Neurolinguistic Analysis: Aspects of Language and Speech Deviations in Palestinian Arabic Aphasics

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0.1. ABBREVIATIONS

VOT	Voice Onset Time
p.	page
pp.	pages
B.	Broca's aphasic
Fig.	figure
Tab.	table
msce	millisecond
Hz	hertz
F1	first formant
F2	second formant
F3	third formant
F4	fourth formant
F0	fundamental frequency
N.	normal speaker
LPC	Linear Predictive Coding
TMA	transcortical motor aphasia
TSA	transcortical sensory aphasia
VL.F	voiceless fricative
V.F	voiced fricative
VL.S	voiceless stop
V.S	voiced stop
PET	Positron Emission Tomography
RH	right hemisphere
LH	left hemisphere
LHD	left-hemisphere-damaged
RHD	right-hemisphere-damaged
fMRI	functional Magnetic Resonance Image
MRI	Magnetic Resonance Image
FFT	Fast Fourier Transfer
MCA	Middle Cerebral Artery
CVA	cerebro-vascular-accident
cf.	compare
e.g.	for example

0.2. LIST OF TABLES

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0.4. ABSTRACT

The characteristics of aphasics' speech in various languages have been the core of numerous studies, but Arabic in general, and Palestinian Arabic in particular, is still a virgin field in this respect. However, it is of vital importance to have a clear picture of the specific aspects of Palestinian Arabic that might be affected in the speech of aphasics in order to establish screening, diagnosis and therapy programs based on a clinical linguistic database. Hence the central questions of this study are what are the main neurolinguistic features of the Palestinian aphasics' speech at the phonetic-acoustic level and to what extent are the results similar or not to those obtained from other languages. In general, this study is a survey of the most prominent features of Palestinian Broca's aphasics' speech.

The main acoustic parameters of vowels and consonants are analysed such as vowel duration, formant frequency, Voice Onset Time (VOT), intensity and frication duration. The deviant patterns among the Broca's aphasics are displayed and compared with those of normal speakers. The nature of deficit, whether phonetic or phonological, is also discussed. Moreover, the coarticulatory characteristics and some prosodic patterns of Broca's aphasics are addressed. Samples were collected from six Broca's aphasics from the same local region.

The acoustic analysis conducted on a range of consonant and vowel parameters displayed differences between the speech patterns of Broca's aphasics and normal speakers. For example, impairments in voicing contrast between the voiced and voiceless stops were found in Broca's aphasics. This feature does not exist for the fricatives produced by the Palestinian Broca's aphasics and hence deviates from data obtained for aphasics' speech from other languages. The Palestinian Broca's aphasics displayed particular problems with the emphatic sounds. They exhibited deviant coarticulation patterns, another feature that is inconsistent with data obtained from studies from other languages. However, several other findings are in accordance with those reported from various other languages such as impairments in the VOT. The results are in accordance with the suggestions that speech production deficits in Broca's aphasics are not related to phoneme selection but rather to articulatory implementation and some speech output impairments are related to timing and planning deficits.

1. INTRODUCTION

This study is an investigation into the neurolinguistic and acoustic aspects of language and speech deviations in Palestinian Broca's aphasics. This chapter describes statement of the problem, the sociolinguistic profile of Palestinian Arabic, participants and corpus, methodology and the organization of the thesis.

1.1. Statement of the problem

Much research has been conducted to characterize the aspects of language and speech abnormalities of the aphasics in English compared to those in Arabic. In this respect, results of studies on English are not necessarily applicable to Arabic. To the researcher's knowledge, little research has been done in this field in the Arab world and in Palestine particularly. The present work is a step towards filling this gap. This study is intended to examine language and speech deviations in Palestinian Broca's aphasics. There are several variations in the speech samples used in previous studies, some of which were conducted with data gathered from the description of pictures, storytelling, written materials and spontaneous speech.

It is important to take into consideration that Arabic is different from other languages such as English and German, therefore, operates differently. Thus, there are many differences between Arabic and these languages at different levels. For example, the phonemic inventory of Arabic includes several sounds that are not available in the English phonemic inventory such as the pharyngeal and emphatic sounds. In addition, some sounds that are found in English and Arabic differ somewhat in their frequency of occurrence, nature of production and coarticulation effects. Moreover, at the phonological and structural levels, remarkable differences are observed including sentence structure, word order and free and inflectional morphemes. Therefore, since Arabic is a highly inflectional language, it is expected that the Palestinian Broca's aphasics will display patterns that are different from those in English, at least in particular aspects.

The beginning of aphasia research in the Palestinian territories is closely related to the clashes in the region. Thus, there has been an acute need for establishing rehabilitation clinics in the West Bank and the Gaza strip to offer the suitable consultations, diagnosis and therapy.

1.2. Sociolinguistic profile of Palestinian Arabic

The term *Palestinian Arabic* (PA) is widely used to classify the varieties of Arabic spoken by Palestinians. Palestinian Arabic conveys the Palestinians' political perspectives and their cultural backgrounds. However, it is noteworthy to indicate that the Palestinian dialects in general are considered a subset of the Arabic-speaking world and do not present with communicative difficulties. Despite this fact, basic differences are found between Palestinian Arabic spoken in the West Bank and Arabic spoken in other areas of the Arab world appearing particularly in prosody. The Palestinians live in different areas: the West Bank, the Gaza Strip, Israel and around the Arab world.

The aphasic patients in the current study are from Hebron, which is one of the biggest cities in the West Bank. Some of its neighbourhoods reach an altitude of 1000 meters above sea level. The old city is situated on the northern flank of a valley at an altitude of approximately 860m. This relatively high altitude grants the city cool weather during summer time and abundant rainfall in winter. The local economy depends on agricultural resources such as fruit cultivation as well as on handicraft and small- and medium-scale construction industries. More than 140,000 inhabitants live in the city.

1.3. Method

1.3.1. Participants and corpus

1.3.1.1. "Normal" speakers

Six native speakers of Palestinian Arabic participated in the study. Their ages ranged from 25 to 55 years. They display no hearing or language disorders. One word has to be said about terminology: when referring to the group of subjects who were not aphasics, we will, for ease of reference, label them the "normals" or "normal" group. This characterization is only meant to denote that this group has no speech and language impairments of the type the aphasic group has. The term "normal" does not imply any further, say social, qualification.

1.3.1.2. Aphasic subjects

Our subjects were five male patients and one female. Palestinian Arabic was their mother language and they were from the same region. They were all right handed with no significant history of educational problems. Each patient underwent a standardized aphasia assessment on the basis of both formal and informal tests and clinical reports. All were diagnosed with mild to moderate Broca's aphasia. Consequently, when referring to the group of subjects who were aphasics "aphasic subjects"or "the aphasics," this is meant "Broca's aphasics." Hearing was within normal limits with no evidence of dysarthria or visual impairments. All of the aphasic subjects suffer from a single left hemisphere lesion at least six months prior to testing. According to the clinical reports, some of them displayed an earlier history of heart trouble, hypertension and high cholesterol levels.

1.3.2. Methodology

1.3.2.1. Software application "Phono Lab"

During the last two decades there has been rapid growth of research into signal analysis linked to the development of various software programs. These computer programs are used for a wide variety of applications, particularly in the acoustic analysis. Descriptions of speech qualities and parameters are important not only for studying normal speech, but also for assessing speakers who are suffering from pathological deficits. Developing such softwares has presented precise knowledge of speech and language production mechanisms.

For this study, we have applied a programme developed at the University of Mainz by Metoui,[1] called "Phono Lab." This program is a user-friendly, designed analytical tool. In general, it enables the researcher to carry out complex digital speech analyses such as visualisation, animation and graphical support. Thus, the program offers the following functions:

1- Articulatory analysis: this function makes it possible to have digital pictures of the anatomical structures involved in speech production. This capability is important for analyzing the coordination, articulation strategies and coarticulation effects. In addition, the movements of the articulators can clearly be seen in terms of digitized mid-sagital sections, digitized X-ray images, scanned images and graphics.
2- Visualisation and animation of the places of articulation by displaying a global identification that can be compared with given references, point by point.
3- Acoustic analysis: analysis of durational and physical parameters of the speech signal by applying LPC, FFT, Cepstrum and other analytical tools.

[1] Cf. Metoui, M. (1995): Phono Lab: Computerprogramm zur Artikulatorisch-Akustischen Datenanalyse.

4- Statistical analysis: this offers the user many possibilities concerning data analysis including mean averages and percentages.

In general, this program provides the user with different functions that can be applied in different fields such as language processing, language pathology, medicine and understanding the nature of language and speech production. Thus, since this software includes different analysis tools, we have used it for the current study in the acoustic analysis.

1.3.2.2. Measurement and procedure

The current study is a comparative analysis between the normal speakers and the aphasic subjects. The analysis is conducted on spontaneous speech. Vowels were chosen from continuous speech of the normal speakers and the aphasic subjects as well. The same procedures used for getting words and sentences from the aphasic subjects in order to get speech samples from spontaneous speech were also applied to the normal speakers. In vowel duration and formant values the corpus consisted of 90 words (appendix 10.1) selected from the aphasic subjects. These words were distributed approximately along the different vowels in order to get valid and reliable results. Furthermore, vowels that were analysed included initial syllables within monosyllabic and polysyllabic words. Vowels in pharyngealized or emphatic contexts were excluded with the exception of the emphatic vowel [ɑ] and its long cognate. This was due to their particular way of production that influenced the formant values. Vowels were analysed acoustically by Praat and Phono Lab software. A Linear Predictive Coding (LPC) was used to extract the formant values.

The duration of the vowels was measured in milliseconds. The onset of the vowel was defined from the point at which the aperiodic energy is accessed until the onset of periodic energy is above 1000 Hz. For the onset definition, the same parameters were implemented to define the vowel offset but in the opposite order. The same words that were used for vowel reduction measurements were used to examine word average duration, which increased from one syllable to three syllables. Afterwards these results were compared with those of the normal speakers. Furthermore, to maintain more consistency in the results, the same words in vowel reduction were chosen for syllable duration measurement. The root syllable was measured in milliseconds in three positions: isolation, disyllabic and trisyllabic.

Regarding the VOT in the stop sounds, for voiceless stops it was defined from the onset of the release burst to the highest point of the first periodic cycle. The VOT values were given positive values in terms of voicing lag. For prevoiced stops, VOT was measured from the onset of the first periodic cycle in the closure period to the beginning of the release burst and was stated as negative numbers as they took place before the stop release that is defined as voicing lead. The stimuli included the non-emphatic stops in Arabic: labial [b], alveolar [t, d] and velar stops [k, g]. The uvular [q] was excluded because it is normally produced in classical Arabic rather than in dialects. Furthermore, the emphatic stop sounds were excluded because of their specific way of production and for the purpose of comparing our results with other languages that do not have emphatic sounds. In fact, because the aphasic subjects did not give unified answers to the questions that they were requested to answer and due to the fact that words were selected from their connected speech, words that have relatively similar phonetic environments and produced simultaneously by more than one aphasic subject were chosen. This has been found by three subjects. Therefore, 35 words that contain the initial stops [b, t, d, k, g] followed by the vowel [a] were selected in order to avoid the effects of vocalic context. These words are presented in appendix (10.2).

Concerning the fricative sounds, the fricative sounds under study were selected from spontaneous speech of Broca's aphasics. As it is difficult to control the productions of the aphasics while interviewing them, we chose the words in which Broca's aphasics produced fricatives without paying attention to the context. Only fricatives in initial positions before the short vowels were considered. The sample of the words is shown in appendix (10.3). The Broca's aphasic subjects who participated in this part of the study were given the serial numbers, B1, B2, B3, B4 and B5. The researcher listened carefully to all words that started with fricatives and a phonetic transcription was provided for each word. The beginning of frication noise was assessed based on the waveform displayed by the presence of high frequency noise, whereas the offset of frication noise was determined by the absence of high frequency noise in the waveform. In general, the boundaries of the fricatives were determined by the presence of high frequency frication noise. The duration of voiceless fricatives was defined from the onset of frication until the onset of voicing corresponding to the following vowel, whereas for voiced fricatives the duration was defined from the onset of frication noise to the point where a noticeable frication was diminished. There were some limitations in considering some of the productions. For example, it was difficult to consider the substitution of [t] for [θ] as impairment because of the dialect's influence, as in saying [tala:t], instead of [θala:θ] 'three.' Hence, it is difficult to consider these substitutions as errors, even though they are unacceptable in standard Arabic. Furthermore, the same finding could be generalized regarding the fricative [ð] that normally changed to [d] in the dialect of the patients, e.g. [ða:b] 'solved' to [da:b]. Thus, as will be seen in chapter 4 (4.2), the sounds under study are [s], [ʃ], [χ], [z] and [sˤ].

Concerning the emphatic sounds, words that included only the emphatic stop [tˤ] were selected due to the fact that this emphatic stop was often produced by the aphasic subjects and it was clear that the aphasic subjects display particular difficulties in its production. Initial syllable positions starting with the sound [tˤ] and its plain counterpart [t] in monosyllabic and polysyllabic words were chosen. These words are shown in appendix (10.4). VOT measurements were made from the onset of the burst to the onset of periodicity. The formants were measured for the vowels [a, u] and [i] in initial syllable position in every stimulus starting with the sound [tˤ] and with [t] if needed.

1.4. Organization of the thesis

This dissertation consists of 10 chapters. The first chapter describes the experimental methods of the study. First, it describes the statement of the problem and the sociolinguistic profile of Palestinian Arabic. It then describes the participants, methodology and organization of the thesis.

Chapter 2 addresses different definitions and descriptions of aphasia. It reports its main causes and highlights the main linguistic features of each of its classical types. Finally, the discussion addresses the issue of cortical lateralization and the role of the subcortical structures in language processing.

Chapter 3 is divided into eight parts and deals with vowel production in Broca's aphasics and the normal speakers. The findings display the main articulatory and acoustic features of Palestinian Arabic vowels as produced by the normal speakers and the aphasic patients. Furthermore, the formant frequencies of the Arabic vowels produced by Broca's aphasics compared to the normal speakers are addressed. The differences between the durational patterns of vowels produced by the aphasic subjects and the normal speakers are also noted.

In addition, explanations of the deviating patterns are presented in terms of neurolinguistic and phonetic aspects. Furthermore, this chapter focuses on vowel reduction patterns displayed by Broca's aphasics compared to the normal speakers. Descriptions of syllable and word duration are presented. The acoustic vowel space of long and short vowels produced by the aphasic subjects and the normal speakers is presented and the performance of each group in each category is discussed. In addition, the shape of the acoustic vowel space involving the long and short vowels as produced by Broca's aphasics is presented. This chapter also deals particularly with formant frequency analysis. Descriptions of the formant patterns among Broca's aphasics compared to the normal speakers are provided.

Chapter 4 describes consonant production by the normal speakers and Broca's aphasics. This chapter consists of three parts. Part 4.1 focuses on voice onset time (VOT) including definition, its critical attribution to the voiced-voiceless phonetic distinction and establishing VOT values for the Palestinian Arabic stop sounds. Moreover, questions as to whether the Palestinian Broca's aphasics display VOT patterns similar to those of the normal speakers are addressed and if they do not, the VOT patterns they produced are presented. In addition, the distributional patterns of the VOT values of the consonant stops in each aphasic patient are displayed. Also, based on the patterns found among the aphasics, a discussion about the nature of the aphasic errors and whether the deficit is phonetic or phonological is introduced. Part 4.2 sheds light on fricative consonants by addressing different questions such as the ability of the aphasic patients to carry out voicing in fricative sounds by exhibiting similar patterns of glottal vibration as the normal subjects and if they do not exhibit normal patterns, what the abnormal patterns that they demonstrate are. This part focuses on displaying the acoustic and the articulatory characteristics of the fricative sounds produced by Broca's aphasics. The results are compared to the normal speakers. Interpretations and discussions of the deviations are presented. Furthermore, a description of the articulatory difficulties in the production of the affricate sounds in Palestinian Broca's aphasics is given.

Chapter 5 analyzes the acoustic and the articulatory features of the emphatic sounds as produced by the normal speakers and the aphasic subjects. Several definitions of "emphasis" are presented. The focus is mainly on the acoustic characteristics of the sound [tˤ] because the aphasic subjects displayed specific difficulty during its production in addition to its frequent use during their spontaneous speech. The patterns of the formant frequencies are displayed in order to establish the acoustic features for distinguishing emphatic sounds in Palestinian Arabic. Moreover, the way in which F2 locus, the tongue position and the place of articulation of the stop consonants influence the transitions of the second and third formant is discussed. Furthermore, the patterns of energy concentration, the frequency values of F2 and F3 for the vowels in alveolar contexts and the shape of the transition are presented. Likewise, the VOT values of the patients are compared to those of the normal speakers.

Chapter 6 investigates the coarticulatory patterns of the aphasic patients compared to the normal speakers. The discussion reports the main results from neurolinguistic studies on coarticulation in aphasia. Specifically, the results are discussed in terms of speech production models, acoustic parameters and motoric aspects.

Chapter 7 focuses on the F0 movement and the influence of the emotional status of Broca's aphasics on F0 and the formant patterns. The stimuli were selected from spontaneous speech of Broca's aphasics and normal speakers. This part of the study is based on declarative statements and interrogatives, since they are produced most often by the aphasic patients. In addition, sentences that signal happiness, anger and sadness are selected due to their frequent use by the aphasics. In addition, the main results have been discussed in terms of theories concerning the lateralization of prosody.

