An Acoustical Study of the Fricative /s/ in the Speech of Palestinian-speaking Broca's Aphasics – Preliminary Findings

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Abstract

This study was conducted with four Palestinian-speaking Broca's aphasics and four normal speakers to examine the production of the fricative /s/ and to analyze the difference in acoustic patterns between the two groups. The acoustic analysis revealed that the Broca's aphasics were able to maintain the phonetic distinction between voiced and voiceless fricatives and did not exhibit voicing or devoicing errors. This result is inconsistent with findings from other languages. The spectral peak of the alveolar /s/ was lower for the aphasic subjects than for the control speakers. The Broca's aphasics displayed a longer duration for /s/ than the control subjects did. The /s/ spectra for the Broca's aphasics were "flatter" than the /s/ spectra for the control speakers and were characterized by a relatively low-frequency energy peak. Substitution errors predominated. In most cases, a one-distinctive-feature error occurred that primarily involved the place of articulation. Generally, the findings of the study suggest that the errors exhibited by Broca's aphasics reflect articulatory movements and articulatory implementation deficits rather than a selection of inappropriate speech segments.

1 Introduction

Aphasia is a language disorder resulting from damage to portions of the brain, specifically the temporal lobe or higher in the frontal lobe. This disorder can affect various linguistic components, such as phonology, morphology, syntax, semantics and pragmatics (Novick et al. 2010; Bastiaanse/Van Zonneveld 2004; Damasio/Anderson/Trenel 2011; Alexander/Naeser/Palummbo 1990). It may also manifest across various modalities, such as writing and reading. A widely used classification divides aphasia into two categories, fluent aphasia and non-fluent aphasia. Individuals diagnosed with fluent aphasia have difficulties with auditory comprehension of spoken and written language. In contrast, people with non-fluent aphasia exhibit difficulty with verbal expression. Their articulation is labored and effortful, accompanied by distorted sounds and disrupted articulatory implementation.

Previous studies on speech errors in Broca's aphasics have generally focused on motor timing as the cause of production deficit. Several studies have claimed that deficits occur at the level of the selection and planning of speech segments (Blumstein 1973; Hatfield/Walton 1975; Klich/Ireland/Weidner 1979). Sands and his colleagues (1978) suggested that Broca's aphasics may have temporal impairments resulting in dyscoordination of interarticulator timing. Shankweiler and Harris (1966) examined articulatory errors in the speech of five subjects with Broca's aphasia and found that fricative and affricate sounds were more difficult than vowels and were inconsistently misarticulated, with voicing features often affected.

Tuller and Story (1988) and Shadle and Celia (1995) stated that Broca's aphasics were able to achieve linguistic contrast between different phonemes despite the deficiency in the motoric coordination required for speech production. For instance, it has been found that Broca's aphasics are able to implement the voicing distinction among the stop sounds by maintaining

the linguistic contrast between voiced and voiceless stops (Baum 1996; Blumstein/Naeser/Palumbo 1990).

Contrasting results on this subject have been reported by Blumstein et al. (1977) and Freeman, Sands and Harris (1978), who claimed that Broca's aphasics were unable to maintain the stop-voicing contrast. A voice onset time (VOT) analysis in this study showed overlapping patterns between voiced and voiceless stops. Code and Ball (1982) also found that Broca's aphasics demonstrate voicing-contrast impairment by devoicing the voiced fricatives, thereby indicating a temporal deficit in the control of voicing (Code/Ball 1982). Although Broca's aphasics exhibit deficits in the production of fricatives, some studies report normal fricative durations (Harmes et al. 1984). Overall, a wide range of studies report temporal abnormalities of consonants and motor speech programming deficits in Broca's aphasics. This study was conducted to provide more insight into this problem.

The purpose of the present study was threefold: (1) to examine some of the acoustic-temporal properties of fricatives in Palestinians diagnosed with Broca's aphasia, such as voicing, duration of noise frication, and spectral frequency; (2) to relate the observed aphasic patterns to the underlying deficit of Broca's aphasia; and (3) to examine whether the patterns of errors are comparable to those found in other languages. The fricative /s/ was selected because it has relatively prominent spectral characteristics compared to other consonants, such as stops (Kent/Read 2002). It has a voiced counterpart /z/ with the same place of articulation.

