops.

The length of VOT for the voiceless stop /t/ as shown by the persons with Broca's aphasia, which is longer than those of typical speakers, follows the universal phonetic tendencies, where VOT increased from bilabials to alveolars to velars (Cho, Ladefoged, 1999; John, et al., 2010). The longer VOT durations may be related to the non-fluent, slow labored speech characterising persons with Broca's aphasia (Kent, Rosenbek, 1983). Several studies have demonstrated that the speaking rate influences VOT values (Miller, Dexter, 1988; Baum, Ryan, 1993; Seung-Rho Lee, et al., 2011).

The analysis of the data obtained from the subjects with Broca's aphasia indicates that these subjects can maintain two discreet VOT categories, by having relatively intact VOT categories. These findings are inconsistent with the results reported from other languages, such as English and Thai, whereby paintings with Broca's aphasia could not maintain the acoustic boundaries that characterize the VOT productions of the voiced and voiceless stops (Baum, et al., 1990; Blumstein, et al., 1977; Gandour, Dardarananda, 1984). In contrast, our results are in accordance with the findings reported by Ryalls et al. (1995), who concluded that French-speaking Broca's aphasics are able to maintain two discreet VOT categories. This result could be interpreted in light of the finding that both French and Arabic have zero VOT value (lead voicing), characterised by a glottal pulsing throughout the production of the stop consonant (Temple, 2000). Accordingly, French, like Arabic "follows a binary system of presence or absence of glottal pulsing during the closure period of the stop" (Khattab, 2000, p. 96).

Another explanation for these unexpected results in the present study may be related to phonetic differences across languages, for example, English and Arabic. As previously mentioned, Khattab (2000) found that the VOT range for Arabic voiceless stops is within the range of voiced stops in English, whereas the voiced Arabic stops and voiceless English stops occupy the end of the continuum, indicating that there are much greater average VOT differences between voiced and voiceless pairs in Arabic compared to English. As a result, this small difference may contribute to the inability of people with Boca's aphasia to maintain the voicing contrast. Speaking slowly resulted in longer VOTs, specifically for voiceless stop consonants (Miller, et al., 1984; Baum, Ryan, 1993). Palestinian speakers with Broca's aphasia also demonstrate increased VOT for the voiceless stop /t/, but it is not the case for the voiced stop /d/.

Previous studies have found contradictory results concerning the nature of the errors in patients with Broca's aphasia. Phonetic errors occur quite commonly in people with Broca's aphasia, while phonemic errors are frequently observed in patients with Wernicke's aphasia. For example, Blumstein (1980) found that 26% of the errors produced by her subjects with Broca's aphasia were phonetic, while in the present study it was only 9%. In contrast to our results, Itoh et al. (1982) and Gandour and Dardarananda (1984) found that the VOT productions of Broca's aphasics are severely impaired. In general, the findings in the present study are not in accord with the literature, where persons with Broca's aphasia are expected to have more phonetic impairments.

Findings of these studies in which persons with Broca's aphasia exhibit patterns of variability in VOT (Blumstein, 1980) and having a combi-

nation of both phonetic and phonemic errors shed light on the nature of these impairments. Blumstein (1980, p. 154) concluded that such a type of error does "suggest a deficit in phonemic selection and organisation as well as one in articulatory implementation". Croot, Patterson and Hodges (1998) address the question of whether these impairments reflect phonological encoding deficits or articulation deficiencies, arising at the motor system involving the articulation apparatus. They concluded that that these impairments could be caused by a "phonetic disintegration".

The overlapping features observed in individuals with Broca's aphasia are generally assumed to reflect phonetic errors rather than phonological impairments. That is, the longer and more inconsistent VOT ranges may correspond to timing deficits in the "control of the timing between their laryngeal and supra-laryngeal articulatory adjustments" (Auzou, et al., 2000, p. 143). Consistent with this assumption, Daprati, Nico, Duval and Lacquaniti (2010) urged that these phonetic errors corresponds to deficits in the integration of the articulatory movements. Consequently, this overlapping implies that these patients are unable to integrate the sound-transitional or co-articulatory aspects of speech (Blumstein, 1991). In accordance with these conclusions, Sharon, McMillan, Gunawardena, Avants, and Morgan et. al (2010) hypothesized that these errors are more likely to correspond to motor planning deficits. The question of whether the phonemic errors exhibited by people with Broca's aphasia reflect the same underlying mechanisms as the phonemic errors observed in persons with Wernicke's aphasia has been widely studied; the results have been controversial (see Blumstein, 1980 for a review).

The inconsistencies between the above-mentioned studies and the current study could be due to the fact that the participants with Broca's aphasia in the present study may by chance have had less phonetic impairment than those in Blumstein's study. In other words, the subjects in this study may have had better timing control and coordination during the production of the stop sounds compared to subjects from investigations on English stops. In contrast, our results are consistent with the results reported by Ryalls, Provost, and Arsenault (1995), who failed to find a higher percentage of phonetic errors during VOT production in French-speaking Broca's aphasics.

## Conclusion

The present study examined VOT production in Palestinian Arabic-speaking Broca's aphasics compared to typical speakers. Surprisingly, our results show that persons with Broca's aphasia could maintain the

voicing contrast between voiced and voiceless stops. This result contradicts the findings reported in studies of other languages, as previously discussed. However, caution should be taken when interpreting the results due to the small number of participants in the current study. Definite and general conclusions cannot be drawn from this study; rather, all conclusions refer only to the groups that were studied here.

The results obtained in the present study are quite consistent with other studies that have reported longer VOTs in the participants with Broca's aphasia compared to typical speakers. The finding that subjects with Broca's aphasia show a degree of overlapping and a combination of both phonetic and phonemic errors, even when they were not significant in the current study, confirms previous research and suggests a deficit in phonemic selection and articulatory implementation. In the speech patterns of the individual with Broca's aphasia and the control participants, the VOT of the voiceless /t/ stop was significantly longer than the VOT of its voiced /d/ counterpart. In fact, the preliminary acoustic findings of this study shed some light on possible phonological and phonetic accounts of the underlying deficits involved in Broca's aphasia, suggesting the importance of studying VOT variations across languages.

Finally, the results may contribute to the field of neurolinguistic research across different languages, particularly because Palestinian Arabic has been studied significantly less than other Arabic dialects and languages. It is also worth noting that cross-language VOT studies using normal speakers and individuals with communication disorders could contribute to a better understanding of VOT variations across languages. Such studies will provide a common understanding of acoustic deviations underlying disordered speech mechanisms.

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