Chapter 8 summarizes the main findings and conclusions of this study and chapter 9 lists its references. Chapter 10 includes the appendices.

2. TYPOLOGY IN APHASIA

2.1. Definition of aphasia

Aphasia is a language disorder caused by damage to the temporal lobe or higher up in the frontal lobe. It can be considered a disability in processing symbolic materials appearing in different modalities of language function such as speaking, writing and reading.[2] It is important to note that language disorders resulting from functional or psychiatric disorders should be excluded. Consequently, aphasia is definitively a language disorder that commonly results from either stroke or damage to a specific area of the brain. There is some evidence for impairments in nonverbal tasks as well. For example, some aphasics show an inability to associate pictures correctly with their corresponding objects.[3]

Aphasia in adults generally results from injury to the brain. These injuries can have various causes. Stroke is one of the most common causes of aphasia as several studies indicated. The middle cerebral artery (MCA) is considered to be the main supplier for the language areas of the brain. A stroke, which can appear in the form of thrombotic or embolic occlusion of blood vessels, causes cerebral infractions that result in the stopping of blood supply to the infected areas.[4] A cerebral hemorrhage ruptures blood vessels through bleeding into cerebral tissues. This form of stroke (cerebral hemorrhage) is also less predictable than occlusive stroke. Thrombosis takes the form of "progressive narrowing and ultimate occlusion of a localized region of a blood vessel due most commonly to atherosclerosis."[5] Trauma is another frequent cause of brain injury. The most common type of aphasia that results from trauma is anomic aphasia. Moreover, bacterial or viral organisms contribute to aphasia. Meningitis and brain abscesses are also frequently seen.

Neurological disorders are found to be primarily attributable to lesions involving the basal ganglia (e.g. Parkinson's and Huntington's disease). It has been suggested that specific parts of the brain are responsible for different functions. Functional and structural brain imaging techniques give evidence for the dominant role of the left hemisphere in speech processing.

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[2] Cf. Bartha, L., & Benke, T. (2003): Acute Conduction Aphasia: An Analysis of 20 Cases, pp. 93-95.
[3] Cf. Saygin, A., Dick, F., Wilson, S., Dronkers, N., & Bates, E. (2003): Neural Resources for Processing Language and Environmental Sounds: Evidence from Aphasia, p. 929.
[4] Cf. Polychronopoulos, P., Gioldasis, G., Ellul, J., Metallinos, I., Lekka N., Paschalis, C., & Papapetropoulos, T. (2002): Family History of Stroke in Stroke Types and Subtypes, p. 118.
[5] Cf. Nancy, H., & Martin, L. (1991): Manual of Aphasia Therapy, p. 68.

For example, Khedr et al.[6] indicated that the left hemisphere is associated with language and speech functions, while the right hemisphere is associated with non-verbal, visual and spatial functions. In this account, Tzourio et al.[7] in a PET study compared activity related to story-listening between right- and left-handed persons. They found that right-handed subjects show significant activity in the left hemisphere. In general, the left hemisphere is primarily responsible for speech and language processing and comprehension. Accordingly, it is not only responsible for language functions, but also for all language related functions.

The cortical areas associated with auditory processing are located in the left and right temporal lobes in the middle and superior temporal gyri and the associative areas extend to the posterior parts of the temporal lobes.[8] The hemispheric specialization for language remains one of the most critical issues in cognitive neuroscience. Hemispheric specialization is a complex process associated with several correlations such as gender and handedness. However, subsequent investigations have revealed that the right hemisphere does process functions which are not processed to the same degree by the left hemisphere.[9] Consequently, the concept of cerebral dominance has been revised, so that now the left hemisphere is understood to be the dominant hemisphere for speech and language.

Cliniconeuroradiological studies give evidence for the function of the subcortical structures in language and the presence of connections between the basal ganglia and cerebral cortex. The role of the basal ganglia and their components in language processing and aphasia, namely the caudate nucleus and putamen in addition to the thalamus, has been addressed in different studies.[10]

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[6] Cf. Khedr, E., Hamed, E., Said, A., & Basahi, J. (2002): Handedness and Language Cerebral Lateralization, pp. 470-473

[7] Cf. Tzourio, N., Crivello, F., Mellet, E., Kanga-Ngila, N., & Mazoyer, B. (1998): Functional Anatomy of Dominance for Speech Comprehension in Left Handers vs. Right Handers, p. 1.

[8] Cf. Hashimoto, F., Homae, K., Nakajima, Y., & Sakai, K. (2000): Functional Differentiation in the Human Auditory and Language Areas Revealed by Dichotic Listening Tasks, p. 147.

[9] Cf. Bartels-Tobin, L., & Hinckley, J. (2005): Right Hemisphere Contributions to Phonological Processing, p. 120.

[10] Cf. Radanovic, M., & Scaff, M. (2003): Speech and Language Disturbances Due to Subcortical Lesions, pp. 348-349.

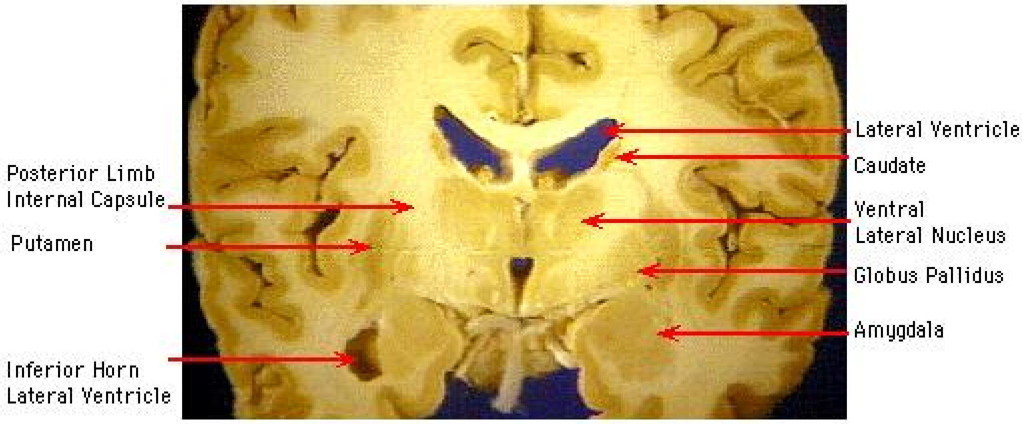

Figure 1: The anatomical structures of the basal ganglia.[11]

The basal ganglia play a role in motor processing including articulation. The thalamus is associated with language functions related to verbal memory. Some investigations exhibited the involvement of the subcortical white matter in language deficits and were found to be important for the process of communication, especially between the posterior and subcortical gray regions and the frontal lobe.[12] The thalamus involvement in language processing is less debated than the disputable role of the basal ganglia.

> "Information originating in the cerebral cortex passes through the basal ganglia and returns via the thalamus to specific areas of the frontal lobe, this feedback circuit often being referred to as the cortico-striato-pallido-thalamo-cortical loop."[13]

The basal ganglia are associated with information processing, including "receiving, transferring, changing, or formulating signals that carry complex information."[14] Several functions were found for the thalamus such as its role in the process of attention. Other studies emphasized its importance in the integration of different modalities of language.[15] Three categories of subcortical aphasias are classified: the thalamic aphasia, striato-capsular

[11] This picture was downloaded from: http://medstat.med.utah.edu/kw/hyperbrain/syllabus/syllabus.html.

[12] Cf. Basso, A., Uhlrich, D., & Bickford, M. (2005): Cortical Function: A View from the Thalamus, pp. 486-488.

[13] Cf. Bruce, E. (2001): Subcortical Brain Mechanisms in Speech and Language, p. 243.

[14] Cf. Crosson B., Zawacki, T., Brinson, G., & Sadek, J. (1997): Models of Subcortical Functions in Language: Current Status, p. 278.

[15] Cf. McHaffie, J., Stanford, T., Stein, B., Coizet, V., & Redgrave, P. (2005): Subcortical Loops through the Basal Ganglia, p. 407.

aphasia and aphasia related to matter paraventricular impairments.[16] Lesions of thalamus structures could result in verbal paraphasias.[17] There are two major categories of aphasia: expressive (motor) and receptive (sensory). These two basic types of aphasia displayed categorical distinction in terms of behavioural and neuroanatomical aspects.

> "Each label focuses on a different dimension of the aphasic impairment, such as whether it primarily affects input or output, how it affects speech production, and whether its associated lesions are in anterior or posterior portions of the left hemisphere."[18]

Expressive aphasics can comprehend language without the ability to express it. They display difficulties in applying the correct mechanism to articulate precisely. The aphasics retain the intellectual abilities for speech. Receptive aphasic patients display severe speech comprehension deficits, but they have no problems with speaking as an event. However, in examining the content of their speech, they show a significant lack in meaning. In general, the left hemisphere is found to be dominant in language processing. It consists of the frontal, temporal, parietal and occipital lobes, as shown in figure 2.

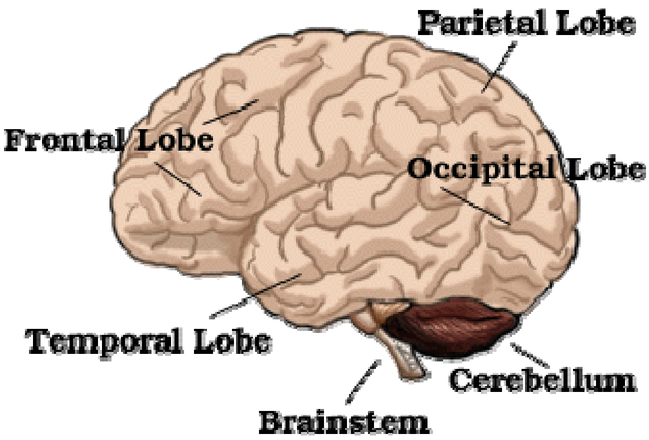

Figure 2: The lobes of the left hemisphere in addition to the cerebellum and the brainstem.[19]

[16] Cf. Kuljic-Obradovic, D. (2003): Subcortical Aphasia: Three Different Language Disorder Syndromes, pp. 445-447.
[17] Cf. Radanovic, M., & Scaff, M. (2003), p. 347.
[18] Cf. Ullman, M., Pancheva, R., Loved, T., Yee, E., Swinney, D., & Hickok, G. (2005): Neural Correlates of Lexicon and Grammar: Evidence from the Production, Reading, and Judgment of Inflection in Aphasia, p. 186.
[19] The figure was downloaded from: www.waiting.com/brainanatomy.html.

The basic anatomical structures of language are believed to be controlled by the primary sensory, the motor efferent and afferent systems that are adjacent to Broca's and Wernicke's areas,[20] as indicated in figure 3. Information flowing and running between Broca's and Wernicke's regions is mediated by the connecting fibers of the "arcuate fasiculus."

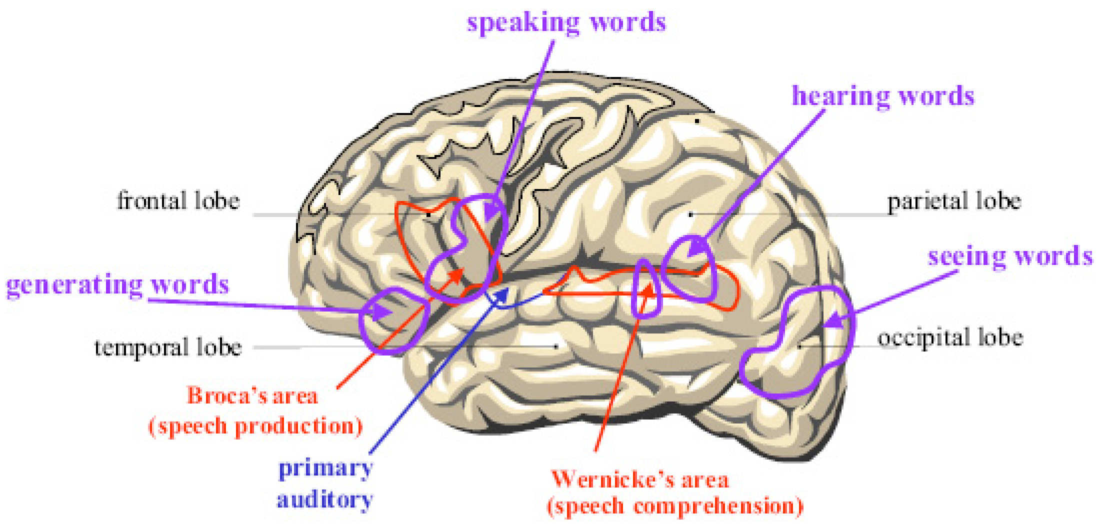

Figure 3: The cortical structures and their role in speech and language processing.[21]

Speech production systems involve a neural network, which predominates over the left hemisphere. This network mainly includes the posterior, superior, temporal and frontal lobe and may also include the parietal cortex.[22] In general, speech production is considered an interaction of different areas and neural systems that are clearly seen in figure 4.

[20] Cf. Soroker, N., Kasher, A., Giora, R., Batori, B., Corn, C., Gil, M., & Zaidel, E. (2005): Processing of Basic Speech Acts Following Localized Brain Damage: A New Light on the Neuroanatomy of Language, p. 216.
[21] The figure was downloaded from: ttp://psy.ucsd.edu/~ifine/psych2.
[22] Cf. Hickok, G., & Poeppel, D. (2000): Towards a Functional Neuroanatomy of Speech Perception, pp. 133-136.

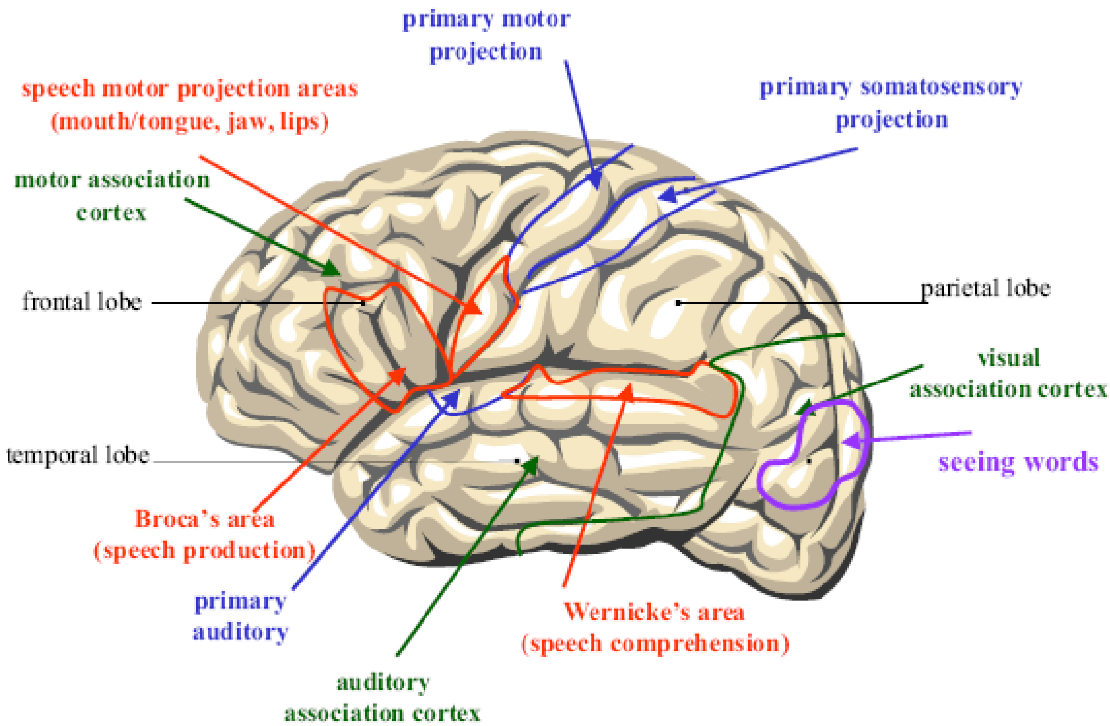

Figure 4: The neural network for language and speech processing system.[23]

Aphasia causes trouble not only in the linguistic aspects of an aphasic's life, but also in the social aspects. Consequently, therapy programmes should take the social needs of those patients into consideration. The development of various imaging technologies has clearly enabled the researchers to study the structure of the brain and as a result has enhanced understanding of the pathophysiology and the pathomechanism underlying aphasia. For example, Computed Transmission Tomography (CT), Magnetic Resonance Image (MRI) and Positron Emission Tomography (PET) have contributed to a better understanding of the function and structure of the brain.

The MRI provides "a very sharp contrast between white and gray brain matter, making it particularly good for visualizing lesions."[24] The fMRI gives us the "potential to reveal areas of brain that are active during a task." The PET makes it possible to present "a picture of the brain's blood supply"[25] during a task or at rest. This method is conducted by giving the subject a small amount of radio active glucose. Pictures were then taken to see the areas of

[23] The figure was downloaded from: ttp://psy.ucsd.edu/~ifine/psych2.
[24] Cf. Papathanasiou, I., & De Bleser, R. (2003), p. 50.
[25] Ibid., p. 51.

increased concentration of glucose, which indicates the active areas in the brain as shown in figure 5.