2 Linguistic and acoustic background

Fricative sounds constitute the largest set of consonants in Arabic. The language has 13 fricatives: [θ], [ħ], [x], [ð], [z], [s], [ʃ], [sˤ], [ðˤ], [ɣ], [ʕ], [f] and [h]. Knowledge of the acoustic features of fricatives in Arabic is limited. In contrast, a wide range of research has examined the acoustic properties of the English sound system, such as frication duration, frequency peaks, and amplitude. A review of the literature on acoustic phonetics indicates that the fricative /s/ displays major frequency peaks within the 3500–5000 Hz range and the 2500–3500 Hz range. In contrast, the fricatives /f/ and /θ/ are characterized by a flat spectrum showing energy peaks from approximately 1800–8500 Hz (Hughes/Halle 1956; Stevens 1960; Johnson 1997). Shadle and Mair (1990) examined the spectral characteristics of /s/ and found that it was characterized by a higher mean and lower standard deviation than the fricative /ʃ/. Jongman et al. (2000) examined the spectral peak locations of fricatives and stated that the peaks fell between 3820 Hz and 7733 Hz.

A study addressing the acoustic features of fricatives demonstrated that the spectrum and the intensity of frication are reliable acoustic cues for the identification of the place of articulation of fricatives (Ali/Spiegel/Mueller 2001). In that study, the authors found that /s/ has a high-frequency spectral peak and that the lowest spectral peak occurred at approximately 4000 Hz.

Several studies have focused on the spectral properties of frication noise and the acoustic properties of /s/ as produced by normal speakers and individuals with speech disorders (Hughes/Halle 1956; Stevens 1960; Shadle 1990; Baum 1996). These studies indicated that the dominant high-frequency peak is the main acoustic characteristic distinguishing the spectrum of the consonant /s/.

Acoustic studies of the duration of frication noise have found that the duration is much greater for voiceless fricatives than for their voiced cognates, which also vary with respect to the place of articulation (Crystal/House 1988; Stevens 1998). For example, the voiceless sibilants /s/ and /ʃ/ are longer than the voiceless interdental /θ/ and labiodental /f/ (Behrens/Blumstein 1988; Jongmann et al. 2000). In general, cross-linguistic studies have found that the changes in spectral properties of fricatives reflect changes in the place of articulation rather than in

voicing, whereas voicing usually serves to reduce the amplitude of the frication noise (Hughes/Halle 1956; Stevens 1998; Jesus/Shadle 2002).

Several investigations have attributed speech production errors in Broca's aphasics to phonetic or articulatory deficits. These studies have suggested that Broca's aphasics have difficulties with the timing and coordination of articulatory movements and with laryngeal control (Shinn/Blumstein 1983; Shankweiler/Harris 1966). These findings indicate that the production of /s/ in word-initial position requires the articulators to implement a number of actions. Chen and Stevens (2001: 1303) state that the following actions are required for the correct production of the fricative /s/:

(a) proper positioning of the tongue body; (b) shaping of the tongue blade so that the airstream is directed against the lower incisors; (c) raising the mandible to position the lower incisors to form an obstacle for the airstream, and maintaining this position during the fricative; (d) spreading of the glottis so that the vocal folds do not vibrate and there is appropriate pressure buildup in the oral cavity; (e) coordination of the decrease in glottal spreading and the release of the tongue-blade constriction as the fricative ends and the following vowel begins; (f) motion of the articulators at a proper rate following the release of the consonant; and (g) in the case of an utterance-initial fricative, coordination of the onset of respiratory pressure and the positioning of the glottal and supraglottal articulators (Chen/Stevens 2001: 1303).

Given the understanding of the actions necessary for a correct production of /s/, we may expect that Broca's aphasics will have difficulty producing a well-articulated /s/ because this sound requires a precise articulatory movement.