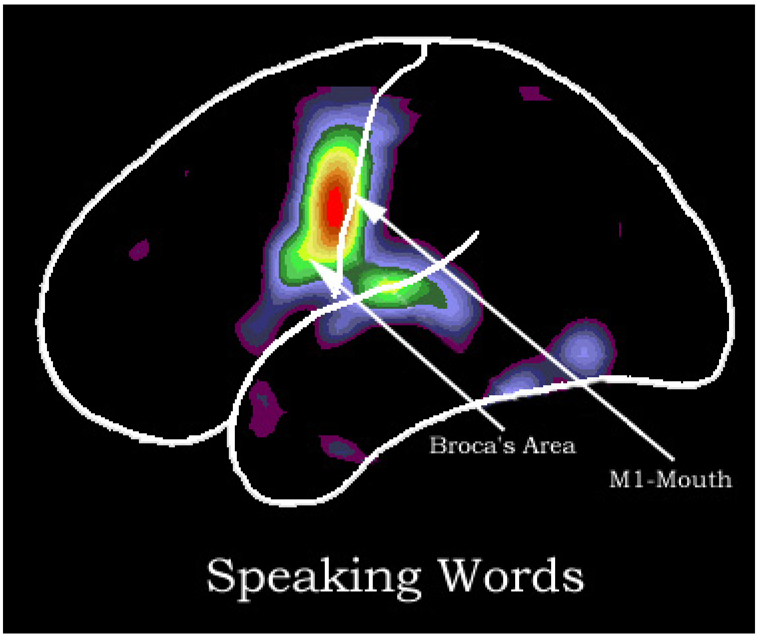

Figure 5: An illustration of the activation of Broca's area by using Positron Emission Tomography (PET).[26]

[26] This picture was downloaded from: http://www.molbio.princeton.edu/courses/mb427/2000/projects/0008/normbrainmain.htm.

2.2. The classical types of aphasia and their main neuroanatomical and neurolinguistic aspects

2.2.1. Broca's aphasia

Broca's area lies in the frontal opercular region and typically occupies the posterior third of the left inferior frontal gyrus. As shown in figure 6, the lesion involves the frontal operculum including Brodmann areas (44) and (45), premotor and motor regions immediately behind and above and extended into the underlying white matter and basal ganglia.[27] Consequently, the damage often extends down into the white matter and in some cases extends posteriorly to the most inferior part of the motor strip. However, lesions in Broca's area do not necessarily result in Broca's aphasia indicating that the relationship between Broca's area and Broca's aphasia is not systematic and consistent.[28] Lesions limited to Broca's area without the adjacent areas are found to result in transient mutism.

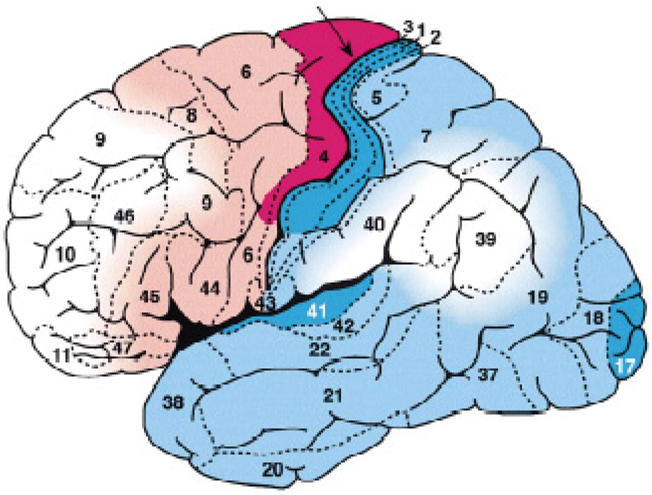

Figure 6: An illustration of the location of Broca's area and its adjacent areas.[29]

The role of Broca's area in language behaviours remains to some extent controversial. For instance, the anatomical proximity of Broca's area to the motor and sensory cortex could reflect sensorimotor impairments of the speech articulators. On the other hand, many investigations have indicated that Broca's aphasics display comprehension impairments when they are tested at high linguistic levels.[30] These observations could suggest subspecializations

[27] Cf. Hagoort, P. (2005): On Broca, Brain, and Binding: A New Framework, pp. 416-420.
[28] Cf. Kaan, E., & Swaab, T. (2002): The Brain Circuitry of Syntactic Comprehension, p. 351.
[29] This picture was downloaded from: http://else.hebis.de/pdflinks/05021322365817313.pdf.
[30] Cf. Kirshner, H. (1995): Classical Aphasia Syndromes, p. 59.

of Broca's area. For example, Price et al.[31] gave evidence for these subfunctions by observing increased activation in area (44) during repetition and reading aloud tasks. They also reported from stimulations in the anterior part of area (45) in single word perception tasks. Friederici and Von Cramon[32] pointed to subspecializations in Broca's area, as well. They indicate that Brodmann's area (44) is associated with working memory for phonological processing and syntactic structure. Moreover, they have shown that Brodmann's area (45) and Brodmann's area (47) become activated for working memory that is essential for semantic characterizations and thematic components. In addition, area (44) of Broca's region is classically involved in motor control of orolaryngeal movements and speech production.[33] Generally, neuroimaging studies have emphasized the different subspecializations of Broca's area.

> "Our results are consistent with the characterization of the posterior portion of Broca's area as participating in the motoric execution of complex articulatory forms, especially those underlying the phonetic level of language structure."[34]

In addition to its role in speech, activations in the posterior part of Broca's area have also been noticed, for example, during syntax processing. Grodzinsky[35] refers to subfunctions of Broca's area in syntactic processing and transformations. This is manifested in a selective loss of grammatical functors and morphemes known as agrammatism. There is evidence for increased activation of Broca's area associated with several motor functions including the imagination and the execution of hand movements.[36] Increased stimulation in area (44) of the left hemisphere responsible for motor preparation and motor planning has also been found.[37] Despite all of the previous findings and observations, there is a debate surrounding the functional features of Broca's area. In general, many neuroimaging studies have shown activation in area (44) of the left hemisphere for tasks not within the scope of the language domain. Damasio[38] has demonstrated that a lesion limited to Broca's area (the foot of the

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[31] Cf. Price, C., Wise, R., Warburton, E., Moore, C, Howard, D., Patterson, K., Frackowiak, R., & Friston, K. (1996): Hearing and Saying, p. 919.

[32] Cf. Friederici, A., & Von Cramon, D. (2000): Syntax in the Brain: Linguistic Versus Neuroanatomical Specificity, p. 33.

[33] Cf. Binkofski, F., & Buccino, G. (2004): Motor Functions of the Broca's Region, p. 366.

[34] Cf. David, P., Corina, L., Susan, L. Carl, D., Kevin, H., Brinkley, J., & Ojemann, G. (1999): Functional Roles of Broca's Area and SMG: Evidence from Cortical Stimulation Mapping in a Deaf Signer, p. 578.

[35] Cf. Grodzinsky, Y. (2000): The Neurology of Syntax, pp. 3-21.

[36] Cf. Binkofski, F., & Buccino, G. (2004), p. 362.

[37] Cf. ibid.

[38] Cf. Damasio, A. (1989): Concepts in the Brain, pp. 24-26.

inferior frontal gyrus) does not produce Broca's aphasia. Such a lesion produces a mild dysprosody and mild agraphia and is occasionally accompanied by word-finding problems and mild dysarthria. Broca's area is generally thought to be responsible for the activation of memories necessary for the sequences of muscular movements required for articulating words.[39] In accordance with this understanding, Broca's aphasic patients have invariably appeared with a right-sided motor deficit.

Symptoms of the patients include the inability to express themselves in complex sentences and they immediately perform poorly articulated verbal output. Their speech lacks morphosyntactical structures, which is widely known as agrammatism. Therefore, they speak short sentences in a telegraphic style with few words and many intervening pauses. Articulation is effortful and is often accompanied by distorted sounds. The general view of their speech is telegraphic due to the selective deletion of many function words and to the disturbance of word order. On the other hand, their comprehension ability is relatively unaffected especially in simple conversations.

However, many studies show defected performance at higher structural levels involving comprehension of grammatically significant structures like passive structures, relative and embedded clauses.[40] Their ability to name objects is always found to be poor, with tests consistently yielding no responses. They display better performance in pointing to the named object than naming the actual object. At the same time, many variables influence the performance of the patients such as word length, word frequency, familiarity and concreteness.[41] The ability to repeat words and sentences is impaired. Depression is a feature distinguishing this syndrome because the patients are often aware of their problem.[42] Reading aloud seems to be more impaired than auditory comprehension. Since writing embodies features of oral language, Broca's aphasics also display writing deficits in form of phono-graphemic matching.[43]

Broca's aphasia should be distinguished from aphemia which is defined as an articulatory disorder caused by generally small lesions underneath the motor cortices or in the vicinity of

[39] Cf. Garret, M. (2003), pp. 710-715.
[40] Cf. Caramazza, A., Capitani, E., Rey, A., & Berndt, R. (2001): Agrammatic Broca's Aphasia Is not Associated with a Single Pattern of Comprehension Performance, p. 158.
[41] Cf. Nickels, L. (2002): Therapy for Naming Disorders: Revisiting, Revising and Reviewing, pp. 943-962.
[42] Cf. Starkstein, S., & Robinson, R. (1988): Aphasia and Depression, p. 7.
[43] Cf. Kirshner, H. (1995), p. 60.

the basal ganglia without hindering the ability to write or to comprehend spoken or written language.[44] In general, this syndrome is restricted to lesions in the lower motor cortex of the left precentral gyrus.[45] Patients with this disorder become acutely mute, though their output is grammatically described as intact. Comprehension, writing and reading abilities are remarkably unaffected.

To conclude, Broca's aphasia can be characterized by effortful, laboured speech and a remarkable reduction in the length of utterances. Moreover, they need more time to express themselves or to describe pictures or events. They display word finding difficulties which are accompanied by long pauses. Their speech is described as agrammatic, since omission and substitution of functional words characterize their speech. They rely mainly on content words compared to adjectives and adverbs.[46] Their comprehension abilities are relatively left intact compared to Wernicke's aphasic patients, whose comprehension has usually been described as poor. Problems with syntactic sentence comprehension were also found. In general, recent psycholinguistic research has shown that comprehension in agrammatism is also impaired. Writing, oral reading and repetition are usually severely disturbed as is speech.

2.2.2. Wernicke's aphasia

The lesion generally lies in the posterior third of the superior temporal gyrus. As shown in figure 7, it is situated in the temporal lobe between the primary auditory cortex and the angular gyrus, which is thought to connect the auditory and visual centers. The area consists of the temporal portion of a region that is known as the interpretive and the knowing area. Wernicke's aphasia results from damage to the posterior region of the left hemisphere, especially the area adjacent to the primary auditory cortex on the posterior portion of the superior left temporal gyrus.[47] The posterior extension of the lesion disrupts visual connections,[48] and therefore the patients show problems with perceptual skills.

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[44] Cf. Kirshner, H. (1995), p. 62.
[45] Cf. Alexander, M., Naeser, M., & Palumbo, C. (1990): Broca's Area Aphasias: Aphasia after Lesions Including the Frontal Operculum, pp. 353-359.
[46] Cf. Sarno, M., Postman, W., Cho, Y., & Norma, R. (2005): Evolution of Phonemic Word Fluency Performance in Post-Stroke Aphasia, pp. 95-105.
[47] Cf. Kirshner, H. (1995), p. 63.
[48] Cf. Amitay, S., Ben-Yehudah, G., Banai, K., & Ahissar, M. (2002): Disabled Readers Suffer from Visual and Auditory Impairments but not from a Specific Magnocellular Deficit, p. 2272.

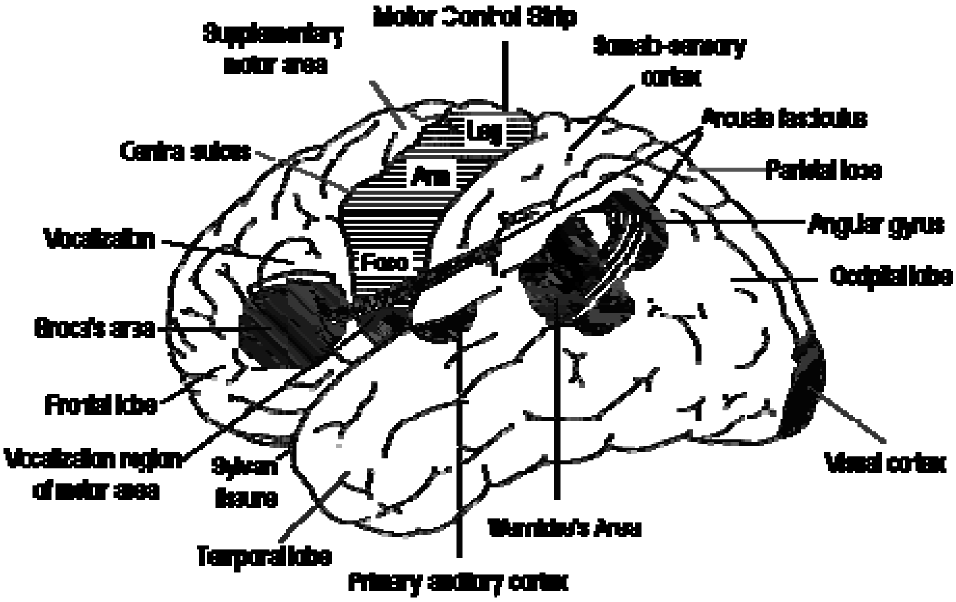

Figure7: Anatomic location of Wernicke's area.[49]

Patients with this disorder can speak fluently, but with frequent paraphasias or producing words incorrectly.[50] Individuals with posterior lesions produce various patterns of errors when attempting to retrieve the target word related to the locus of their deficit on the lexical processing.[51] Consequently, a deficit in the lexical-semantic level resulted in particularly semantic paraphasias. Several studies have investigated naming deficits including paraphasias and their correlations and categories.[52] Phonemic paraphasia (literal) refers to an inappropriate phoneme use[53] that is found to be predominant in anterior aphasia. Verbal paraphasia (semantic) refers to "the erroneous use of a word belonging to an inventory of the language in place of another word that also belongs to one of the language inventories."[54] Thus, the words mean the same thing but do not sound alike. However, several subcategories of verbal paraphasia have been mentioned in various investigations.[55] Neologistic (jargon) paraphasia

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[49] This picture was downloaded from: http://www.sparknotes.com/psychology/neuro/brainanatomy/language.htm.
[50] Cf. Berg, T. (2005): A Structural Account of Phonological Paraphasias, p. 109.
[51] Cf. Friedmann, N., & Biran, M. (2003): When Is Gender Accessed? A Study of Paraphasias in Hebrew Anomia, pp. 445-453.
[52] Cf. Gagnon, D., Schwartz, M., Martin, N., Dell, G., & Saffran, E. (1997): The Origin of Formal Paraphasias in Aphasics: Picture Naming.
[53] Cf. Buckingham, H. (1989): Phonological Paraphasia, p. 90.
[54] Benson, D., & Alfredo, A. (1996): Aphasia: A Clinical Perspective, p. 52.
[55] Cf. Butterworth, B. (1979): Hesitation and Production of Verbal Paraphasias and Neologisms in Jargon Aphasia, pp. 147-156.

involves a substitution of sounds phonetically and semantically unrelated to the target word. Furthermore, their syntactic structures appear to be less impaired than in Broca's aphasics. Due to the lack of emotional sensitivity, Wernicke's aphasics are less frustrated than Broca's patients. Their repetition is also affected. Reading is impaired in a manner similar to auditory comprehension. They have no hemiparesis and write effortlessly. The content of their writing is abnormal and full of spelling errors which affects its intelligibility.

Some subtypes of Wernicke's aphasia in which the subjects demonstrated worse visual reading than auditory oral comprehension have been observed. Consequently, patients who have such versions of Wernicke's aphasia can better understand what has been said than comprehend written material, a condition known as "pure word blindness." An outstanding feature of this syndrome is a severe comprehension deficit. Several studies attributed this deficit to phonemic perception in which the patients had difficulty in perceiving or distinguishing phonemes varying only in one feature[56] such as [d] and [t]. Luria and Hutton[57] indicate that the core problem of Wernicke's aphasia is the comprehension deficit of phonemes.

However, Wernicke's aphasics can sometimes understand many words depending on the nature of the task, but this understanding "can be maintained only for short intervals and requires apparent effort by the patient."[58] Blumstein et al.[59] indicated that the inability to discriminate is harder when the phonemes differ only in one feature. It can also be observed that the comprehension deficit involves the relationship between the perceived phonemes and the meanings of the word. Taking this observation into consideration, it has been questioned whether this deficit relates to a reduced speed of auditory sequencing of perceived phonemes. Tallal and Newcombe[60] conclude that patients with a left hemisphere lesion show selective impairments on both verbal and non-verbal tests and the deficit of auditory processing of rapid acoustic events correlates with the degree of comprehension disturbance. Accordingly, the ability to differentiate between phonemes or the sequencing of rapid acoustic stimuli is impaired in Wernicke's aphasics. In fact, Broca's aphasia and Wernicke's aphasia have

[56] Cf. Kirshner, H. (1995), p. 64.
[57] Cf. Luria, A., & Hutton, A. (1977): A Modern Assessment of the Basic Forms of Aphasia, p. 129.
[58] Benson, D., & Alfredo, A. (1996), p. 139.
[59] Cf. Blumstein, S., Tarter, V., Nigro, G., & Statslenders, S. (1984): Acoustic Cues for the Perception of Place of Articulation in Aphasia, pp. 147-148.
[60] Cf. Tallal, P., & Newconmbe, F. (1978): Impairments of Auditory Perception and Language Comprehension in Dysphasia, p. 13.

different levels of comprehension abilities manifested in the nature and basis of contrast between these two types.