3 Methods

3.1 Participants

The participants in this study were four Palestinian-speaking Broca's aphasic patients between the ages of 47 and 55 years, with a mean age of 50.75. The severity of the deficits in these participants ranged from mild to moderate Broca's aphasia. The diagnosis was based on an adaptation of the Boston Diagnostic Aphasia Examination (Goodglass/Kaplan 1983) and the Bilingual Aphasia Test, Jordanian Arabic version (Paradis 1987). The post-onset duration ranged from one to eight years. The subjects had at least 10 to 15 years of formal education. All of the participants were right-handed and had acquired aphasia due to a single left-hemisphere lesion. Potential participants were excluded if they exhibited any hearing problems, dysarthria, cognitive deficits or visual impairments. The four participants served as the experimental group. Four native speakers with no language or speech impairments and matched in age to the subjects served as the control group. Table 1 presents the patient data for the study.

Aphasic Subjects	Age	Etiology	MPO	Gender
A1	47	CVA-L	12	M
A2	50	CVA-L	25	M
A3	51	CVA-L	74	M
A4	55	CVA-L	96	M

Table 1: Patient data (A: aphasic subject; CVA: Cerebrovascular accident; L: left hemisphere; MPO: months post onset; M: male).

3.2 Procedure and Analysis

The utterances analyzed in the present study were selected from a sample of spontaneous speech. The speech samples were transcribed phonetically by the researcher. The subjects

were asked about their hobbies, profession, daily activities, former jobs, and family. The responses were recorded using a high-quality microphone positioned approximately 2.5 centimeters from the participant's mouth. A total of 35 words with an initial /s/ from single-word utterances of each participant were selected and digitized. Due to coarticulatory effects and articulatory difficulties exhibited by Broca's aphasics, only single-word utterances were chosen. The acoustic analysis was conducted using the PRAAT (Boersma/Weenink 2008) and Phono-Lab (Metoui 1995) software. The data were recorded using a sampling rate of 16 Hz at 16 bits.

The onset of the fricative /s/ was defined as the beginning of the frication, identified by the presence of high-frequency noise and by an increase in the amplitude of the frication noise. The offset of the frication noise was determined by the absence of high-frequency noise in the waveform, considering the end of the frication as the beginning of the following vowel. Duration of voiceless fricatives was defined from the onset of frication until the onset of the voicing corresponding to the following vowel. Broadband spectrograms (6.4 ms Hamming window) were produced for each of the 35 word-initial /s/ utterances by all participants.

4 Results and Discussion

The acoustic analysis revealed that Broca's aphasics produced /s/ with a relatively flattened spectrum whose largest spectral peak was located between 480–1090 Hz. In contrast, the normal subjects showed well-defined peaks between approximately 4680 Hz and 8000 Hz, with a higher frequency range. The dominant frequency ranges of the aphasics and the control speakers differed significantly. The spectrum of /s/ for the aphasic subjects was characterized by a decrease in amplitude at high frequencies and an increase in energy at low frequencies (figure 1). The relative frication duration of the initial /s/ was longer for Broca's aphasics (116 msec) than for the normal speakers (109 msec).