> "Traditionally, the contrast between Broca's and Wernicke's aphasia has been at two levels. At one level, the distinction has been made on what can be observed in spontaneous speech and performance in comprehension tasks. At another level, inferences about the nature of the underlying deficit have been drawn based on the errors made in spontaneous speech from a range of psycholinguistic tasks."[61]

To sum up, speech of Wernicke's aphasics is considered to be fluent and well-articulated, but it is often incomprehendable. This is related to the phoneme substitutions (paraphasias) and neologisms in which a real word is substituted by a non-word for which it is unclear what the target word should be. Semantic or verbal paraphasias are common in which one word is replaced by another that exists in the speaker's language (e.g. replacing 'boy' with 'girl'). In spite of the use of morphological structures, their production is associated with grammatically anomalous structures represented in how those are selected, combined and positioned such as in passive sentences. In general, language comprehension in Wernicke's aphasia is mainly impaired not only at the word level, but also at the sentence level. In addition to the comprehension deficits, Wernicke's aphasics also display writing impairments. Reading is generally impaired and usually appears parallel to impairments in the comprehension of spoken language.

2.2.3. Anomic aphasia

This syndrome has been called amnesic aphasia, nominal aphasia and verbal amnesia. It seems that all these names are synonymous. Indeed, virtually every aphasic syndrome contains an anomic component because any lesion near the zone of language can produce anomia. That is, anomic aphasia rarely occurs alone. Graf and Schacter[62] conclude that damage to the left anterior cortex is essential in causing this syndrome. The lesion is often in the temporal parietal area.

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[61] Cf. Bastiaanse, R., & Edwards, S. (2004): Word Order and Finiteness in Dutch and English Broca's and Wernicke's Aphasia, p. 92.

[62] Cf. Graf, P., & Schacter, D. (1985): Implicit and Explicit Memory for Associations in Normal and Amnesic Subjects, pp. 508-516.

The site of the lesion, as Geschwind[63] pointed out, is in the angular gyrus (figure 7). Also, the site of the lesion is associated with a posterior lesion, but with an intact Wernicke's area. Patients with angular gyrus deficits also demonstrated alexia, agraphia and sensory deficits such as finger agnosia.[64] The neuropathology of anomic aphasia includes left hemisphere strokes, tumours and cognitive diseases such as Alzheimer's disease.

Anomic aphasia is characterized by word-finding difficulty that can be categorized into semantic and syntactic. Regarding difficulty in naming objects, some patients demonstrate dissociations between semantic categories. For example, some of them display difficulties with vegetables rather than with fruits or vice versa or between proper names and other nouns[65] influenced by several variables affecting their naming abilities. Their speech is well-articulated, but often marked by pauses as well as circumlocutions instead of the appropriate words.[66] Sentences are grammatically acceptable. Their comprehension ability is better than those with other kinds of aphasia until they are examined at complex levels. Repetition, auditory comprehension, reading and writing are relatively unaffected. In general, they produce correct syntactic forms with mild articulation deficits or none at all.

2.2.4. Conduction aphasia

Conduction aphasia results from lesions of the arcuate fasciculus that connects Broca's area with Wernicke's area, as shown in figure 8. The lesion involves the white matter underlying the dominant supramarginal gyrus. Generally, the site of the lesion is in the region of the supra-marginal gyrus or inferior parietal lobe.[67] The supra-marginal gyrus may be completely spared and the damage limited to the insula and primary auditory cortex[68] or even to the insula alone. Lesions in the temporo-occipital region have also been identified.[69] It is important to take into consideration that Wernicke's area is not involved in this syndrome.

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[63] Cf. Geschwind, N. (1970): The Organization of Language and Brain, pp. 940-944.
[64] Cf. Kirshner, H. (1995), p. 71.
[65] Cf. Henderson, V. (1995): Naming and Naming Disorders, p. 172.
[66] Cf. Lambon Ralp, M., Sage, K., & Roberts, J. (2000): Classical Anomia: A Neuropsychological Perspective on Speech Production, p. 187.
[67] Cf. Benson, D., & Ardila, A. (1995): Conduction Aphasia: A Syndrome of Language Network Disruption, p. 155.
[68] Cf. Axer, H., Keyserlingk, A., Berks, G., & Keyserlingk, D. (2001): Supra- and Infrasylvian Conduction Aphasia, p. 326.
[69] Cf. Bartha, L., & Benke, T. (2003), p. 101.

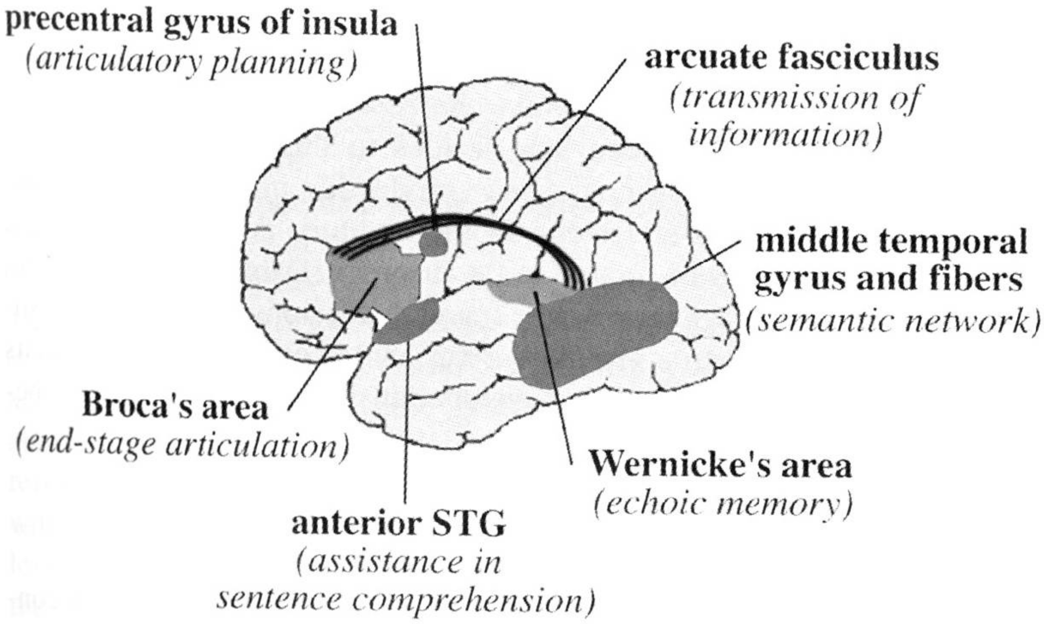

Figure 8: Picture of the arcuate fasciculus and other language zones.[70]

Several researchers have emphasized that the poor ability to repeat words is the main feature identifying this syndrome, attributed to an anatomical disconnection[71] between Wernicke's and Broca's areas. Patients diagnosed with conduction aphasia suffer from a general deficit in phonemic encoding.[72] Sturb[73] found that linguistic factors such as linguistic processing, sequencing of phonemes and auditory short-term memory underlay the repetition deficit. On the other hand, Feinberg et al.[74] found that the conduction aphasic subjects have the ability to identify rhymed words and estimate word length. Thus, inner speech does not appear to account for conduction aphasia.

The clinical picture of this syndrome includes the absence of hemeiplegia, infrequency of visual field impairment, constant presence of acalculia and an inability to produce rhythms despite the preservation of the sense of duration.[75]

[70] This figure was downloaded from: http://www.ssc.uwo.ca/psychology/undergraduate/psych324a/324a_2002/324a_2002_1.0_carina.ppt.
[71] Cf. Damasio, H., & Damasio, A. (1980): The Anatomical Basis of Conduction Aphasia, pp. 337-348.
[72] Cf. Benson, D., & Ardila, A. (1995), p. 157.
[73] Cf. Strub, R. (1974): The Repetition Defect in Conduction Aphasia: Amenestic or Linguistic?, p. 241.
[74] Cf. Feinberg, T., Rothi, L., & Heilman, K. (1986): Inner Speech in Conduction Aphasia, p. 591.
[75] Cf. Benson, D., & Ardila, A. (1995), p. 151.

Disrupted repetition is the classical feature of this syndrome.[76] Patients with conduction aphasia are mostly distinguished by their salient deficit in repetition by revealing difficulties in the selection and sequencing of phonemes. In severe cases this problem is usually much more prominent in syllables and sentences. Repetition in patients with conduction aphasia is "often poorer than their ability to produce the same words in conversational speech."[77] In addition, they exhibit word-finding difficulties and paraphasic errors in spontaneous speech. Similar to other aphasia syndromes, speech of patients with conduction aphasia is characterized by a predominance of phonological errors such as omissions, substitutions and epentheses.[78] As with Broca's aphasic subjects, patients with conduction aphasia give indications that they are aware of the inaccuracy of their speech by displaying self-correction attempts.

Moreover, difficulties in word-finding and reading aloud characterize their speech. They display a high degree of variability in fluency of spontaneous speech. In some cases, speech is fluent with normal length utterances. However, in other cases it is non-fluent and effortful with frequent pauses and hesitation while searching for the target word.[79] In contrast to Broca's aphasia, patients with conduction aphasia are able to produce relatively complex grammatical structures and demonstrate correct phoneme production. Comprehension of the spoken language is usually good, but in complex structures their performance is poor. Remarkable deficits can be noticed in their ability to read aloud, whereas comprehension is better in silent reading.[80] Those patients possess the ability to write some words and letters, but their spelling is found to be poor. In general, their writing lacks accuracy and is frequently disturbed.[81]

To sum up, conduction aphasia is characterized by good auditory comprehension and fluent speech. Speech of patients with conduction aphasia is relatively impaired. This is classically considered a disconnection syndrome because the deficit lies in the arcuate fasciculus, which connects the anterior language centre with the posterior one. Deficit in repetition is the salient feature distinguishing conduction aphasia. Damage to the inferior parietal lobe structures

[76] Cf. Shuren, J., Sche, T., Yeh, H., Privitera, M., Cahill, W., & Houston, W. (1995): Repetition and the Arcuate Fasciculus, p. 596.
[77] Benson, D., & Alfredo, A. (1996), p. 132.
[78] Cf. Bartha, L., & Benke, T. (2003), p. 93.
[79] Cf. ibid, p. 97.
[80] Cf. Kirshner, H. (1995), p. 69.
[81] Cf. Balasubramanian, V. (2005): Dysgraphia in Two Forms of Conduction Aphasia, p. 9.

results in conduction aphasia. However, several explanations for the underlying deficit of conduction aphasia have been developed, reflecting at the same time how it is questionable to put a fixed label associated with different neurological and behavioural features. Accordingly, it has been suggested that conduction aphasia does not represent a unitary disorder. Phonemic praphasias and naming difficulties disrupt their spoken language.

2.2.5. Global aphasia

The term "global aphasia" implies a deficit in expression as well as in comprehension. The generalization of the definition is sometimes misleading, since some patients show preserved functioning areas that should be carefully investigated to find a way to communicate with patients in this category. The lesion of global aphasia is huge and it extends to cover most of the cortex involving the frontal, temporal and parietal lobe. Hemorrhage in the left basal ganglia may also produce global aphasia.[82] In general, the location of the lesion in global aphasia involves damage to large areas of the perisylvian with infarction of the frontal and temporal branches of the left middle cerebral artery.[83] Patients with global aphasia are characterized by poor language skills in terms of speech agility, accuracy, repetition, reading, writing, naming and auditory comprehension. Because of the high severity of the symptom it is frequently called "irreversible aphasia syndrome."[84] However, individual differences in the performance of these skills by patients with global aphasia have been found. For example, they show better performance on writing compared to oral naming.[85] Global aphasia is also marked by non-fluent speech, poor articulation and severe disorders of language comprehension. Moreover, their speech is full of perseverations and recurring utterances (e.g. ah, oh, ok). Severe impairments in repetition and naming tasks particularly in confrontation naming were observed.[86] Writing and reading are always impaired and usually are paralleled by deficits in language comprehension and production.

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[82] Cf. Alexander, M., & Lo Verme, S. (1980): Aphasia after Left Hemispheric Intracerebral Haemorrhage, pp. 1195-1200.

[83] Cf. Hanlon, R., Lux, W., & Dromerick, A. (1999): Global Aphasia Without Hemiparesis: Language Profile and Lesion Distribution, pp. 365-367.

[84] Cf. Damasio, A. (1989), p. 24.

[85] Cf. Mohr, J., Sidman, M., Stoddarad, L., Leicester, J., & Rosenberger, P. (1973): Evolution of the Deficit in Total Aphasia, pp. 1302-1310.

[86] Cf. Kirshner, H. (1995), p. 68.

2.2.6. Transcortical aphasia (TA)

The term "transcortical aphasia" was coined by Lichtheim.[87] This term refers to lesions that occur outside the preisylvian language circuit from Wernicke's and Broca's areas. Two main types of classical transcortical aphasias are classified: transcortical motor and transcortical sensory. Patients with transcortical aphasia display echolalic utterances. They show deficits in various skills such as comprehension, naming, production and reading.

2.2.6.1. Transcortical sensory aphasia (TSA)

The neuroanatomical picture of this type became clear after the use of the computerized tomography. The lesion generally lies in the posterior sector of the middle temporal gyrus and in the angular gyrus or within the white matter underlying these cortices.[88] Their speech is fluent, but the ability to read and write appropriately is impaired. Paraphasias are found frequently in their speech. The spared repetition distinguishes TSA from other receptive aphasias and agnosias including Wernicke's aphasia and pure word deafness.[89]

2.2.6.2. Transcortical motor aphasia (TMA)

The main difference between TMA and Broca's aphasia lies in verbal repetition, which is unaffected in the former and impaired in the later. Lesions in transcortical motor aphasia involve the interruption of the link between the supplementary motor cortex and Broca's area, but with an unaffected Broca's area.[90]

The white matter deep in the frontal operculum and the portions of the anterior limb of the internal capsule might associate with TMA.[91] The lesion might extend to parts of Broca's area.[92] The prominent feature characterizing this syndrome is intact repetition. Nevertheless, those patients do not speak unless they are prompted to do so. Non-fluent speech is a common feature except in repetition tasks. Comprehension is well intact and the patients are aware of their errors. Reading comprehension is found to be preserved, whereas writing is impaired.

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[87] Cf. Kirshner, H. (1995), p. 72.
[88] Cf. Helm-Estabrooks, N., & Albert, M. (1991): Manual of Aphasia Therapy, p. 26.
[89] Cf. Rubens, A. (1982): The Transcortical Aphasias, p. 121.
[90] Cf. Freedman, M., Alexander, M., & Naeser, M. (1984): Anatomic Basis of Transcortical Motor Aphasia, p. 409.
[91] Cf. Hillis, A., Barker, P., Wityk, R., Aldrich, E., Restrepo, L., Breese, E., & Work, M. (2004): Variability in Subcortical Aphasia Is Due to Variable Sites of Cortical Hypoperfusion, p. 525.
[92] Cf. Rubens, A. (1982), p. 116.

Patients with TMA display expressive language deficit. Their speech might be described as functionally mute.[93] Laboured speech, paraphasias, perseverations and echolalia characterize their speech. Naming ability is usually spared. Reading comprehension, oral reading and auditory comprehension are relatively well performed. Their writing has the same features as their speech.

[93] Cf. Rubens, A. (1982), p. 116.

3. VOWEL PRODUCTION BY THE APHASIC SUBJECTS AND NORMAL SPEAKERS

3.1. Vowels produced by the normal speakers

Vowels are very problematic compared to consonants. In fact, not only is their production found to be complex, but also their perception.[94] The physical description of actual vowel sounds is not easy by reusing the parameters already introduced for consonants due to the fact that vowels are completely different in the way of description, production and classification. Several studies have displayed that the formants are to some extent a possible mechanism by which vowels are perceived.[95]

The vowel system in Al-Quran Arabic (classical Arabic) can be described as a triangular[96] system, since it is composed of three short vowels [a], [u] and [i] and their long counterparts [a:], [u:] and [i:]. However, in dialects other forms are found such as the vowels [ɛ:] and [o:].

> "The vowel system of Classical Arabic/Modern Standard Arabic is a simple one of three vowel units or phonemes open, close front, close back with a superposed short/long distinction applicable to all three."[97]

From an acoustic point of view, there is fair amount of studies which have focued on Arabic vowels obtained from different Arabic language environments[98] and countries (Jordan, Tunisia, Egypt, Libya, Algeria and Iraq). Functionally, some studies address the issue of the emphatic sounds[99] and demonstrate values for the vowel formants in emphatic and in plain environments.[100] As far as the direction of phonetic studies in Arabic is concerned, more priority has, in fact, been given to the classification and the description of consonants rather than vowels.