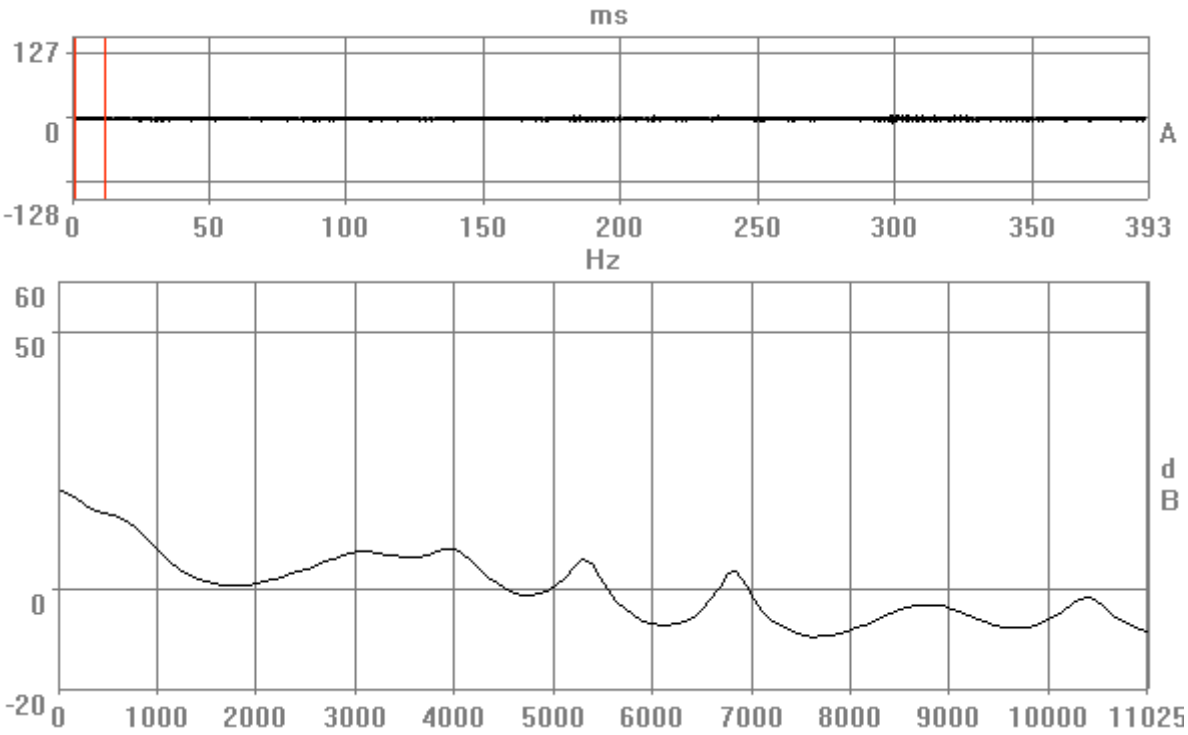

Figure 1: Distribution of energy peaks of /s/ as produced by an aphasic subject.

A noteworthy result of the present study is that the Broca's aphasics could maintain the voicing contrast between the voiceless fricatives and their voiced counterparts. These patients did not substitute the voiceless /s/ for its voiced counterpart /z/ and none of them substituted the

voiced fricative /z/ for its voiceless counterpart /s/. This result is intriguing because some evidence of voicing and devoicing deficits, particularly devoicing impairments, is reported from other languages (Code/Ball 1982).

The acoustic analysis also indicated that the mean durations for vowels preceding the voiceless fricative /s/ were significantly longer than those of normal speakers (table 2).

Consonant	Normal speakers	Aphasic Subjects
/s/	172	238

Table 2: Mean duration for vowels preceding the voiceless fricative /s/.

In addition, the spectra obtained from the aphasic subjects showed "change error", the addition of a sound that does not belong to the initial sound of the target sound. For example, the stop [d] was added in the attempts to produce a target word starting with the initial /s/ (figure 2).

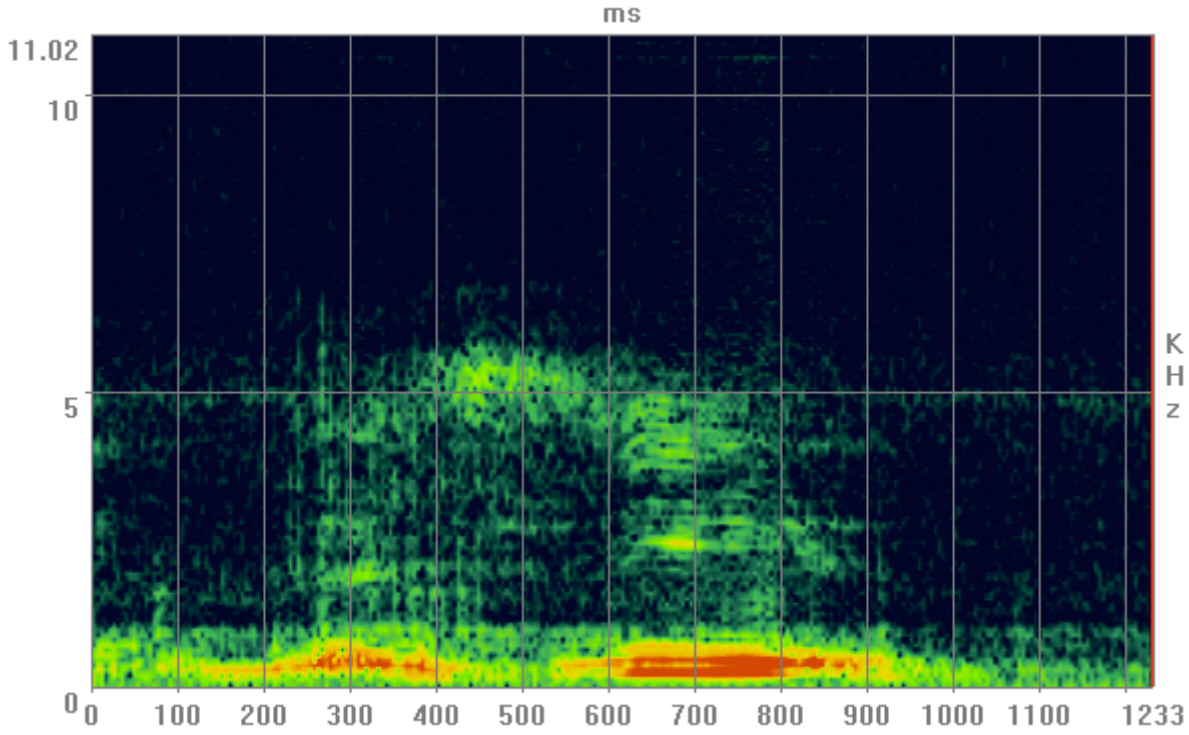

Figure 2: Spectrogram of a "change error" in an attempt to produce the target word [sarear] "bed".

The acoustic analysis also revealed that Broca's aphasics substituted /s/ and /ʃ/. This finding indicates that they were unable to maintain a clear distinction between the fricative sounds to reach the articulatory configuration required for the production of /s/. In this case, the spectra of /s/ had a substantial decrease in energy at 2700 Hz and higher. This decrease indicates a type of overlap with the higher end of the fricative /ʃ/. As indicated by these results, it is probable that the phoneme substitution is an error involving one distinctive feature. That is, the target phoneme and the substituted phoneme usually reflected a single-feature error, with the place of articulation most frequently substituted. For instance, none of the errors produced by Broca's aphasics involved both place and voice errors. The analysis of the phoneme substitution was based on the concept of a one-place-distance error. This type of error usually involves the substitution of a phoneme having the same place of articulation as the target phoneme.

The findings suggest that the errors in the productions of Broca's aphasics indicate a deficit in the integration of the articulatory movements and in the articulatory implementation required for the production of the target segment. Thus, these errors are considered to be phonetic rather than phonological and furnish evidence for the underlying deficits in timing and speech motor control.

5 Conclusions

The present study sought to investigate the acoustical features and the types of errors in the fricative /s/ in the speech of Palestinian-speaking Broca's aphasics. The acoustic analysis showed that Broca's aphasics were able to maintain the acoustic boundaries of the fricative sounds by maintaining the phonetic distinction between voiced and voiceless fricatives. Thus, they did not make voicing errors. This finding is inconsistent with those reported by other studies (Code/Ball 1982).

The spectral peak of the alveolar /s/ was lower for the aphasic subjects than for the control speakers. The results also showed that the Broca's aphasics displayed a longer duration for /s/ than the control subjects. The /s/ spectrum for the Broca's aphasics was "flatter" than the /s/ spectra for the control speakers. The acoustic data also indicated that the spectral shape for /s/ was characterized by a relatively low-frequency energy peak compared to that shown by the healthy speakers. A significant reduction of energy at the higher frequencies was observed in the Broca's aphasics. The analysis of phoneme-substitution errors showed that it is probable that substitutions are a one-distinctive-feature error primarily involving the place of articulation. Generally, these findings suggest that the error pattern of the Broca's aphasics reflects phonetic-motoric deficits related to articulatory movements and articulatory implementation deficits rather than a selection of inappropriate speech segments.

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