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[94] Cf. Stevens, H., & Wickesberg, R. (2005): Auditory Nerve Representation of Naturally-produced Vowels with Variable Acoustics, p. 21.
[95] Cf. ibid., p. 30.
[96] Cf. Kinberg, N. (2001): Studies in the Linguistic Structure of Classical Arabic, pp. 185-190.
[97] Mitchell, T. (1993): Pronouncing Arabic, p. 138.
[98] Cf. Daniel, L., & Verhoeven, J. (2002): Frequency Analysis of Arabic Vowels in Connected Speech, pp. 77-85.
[99] Cf. Metoui, M. (1998): Über die emphatischen Konsonanten.
[100] Cf. Metoui, M. (2001): Strategien der Artikulation über die Steuerungsprozesse des Sprechens., pp. 124-125.

In this account, the general description of Arabic vowels tends to start with the traditional three vowel "triangle" of the fundamental vowels.[101] The general pattern of this system consists of three vowels, open, close front, close back and with their three long cognates:

[a] and [a:]

[i] and [i:]

[u] and [u:]

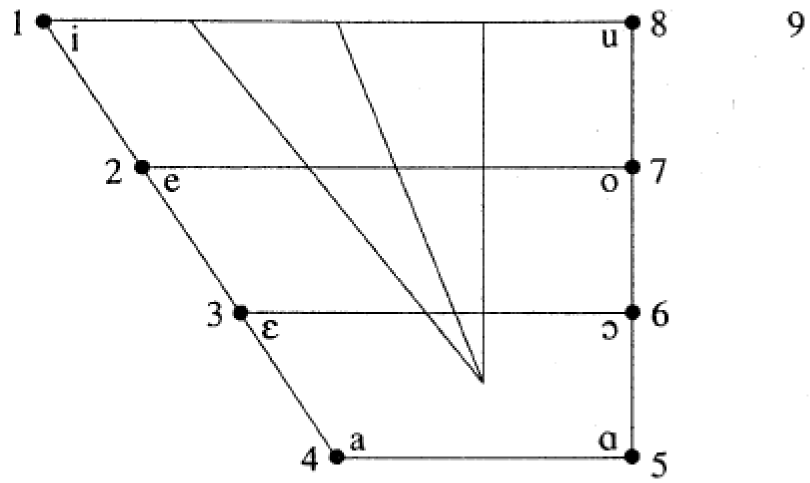

Figure 9: The cardinal vowels as presented by Daniel Jones.

This model is based on two articulators: the tongue and the lips that play an important role in the production of vowels. These two articulators are responsible for the modification of the airstream mechanism. In classifying vowels, we refer to their height, frontness of the tongue and rounding of the lips. In addition, these vowels could be short or long at least in the Arabic language. As already mentioned, Arabic dialects are more vowel inventory oriented than the Quran language is.

3.1.1. The phonetic description of the Palestinian Arabic vowels

As many studies indicated, the Arabic vowels[102] and the Palestinian[103] ones particularly can be divided into short and long vowels. Based on several articulatory studies, the vowels can be described as follows:

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[101] Cf. Jones, D. (1964): An Outline of English Phonetics.

[102] Cf. Metoui, M. (1990): Atlas der arabischen Sprache: Radiokinematographische Untersuchung der Konsonanten- und Vokalsysteme von Tunis.

[103] Cf. Raz, S. (1996): Prominence and Vowel Duration in Some Spoken Arabic Dialects, pp. 193-197.

The short vowel [i]

This vowel is relatively near in its position to the cardinal vowel [i]. The difference is that the front of the tongue is less close than for the cardinal vowel [i] and the lips are rounded. The highest point of the tongue moves somewhat to the back of the mouth. Accordingly, the Arabic [i] can be described as a close front short vowel, the front of the tongue is raised to the front of the hard palate without causing a narrowing in the vocal tract.[104] It can be seen that there is also a degree of centralization caused by the emphatic environment such as in the word [tˤir] 'imperative form of fly' and the pharyngeal consonants like [ħil] 'go away.'

The short vowel [a]

This vowel can be either front or back. The lips indicate no rounding during its production. Significantly, this vowel can be classified as non-emphatic or emphatic. These phonetic variations can be described as follows:

1- [a]

It is produced by raising the front of the tongue to a point below the half open position. At the same time, the tongue moves towards a central opened position as in the word [dam] 'blood.'

2- [ɑ]

It is important to recognize that this vowel is associated with the emphatic environment, e.g. [tˤɑlab] 'request.' During its production the highest point of the tongue is far back and away from the velum. The lips are spread.[105]

The short vowel [u]

During its production, the back part of the tongue moves towards the back of the soft palate without closing the airway or causing friction. The lips are rounded. This vowel can be described generally as back, closed and rounded.

The long vowel [i:]

This is the long cognate of the short [i] and described as close and front. This long vowel seems to be more opened and centralized in the environment of the emphatic sounds like in the word [ʃari:tˤ] 'cassette' and in the pharyngeal consonants.

---

[104] Cf. Lieberman, P., & Blumstein, S. (1990): Speech Physiology, Speech Perception and Acoustic Phonetics, p. 174

[105] Cf. Laufer, A. & Baer, T. (1988): The Emphatic and Pharyngeal Sounds in Hebrew and in Arabic, pp. 190-198.

The long vowel [ɛ:]

This vowel is clearly produced in dialects. Basically it is produced by raising the front of the tongue towards the hard palate and reaching the position of the cardinal vowel [2] by spreading the lips. In addition, as predicted, there is more centralization for this vowel in the emphatic and the pharyngeal environment as can be observed in words such as [tˤɛ:r] 'bird' and [zɛ:t] 'oil.'

The long vowel [a:]

A full openness of the front of the tongue accompanies its production. Phonetically, it can be described as a front long open vowel, e.g. [sa:l] 'flowed.'

The long vowel [ɑ:]

From a phonetic point of view, it is described as a back open vowel. In addition, in the environment of the emphatic consonants, the vowel quality characterizing this sound has a backing feature, e.g. [tˤɑ:r] 'fly.'

The long vowel [o:]

Producing this vowel requires raising the back of the tongue to the position of the cardinal vowel [7],[106] as shown in figure 9. It must be noted that this vowel is only used in dialects. In general, it can be described as a mid to half closed long rounded vowel, e.g. [lo:ħ] 'board.'

The long vowel [u:]

In fact, this vowel is considered to be the long cognate of the short vowel [u], but the tongue height is relaxed and more advanced from the true back. It can be seen that in the environment of the emphatic consonants a kind of centralization occurs, e.g. [jaʕudˤ] 'bite.'

3.1.2. The acoustic features of the Palestinian Arabic vowels as produced by the normal speakers

1- The short vowel [a] and its long cognate [a:]

Table 1 clearly displays that the F1 average of the short vowel [a] is higher than that of the long cognate [a:] with a frequency of 575Hz and 540Hz respectively. However, an opposite pattern was observed in F2. Values increased for long [a:] in comparison to [a], as figure 10 indicates.

[106] Cf. Mitleb, F. (1984): Vowel Length Contrast in Arabic and English: A Spectrographic Test, p. 231.

Vowel	F1	F2
[a]	575	1576
[a:]	540	1630

Table 1: Mean average values of F1 and F2 (Hz) for the short vowel [a] and its long cognate [a:] as produced by the normal speakers.

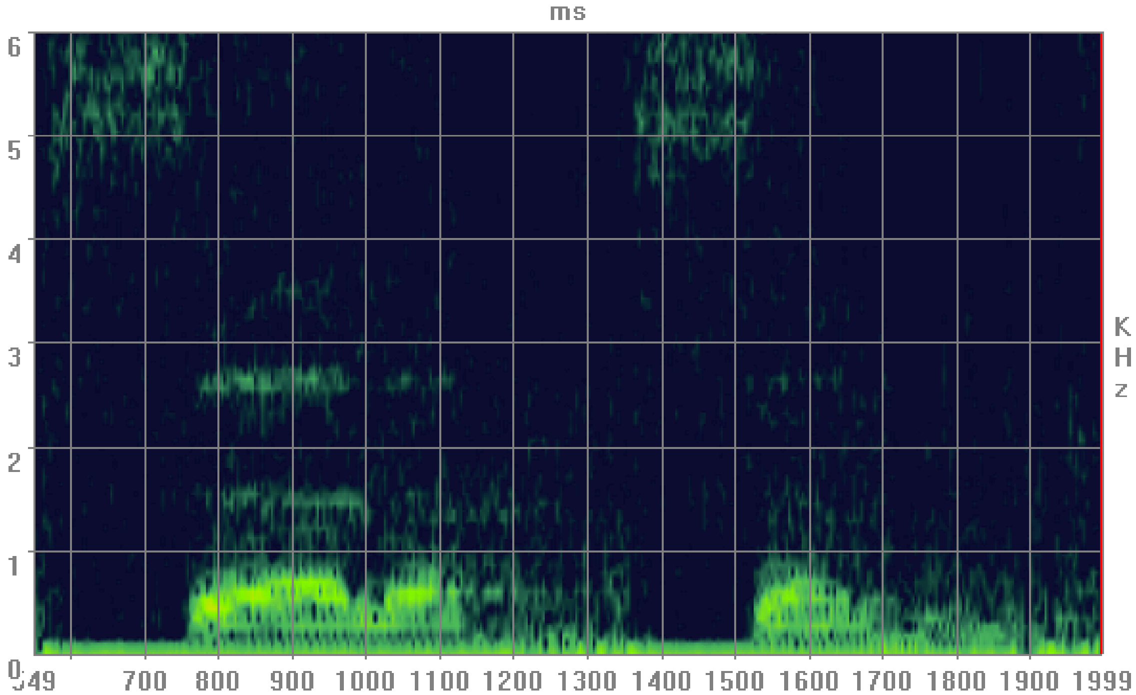


Figure 10: Spectrogram of the short and the long vowels [a:] and [a] in the words [saːlah] and [sal] as produced by a normal speaker.

2- The emphatic [ɑ] and its non-emphatic cognate [a]

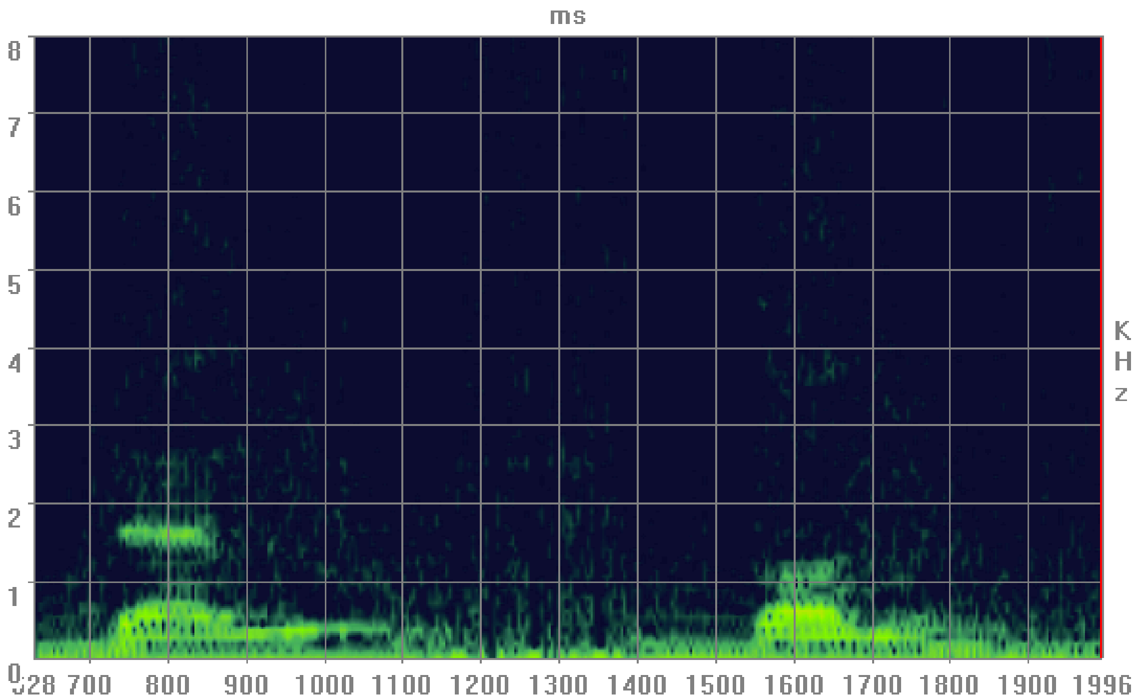
Vowel	F1	F2
[ɑ]	630	1088
[a]	575	1576

Table 2: Mean average values of F1 and F2 (Hz) for the short vowel [ɑ] and its plain cognate [a] as produced by the normal speakers.

As it has been previously discussed, during the production of [a] the front of the tongue is raised just below the half-open position and the tongue is retracted towards a central position. A notable change in the size of the pharyngeal, oral and labial cavities affects the formant values. Concerning the F1 and F2 values of the non-emphatic [a] and the emphatic [ɑ], the following conclusions can be drawn:

1- The F1 average for the emphatic [ɑ] was 630Hz and for the non-emphatic [a] it was 575Hz. In fact, the difference between the two vowels relates to the way they are produced. That is, the front of the tongue during the production of emphatic [ɑ] vowel is in an open position that increases the distance between the hard palate and the raised part of the tongue, and consequently resulting in an increase in F1.
2- The mean average of F2 for the emphatic [ɑ] was 1088Hz and for the non-emphatic it was 1576Hz. A finding of considerable importance is the lowering of F2 in the emphatic environment (488Hz). It seems reasonable to assume that F2 may play a crucial role in distinguishing the emphatic sounds. As mentioned before, the non-emphatic vowel is frontally produced and the emphatic one posteriorly. Thus, it can be said that the further back the tongue is, the lower the F2 will be.

Based upon the previously mentioned observations, there is some evidence to indicate that the lowering of F2 with the emphatic [ɑ], as the second word in figure 11 shows, could be related to the place of articulation, which takes place posteriorly in the oral cavity and increases the front part of the cavity. Furthermore, the slight raising of the tongue during the production of [ɑ], its retraction to the back and the spread of the lips contribute to enlarge the oral cavity. In this sense, this leads to decreasing the velocity of the airstream accompanied by its production and resulting in a lowering of F2.



d a l d^ʕ ɑ l

Figure 11: Spectrogram of the vowels [a] and [ɑ] in the words [dal] and [d^{ʕ}ɑl] as produced by a normal speaker.

3- The short vowel [ɑ] and its emphatic cognate [ɑ:]

Table 3 and figure 12 clearly show that the mean average of F1 for the short emphatic [ɑ] is lower than the long emphatic [ɑ:], whereas an opposite pattern was displayed by F2 where the long vowel [ɑ:] has a lower F2 and the short vowel [ɑ] displays a higher value.

Vowel	F1	F2
[ɑ]	630	1088
[ɑ:]	670	1025

Table 3: Mean average values of F1 and F2 (Hz) for the short vowel [ɑ] and its long emphatic cognate [ɑ:] as produced by the normal speakers.

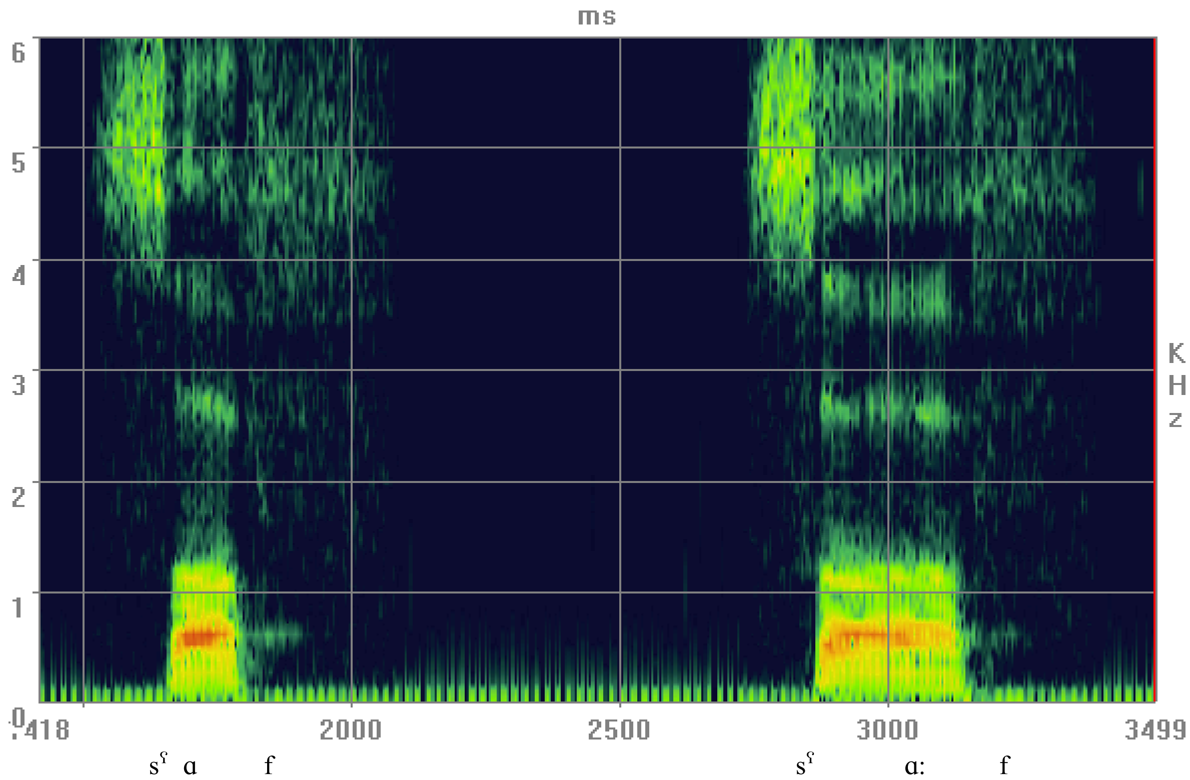


Figure 12: Spectrogram of the short and the long vowels [ɑ] and [ɑ:] in the words [sˤɑf] and [sˤɑ:f] as produced by a normal speaker.

4- The short vowel [u] and its long cognate [u:]

Regarding the vowels [u] and [u:], it is notable, as table 4 and figure 13 illustrate, that the F1 of the long vowel [u:] is lower than [u], which could be due to the fact that the tongue is highly raised in comparison to the production of [u] leading to increase the accompanied area of constriction. In addition, one would then argue that lowering F2 for [u:] is associated with the retraction of the tongue and at the same time to its movement towards the soft palate in contrast to [u]. It thus appears that the lowering of F1 and F2, as shown in figure 13, is predictable because of the backness of the tongue, which leads to lowering the values of the formants.

Vowel	F1	F2
[u]	390	1010
[u:]	350	978

Table 4: Mean average values of F1 and F2 (Hz) for the short vowel [u] and its long cognate [u:] as produced by the normal speakers.

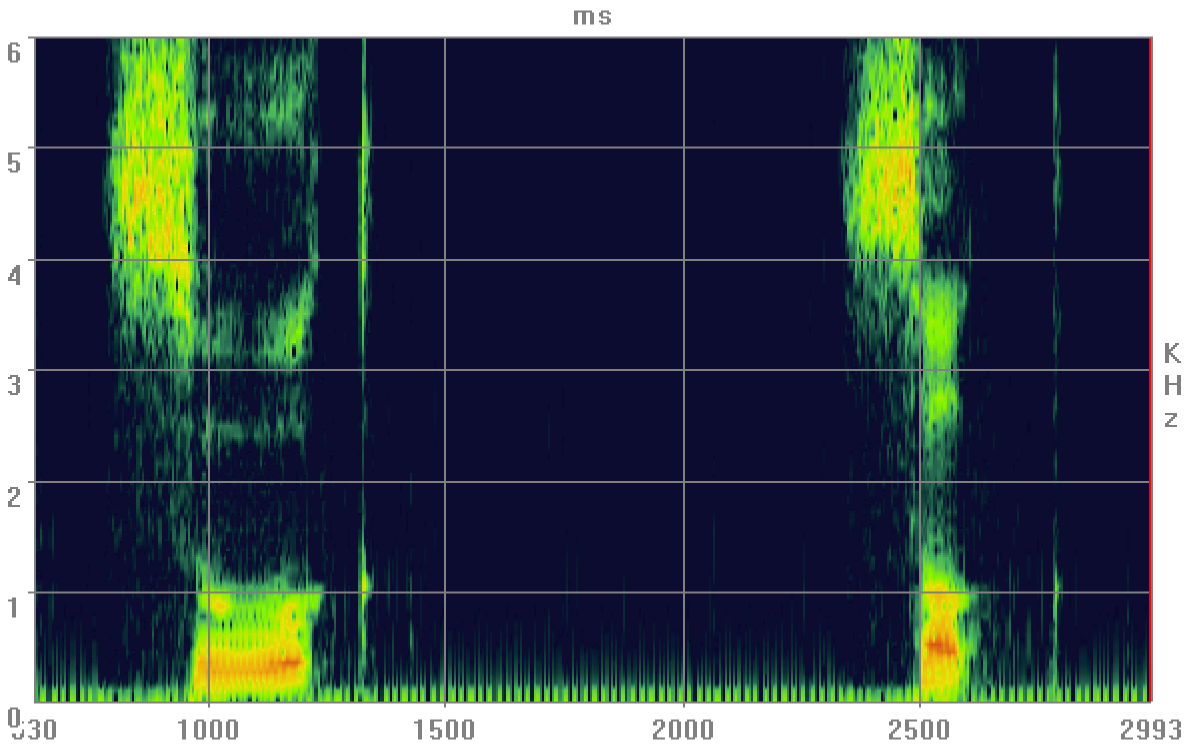


Figure 13: Spectrogram of the short and the long vowels [u] and [u:] in the words [su: q] and [suq] as produced by a normal speaker.

5- The long vowels [u:] and [o:]

Based on table 5, significant differences between the acoustic features of [u:] and [o:] were found:

1- The mean average of F1 with [u:] is 350Hz and with [o:] is 560Hz. As seen, there is an increase in value of F1 with [o:] because of the relative decreasing in the degree of narrowing that has been built during its production in comparison to [u:]. In addition, the lowering of the tongue in the pharyngeal cavity with [o:] to a point relatively lower than the place of articulation for [u:] at the same region leads to a slight narrowing.[107] This tendency confirms that the lowering of F1 by moving the closed vowels to the open ones increases the pharyngeal cavity.

2- The mean average for F2 with [u:] is 978Hz and with [o:] is 1188Hz. It is apparent that the increasing of F2 with [o:] could be interpreted in terms of the fact that during its production the accompanied narrowing is light and the tongue has moved somewhat forward. In this regard, the oral narrowing with the back vowels is

[107] Cf. Butcher, A., & Ahmad, K. (1987): Some Acoustic and Aerodynamic Characteristics of Pharyngeal Consonants in Iraqi Arabic, p. 158.

decreased while the pharyngeal narrowing is increased leading to an increase in the values of F1 and F2.

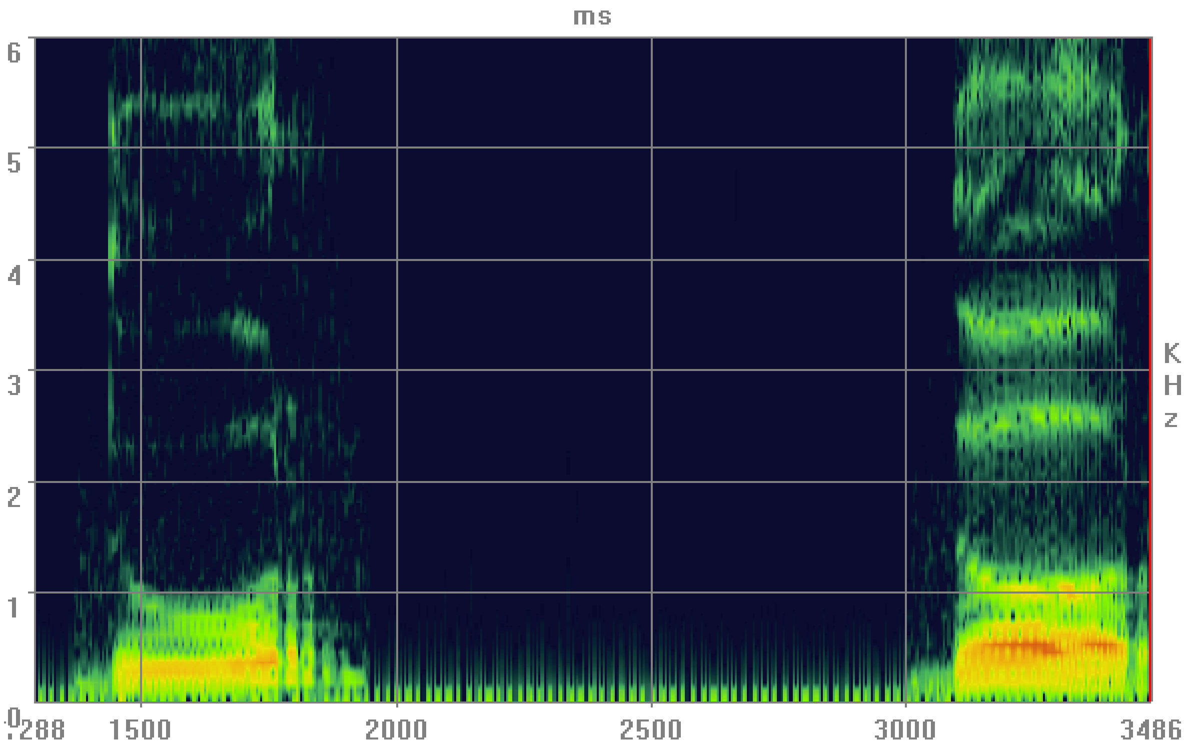
3- The protrusion of the lips participated in raising the values of F1 and F2 for [o:]. However, the lip protrusion during the production of [u:] increases the length of the vocal tract and thus causes a lowering in the formants.

Vowel	F1	F2
[u:]	350	978
[o:]	560	1188

Table 5: Mean average values of F1 and F2 (Hz) for the long vowels [u:] and [o:] as produced by the normal speakers.

Pickett indicated that the back vowels [u] and [o] differ "in amount of constriction at a place near the back of the palate."[108] According to his study, the vowel [u] is more constricted than [o]. [109]In light of the results obtained from the current study, based on the acoustic data, the vowel [o:] is produced with less tongue constriction than [u:]. In this account, the higher F2 of [o:] compared to [u:] confirms the previous conclusion due to the fact that the greater the constriction the more F2 is lowered, as the F2 frequencies of the words in figure 14 clearly show. Moreover, X-ray studies of articulation emphasized that the point of constriction is back for [u].[110]

[108] Pickett, J. (1980): The sounds of Speech Communication. A Primer of Acoustic Phonetics and Speech Perception, p. 49.
[109] Cf. ibid., pp. 49-50.
[110] Cf. Johansson, C., Sundberg, J., & Wilbrand, H. (1985): X-ray Study of Articulation and Formant Frequencies in Two Female Singers, pp. 210-218.



d u: r d o: r

Figure 14: Spectrogram of the vowels [u:] and [o:] in the words [du:r] and [do:r] as produced by a normal speaker.

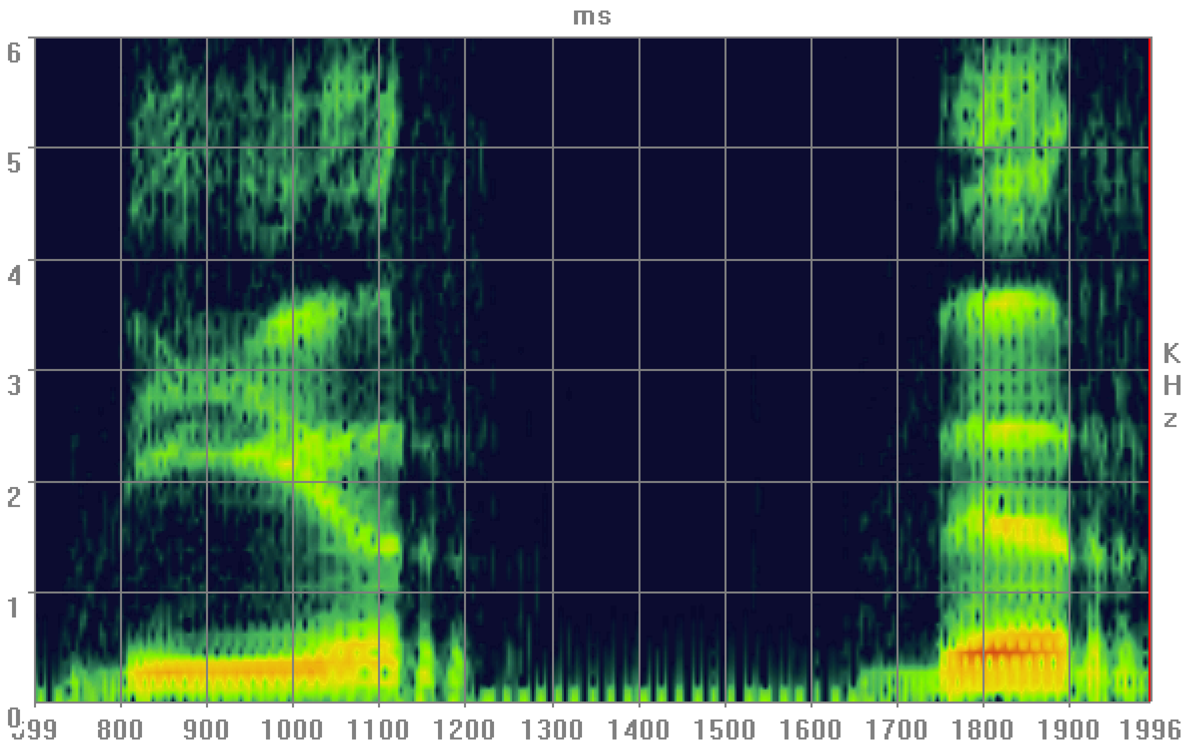
6- The vowels [i] and [i:]

Significant acoustic differences between the two vowels can clearly be seen as shown in table 6 and figure 8. These differences can be summarized as follows:

1- F1's average of the long vowel [i:] is lower than that of the short vowel [i] indicating tongue rising.
2- F2's average of the vowel [i:] is greater than that of [i], which could refer to the fact that during the production of [i:] the tongue is more advanced and higher than of the short [i]. This would increase the degree of constriction between the surface of the tongue and the hard palate.

Vowel	F1	F2
[i]	417	1727
[i:]	319	2049

Table 6: Mean average values of F1 and F2 (Hz) for the vowels [i:] and [i:] as produced by the normal speakers.



b i: r b i r

Figure 15: Spectrogram of the short and the long vowels [i] and [i:] in the words [bi: r] and [bir] as produced by a normal speaker.

7- The vowels [i:] and [ɛ:]

Vowel	F1	F2
[i:]	319	2049
[ɛ:]	485	1780

Table 7: Mean average values of F1 and F2 (Hz) for the long vowels [i:] and [ɛ:] as produced by the normal speakers.

The main acoustic features of both vowels are presented based on table 7:

1- The average value of F1 for [i:] is 319Hz and 485Hz for [ɛ:]. It is notable that there is a remarkable increase in the frequency of F1 for the vowel [ɛ:]. This could be interpreted in terms of lowering the tongue to a point that is lower than the place of production for [i:].
2- The average value of F2 for [i:] is 2049Hz and for [ɛ:] is 1780Hz. This reduction of F2 frequency for [ɛ:], as figure 16 shows, is related to its way of production where the

tongue moves somewhat to the back resulting in an increase between the distance of the raised part of the tongue and the hard palate. This suggests a reduction in the velocity of air, pressure and frequency. In sequence, the direction of movement by depressing the tongue causes a decrease in F2 and an increase in F1 in comparison to [i:].

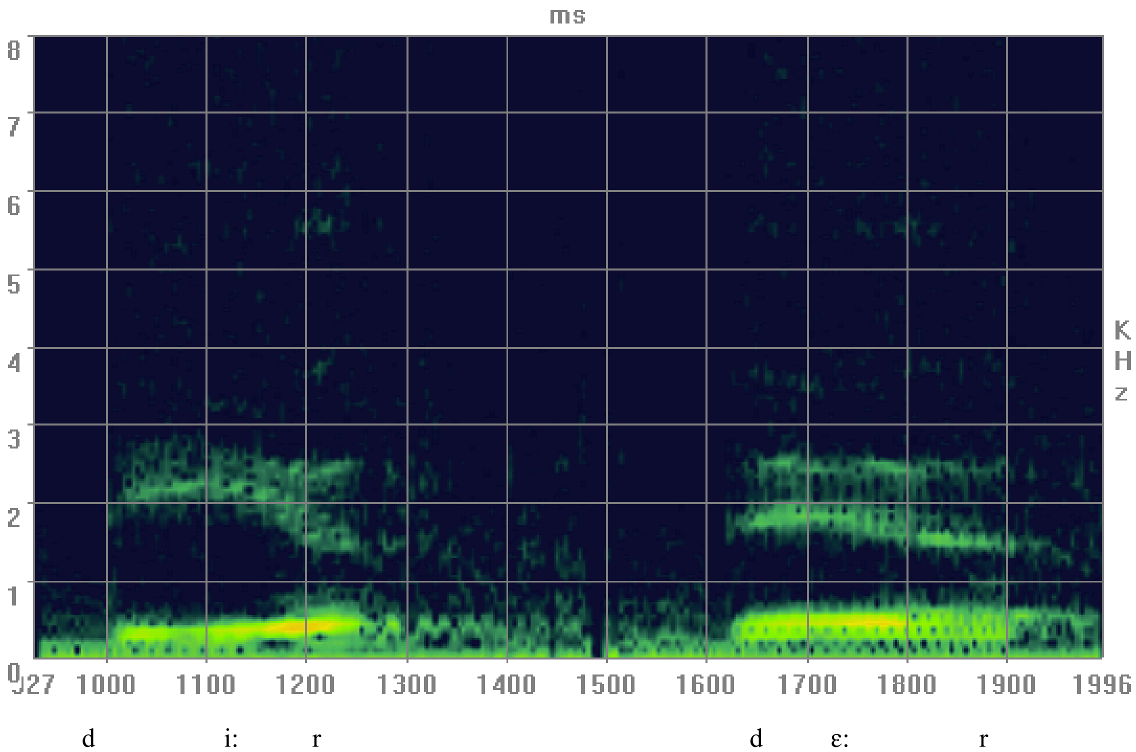


Figure 16: Spectrogram of the vowels [i:] and [ɛ:] in the words [di:r] and [dɛ:r] as produced by a normal speaker.

In conclusion to this subsection, it can be said that the vocal resonators are distinguished by a continuous change in shape and area. Tongue movement and lip protrusion affect the formant frequency. In addition, tongue backness during the production of the vowel increases the area that forms in the oral cavity and reduces the pharyngeal cavity. On the other hand, the elevation and fronting of the tongue produce a small area in the oral cavity, but at the same time enlarge the area of the pharyngeal cavity. Lip protrusion increases the length of the vocal tract and consequently lowers the formant frequencies.[111] Consequently, the interaction between the mentioned factors and the different configurations of the vocal tract affects the formant frequencies. Furthermore, a problem of considerable interest is the role of

[111] Cf. Neppert, J., & Pétursson, M. (1986): Elemente einer akustischen Phonetik, p. 110.

coarticulation in producing vowels. This clearly appears in the movement of the tongue by affecting its degree of backness, frontness and elevation.

3.1.3. Comparison of the acoustic vowel data from various studies and our data based on F1 and F2

Different values of F1 and F2 for the Arabic vowels exhibited from several studies are clearly shown in tables 8 and 9 in addition to figure 17. It can be seen that the vowels [a] and [a:] in the data of the current study have relatively lower values compared to those reported from other investigations. Significantly, little differences were found between the frequency of F1 and F2 for the current study and Tunisian Arabic, as shown in table 9. On the other hand, comparing our findings with Abou Haidar's study, which is based on countries, it is apparent that the open vowels [a] and [a:] exhibit low values in comparison to the values from different Arabic countries with a notable exception of F2 values for the vowel [a:]. In addition, the value of F1 for [i:] in the current study is comparable to the results from Haider and Ghazali. These results are not near those established by Al-Ani. This may be due to the fact that his study was conducted on isolated vowels. However, F2 for [i:] displays a large difference between our values and those from other studies with the observation that our value is closely related to the value of F2 reported by Abou Haidar for Syrian subjects. In addition, F1 of the vowel [i] was relatively near to the findings of Ghazli and Haidar, and higher than the Metoui data.

In general, the results from the current study further indicate that F1 and F2 for [i] can be respectively compared to Syrian values as reported by Abou Haidar, with the exception of F2 for [i] being highest among all other values found by researchers.

	iˇ		i		uˇ		u		aˇ		a	
	F1	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**
Al-Ani	285	2200	290	**2200**	285	775	290	800	675	1200	600	1500
Ghazeli	310	2225	455	1780	330	900	450	1125				
Belkaid	285	2195	355	1830	310	790	340	995	425	1720	400	**1640**
Haidar	315	**2230**	**485**	1750	335	835	500	1120	**690**	**1500**	**675**	1585
Newman-Verhoeven	**390**	1725	440	1770	**470**	**1120**	**480**	**1170**	620	1455	616	1460
Spread	105	525	195	450	195	345	190	370	275	300	275	180

List of vowel frequencies (Hz) in Abou Haidar (1994). Values in bold are the highest in range, those underscored the lowest.

	iˇ		i		uˇ		u		aˇ		a	
	F1	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**
Qatari	310	1990	500	1400	310	830	490	1005	621	1280	620	1540
Lebanon	280	2010	490	1530	330	795	475	1060	610	1430	640	1390
Saudi	305	2530	540	1830	375	930	540	1190	730	1540	695	1590
Tunisia	315	2275	510	1690	360	830	540	1135	610	**1780**	650	1590
Syria	330	2465	415	**2135**	320	620	430	1200	710	1560	700	**1680**
Sudan	325	2220	420	2000	**380**	900	455	1040	730	1500	660	1600
UAE	**335**	2065	460	1720	350	**990**	475	1075	730	1380	640	1660
Jordan	320	2295	565	1720	260	795	**580**	**1240**	770	1521	**780**	1620
Spread	50	470	150	600	70	350	150	240	150	500	150	300

Figure 17: F1 and F2 values for Arabic vowels as found by different studies.[112]

[112] This table was downloaded from: http://www.uia.ac.be/apil/apil100/Arabic2.pdf.

Vowel	F1	F2
[a]	575	1576
[a:]	540	1630
[ɑ]	630	1088
[ɑ:]	670	1025
[u]	390	1010
[u:]	350	978
[i]	417	1727
[i:]	319	2049
[ɛ]	450	1760
[ɛ:]	485	1780
[o:]	560	1188

Table 8: Mean average values of F1 and F2 (Hz) for the vowels as produced by the Palestinian speakers in the current study.

Vowel	F1	F2
[a]	602	1345
[a:]	628	1419
[ɑ]	685	1245
[ɑ:]	710	1204
[u]	361	991
[u:]	386	876
[i]	342	2028
[i:]	363	2049
[ɛ]	528	1697
[ɛ:]	578	1752

Table 9: Mean average values of F1 and F2 (Hz) for vowels as produced by Tunisian speakers.[113]

[113] Metoui, M. (2001), p. 125.

3.2. The formant frequencies of Palestinian Arabic vowels as produced by the aphasic subjects compared to the normal speakers

The acoustical investigations enable us to see whether the aphasic subjects implemented normal vocal tract configurations or not. Ryalls[114] pointed out in an acoustic study of vowel production in aphasia that the aphasics tended to vary their vowel production with significant formant mean differences. Kent and Rosenbeck[115] reported that their subjects show formant values relatively similar to normal English speakers with the exception of some individual differences.

In fact, it is also worthy to note that these studies were conducted on non-Arabic aphasics. Therefore, the purpose of this part of the study is to draw descriptions for the formant patterns of the vowels produced by Palestinian Broca's aphasics. Applied to the cases being considered in other studies, the purpose of the current study is to investigate the patterns exhibited by those patients by raising the question whether those among the Palestinian Broca's aphasics differ from normal speakers and simultaneously comparing the results with previous investigations conducted on other languages.

3.2.1. Results

Based on table 10, the aphasic subjects had a higher F1 value compared to the normal speakers. They demonstrated a considerable compliance with the F1 whose value is lowered as the amount of oral configuration increases during the production of the high front vowel [i]. Significantly, the aphasic subjects did not comply with the low vowel rule, since they did not have the highest value for this vowel as is the case for normal subjects. Additionally, at the individual level, 80% of Broca's aphasics produced higher F1 values than the normal speakers for the short high vowel [i] and 100 % for the long vowel [i:]. To a limited extent, this could be related to the undershooting of the tongue elevation and fronting. Furthermore, their formant averages suggest that they implemented the acoustic-phonetic rules variably. In other words, this means that they could maintain the rules with high vowels, but they were unable to achieve this with low vowels, suggesting that they display relatively limited mobility of their articulation apparatus. However, the tendencies with long vowels, as shown in figure 19, have been somewhat changed, since Broca's aphasics show a complete

[114] Cf. Ryalls, J. (1986): An Acoustic Study of Vowel Production in Aphasia, p. 62.
[115] Cf. Kent, R., & Rosenbek, J. (1983): Acoustic Patterns of Apraxia of Speech, p. 242.

compliance with F1 and the value of F1 has increased as the amount of oral configuration decreased during the production. In addition, it is true for the normal speakers as well as for the aphasic patients that F1 for the long vowel [a:] has a higher value than that of the other vowels except for the vowel [o:].

Subjects	[a]	[u]	[i]	[ɛ]
Normal speakers	575	390	417	450
Aphasic subjects	585	610	517	540

Table 10: F1 mean average frequency (Hz) for short vowels as produced by the aphasics and the normal speakers.

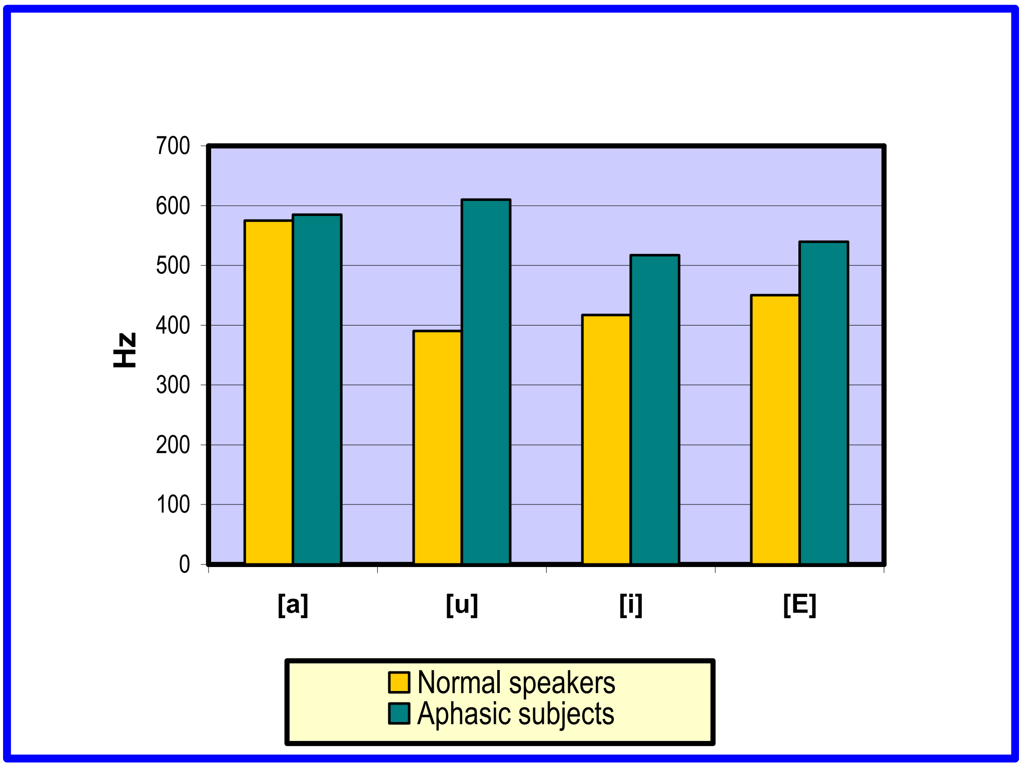


Figure 18: F1 mean average of short vowels (Hz) as produced by the normal speakers and the aphasic subjects.

Subjects	[a:]	[u:]	[i:]	[ɛ:]	[o:]
Normal speakers	540	350	319	485	560
Aphasic subjects	645	563	473	432	511

Table 11: F1 average frequency (Hz) for long vowels as produced by the aphasics and the normal speakers.

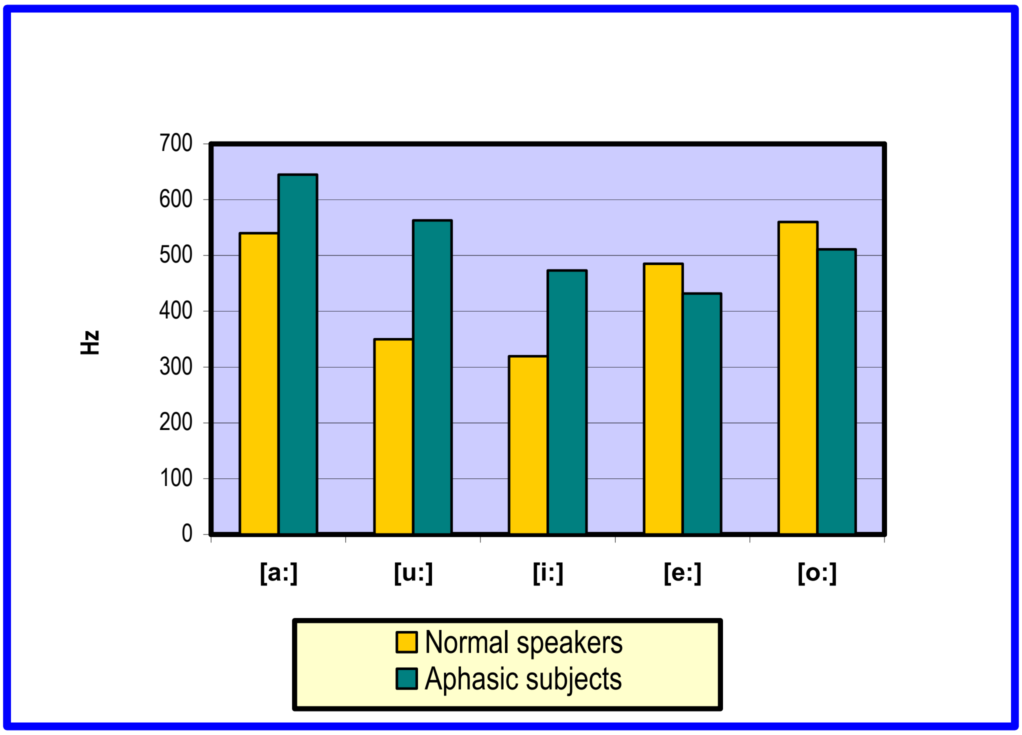


Figure 19: F1 mean average of long vowels (Hz) as produced by the normal speakers and the aphasic subjects.

Regarding F1 for the vowel [o:] in the normal speakers group, a drop of this formant was clearly noticed. The aphasic subjects reversed the pattern, which indicated a remarkable increasing of F1. This finding would indicate that the production of this vowel required a fine coordination in the motoric apparatus, since it is produced by raising the back of the tongue to the position of the cardinal vowel [7], as shown in figure 9.

The results of this study like previous investigations indicated that the aphasic subjects exhibit higher F1 than the normal speakers. For example, Ryalls[116] indicated that vowels produced by Broca's aphasics had a higher F1 than those of the normal speakers. This could be interpreted in terms of the production of vowels by Broca's aphasics is associated with a wider vocal tract configuration. With respect to the values of F2 for the short vowels, it was obvious that the interaction between quality and vowel length was considerable. Furthermore, the data for the aphasic subjects and the normal speakers yielded further differences across groups. Notably, for the normal speakers, as shown in figures 20 and 21, there was a clear lowering of F2 in the short front vowel compared to its long cognate. Furthermore, the short back vowel was distinguished by higher F2 compared to the long back vowel. Interestingly, however, while

[116] Cf. Ryalls, J. (1986), pp. 55-60.

Broca's aphasics oppose the trends by displaying higher F2 values for the front short vowel [i] than for the front long vowels, they behave in the same way as the normal speakers in producing the short back vowel with a higher F2 value than the long back one. In addition, the F2 of the vowel [ɛ] as produced by Broca's aphasics was somewhere between the vowels [u] and [i].

Subjects	[a]	[u]	[i]	[ɛ]
Normal speakers	1576	1010	1727	1760
Aphasic subjects	1587	1826	1936	1792

Table 12: F2 mean average frequency (Hz) for short vowels as produced by the aphasics and the normal speakers.

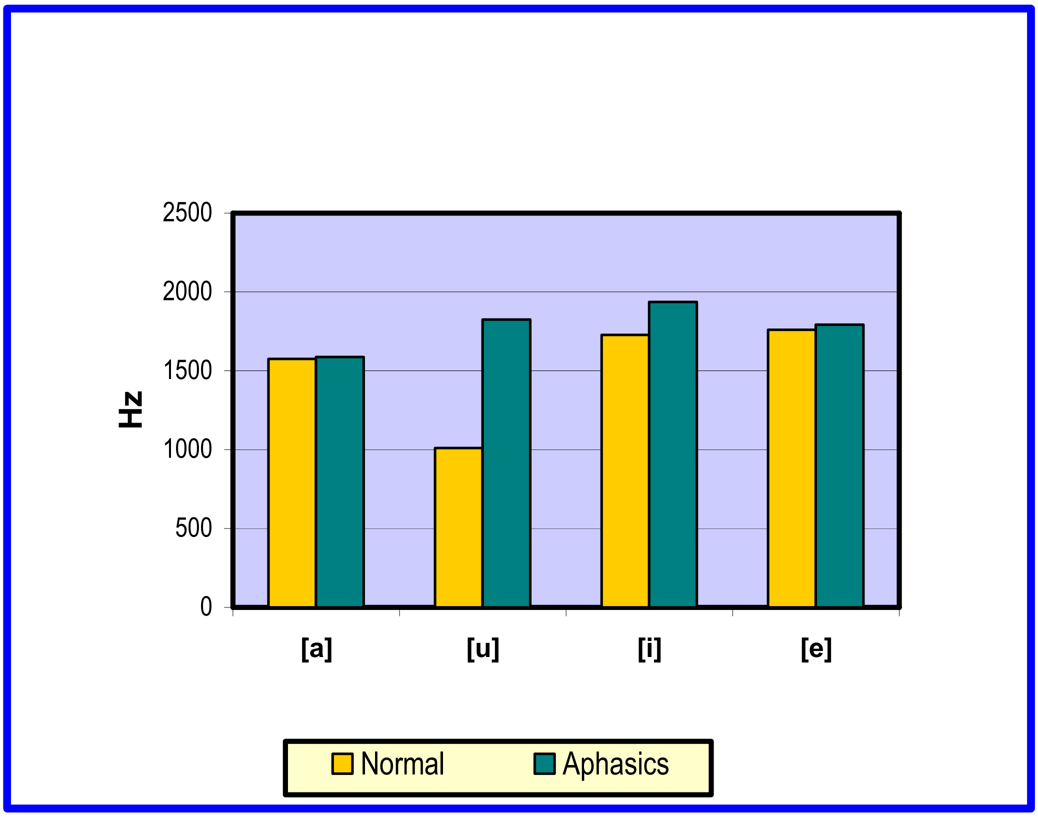


Figure 20: F2 mean average (Hz) for short vowels as produced by the aphasics and the normal speakers.

Subjects	[a:]	[u:]	[i:]	[ɛ:]
Normal speakers	1630	978	2049	1780
Aphasic subjects	1578	1743	1678	1810

Table 13: F2 mean average (Hz) for long vowels as produced by the normal speakers and the aphasic subjects.

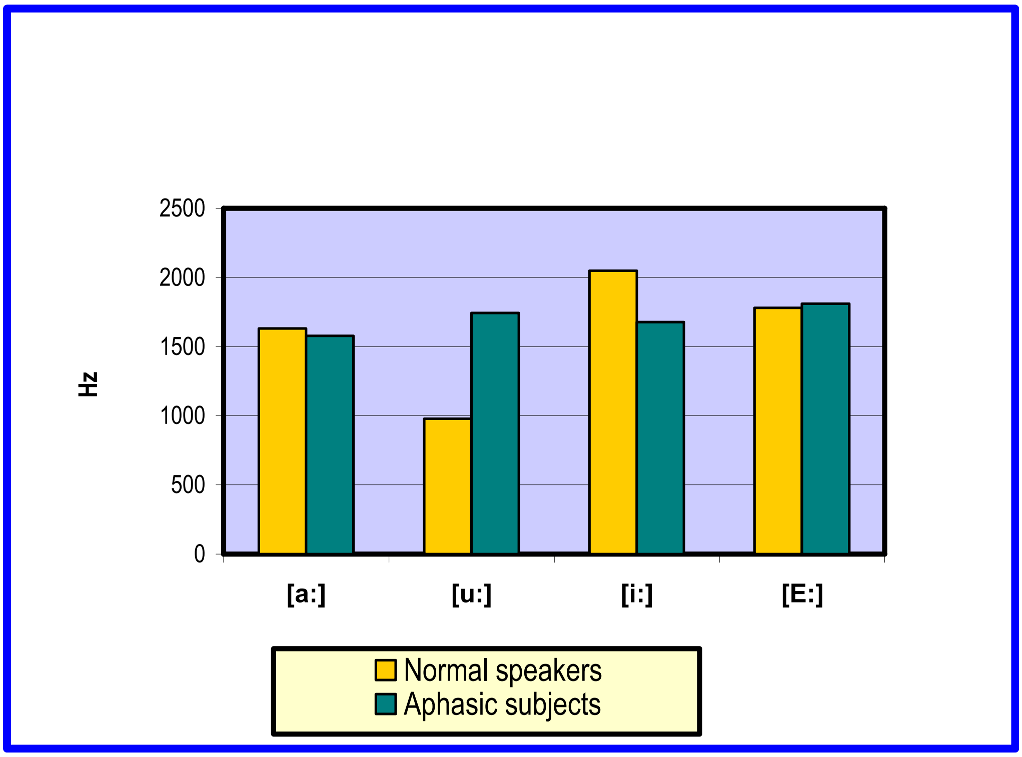


Figure 21: F2 mean average (Hz) for long vowels as produced by the normal speakers and the aphasic subjects.

The data of F3 suggests more random variations than the one of F1 and F2. Thus, according to figures 22 and 23, the normal speakers display a higher F3 value for the short back vowel [u] than the long back vowel [u:]. For the aphasic group, there is a higher F3 value for the front short vowel [a] than for its long cognate [a:]. On the other hand, a decrease of F3 for the short vowel [i] as compared to its long counterpart [i:] was observed.

Subjects	[a]	[u]	[i]	[ɛ]
Normal speakers	2777	2470	2680	2402
Aphasic subjects	2989	2935	2985	2690

Table 14: F3 mean average frequency (Hz) for short vowels as produced by the aphasics and the normal speakers.

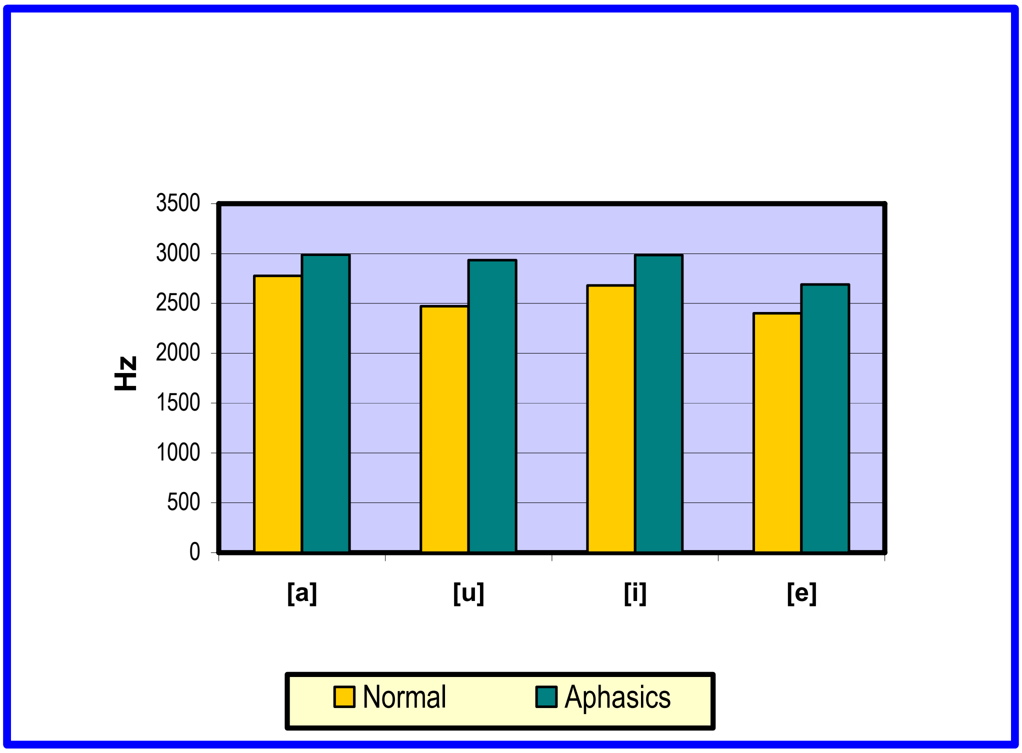


Figure 22: F3 average frequency (Hz) for short vowels as produced by the aphasics and the normal speakers.

Subjects	[a:]	[u:]	[i:]	[ɛ:]	[o:]
Normal speakers	2644	2610	2943	2465	2770
Aphasic subjects	2984	3181	2831	2741	2698

Table 15: F3 mean average frequency (Hz) for long vowels as produced by the aphasics and the normal speakers.

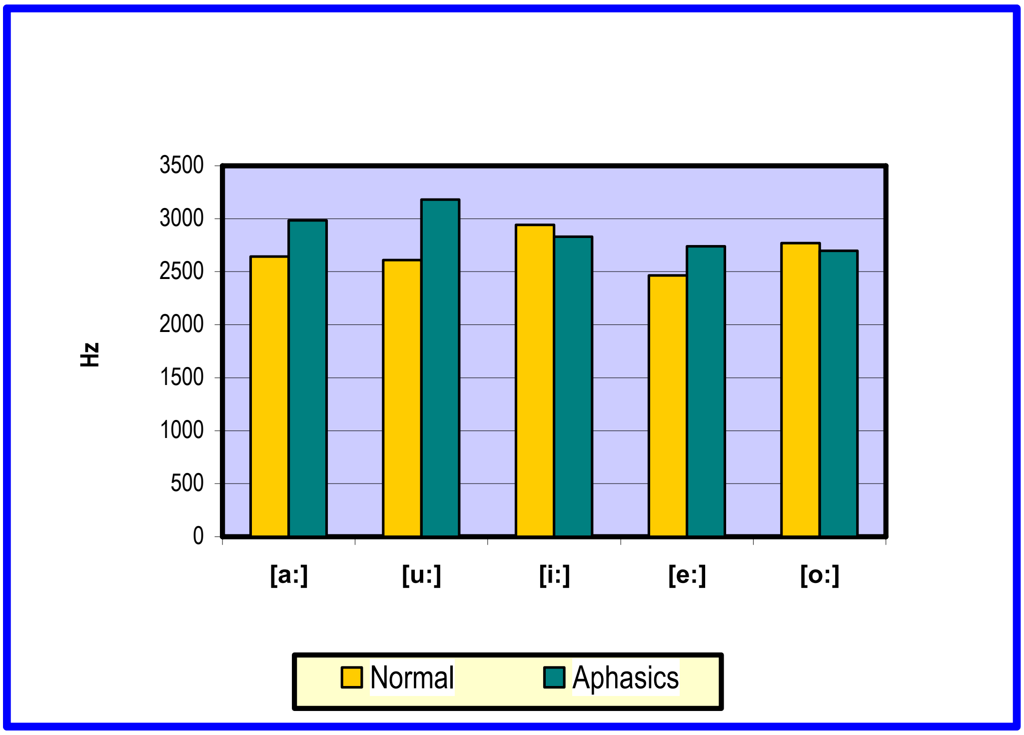


Figure 23: F3 average frequency (Hz) for long vowels as produced by the aphasics and the normal speakers.

Interestingly, whereas the aphasic subjects showed higher F3 values for the short front vowels [a] and [i] than for the front long vowels [i:] and [a:], there was clearly a higher F3 value for the long back vowel [u:] than for the short back vowel [u]. Additionally, a different pattern was seen in the aphasic group by revealing lower F3 for the vowels [i:] and [o:] than those for the normal speakers. On average, for example, if it is to be accounted for the three classical vowels in Arabic, we find then that the normal speakers displayed higher F3 for the front high vowels [i:] and [i] (2812Hz) than the low vowels [a:] and [a] (2710Hz), suggesting an enhancement of the acoustic[117] feature of F3 for the vowel [i:], whereas the back vowel [u:] and [u] had the lowest average (2557Hz). Contrary to the normal speakers, the aphasic subjects revealed higher F3 values for the front low vowels [a] and [a:] (2987Hz) than for the front high vowels [i] and [i:] (2908), whereas the back vowels [u] and [u:] (3085) had the highest F3 average. Clearly, the average of F3 indicates that Broca's aphasics exhibit relatively higher F3 than the normal speakers do.

[117] Cf. Tabain, M., & Perrier, P. (2005): Articulation and Acoustics of /i/ in Preboundary Position in French, p. 77

Like previous results of F3, Broca's aphasics displayed also higher F4 than those of the normal speakers, as shown in figures 24 and 25. Among the aphasic patients, F4 was produced on average with higher formant frequencies than among the normal speakers. Thus, even though they revealed a high F3 average, there is a clear tendency for the fourth formant to be the most dynamic. It has the widest frequency range up to 4239Hz by Broca's aphasics with the vowel [ɛ:] and up to 3782Hz by the normal speakers with [i:].

Subjects	[a]	[u]	[i]	[ɛ]
Normal speakers	3537	3461	3666	3605
Aphasic subjects	3913	3941	3895	4252

Table 16: F4 average frequency (Hz) for short vowels as produced by the aphasics and the normal speakers.

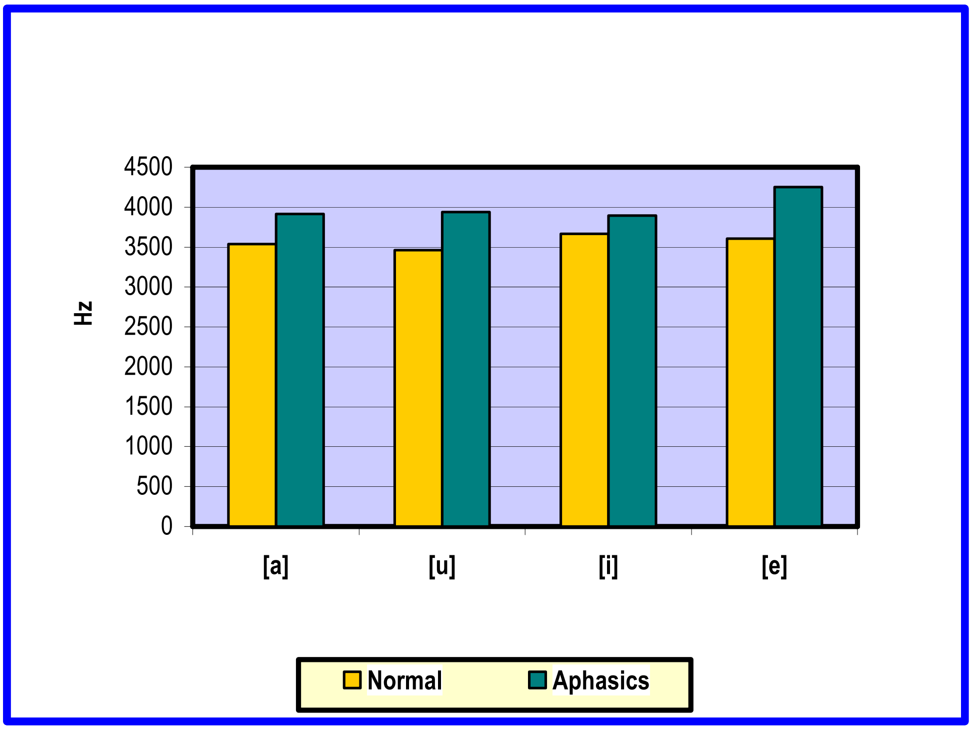


Figure 24: F4 average (Hz) for short vowels as produced by the aphasics and the normal speakers.

Subjects	[a:]	[u:]	[i:]	[ɛ:]	[o:]
Normal speakers	3682	3540	3782	3598	3508
Aphasic subjects	3989	4186	4039	4239	4079

Table 17: F4 average frequency (Hz) for long vowels as produced by the aphasics and the normal speakers.

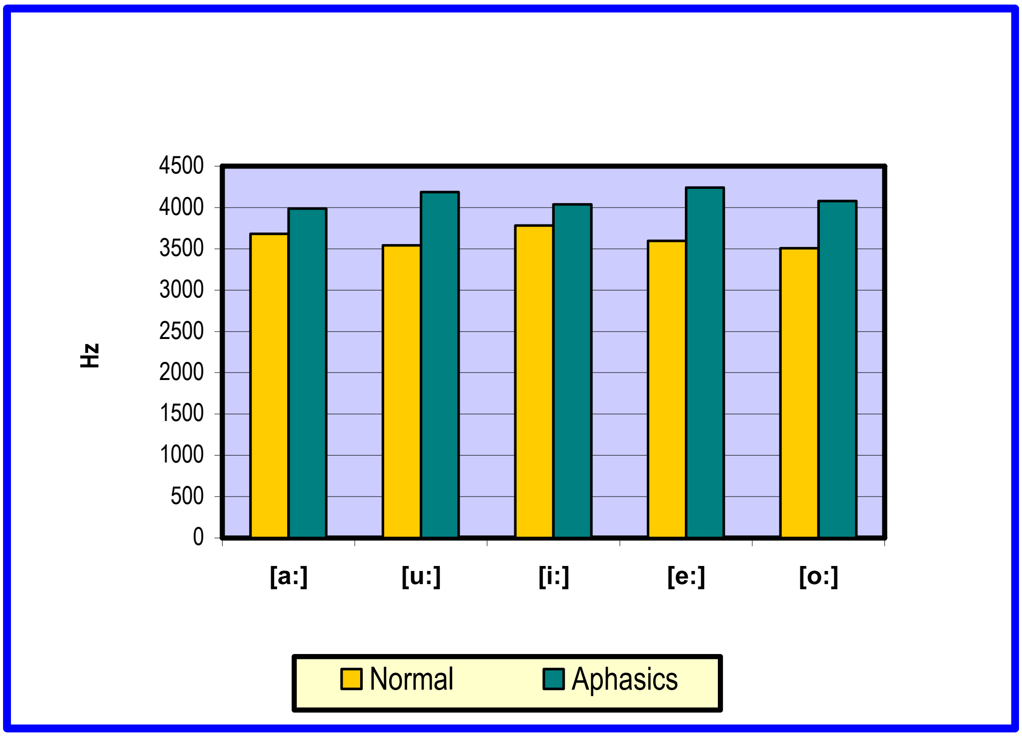


Figure 25: F4 average (Hz) for long vowels as produced by the aphasics and the normal speakers.

3.2.2. Discussion and conclusion

The results of this study indicate a significant variability and inconsistency across the aphasic subjects that are further supported by the fact that the high formant values refer to deviant productions compared to normal speakers. However, interestingly, the results show that the aphasic's vowel space area of F3 and F4 is larger than their acoustic vowel space of F1 and F2, as will be discussed in depth in the following chapters. In this account, many investigations have pointed out that the degree of expansion of the vowel space reflects the intelligibility of words and sentences.

For example, by measuring the size of the acoustic vowel space of the vowels [i], [a] and [u] for each speaker, Bradlow et al.[118] found a relationship between the speaker's vowel space area and the intelligibility of the speaker's utterances. Furthermore, the influence of vowel space area on speech intelligibility has been addressed by studies on patients with speech disorders and it has been reported on a significant correlation between these two parameters.[119] Thus far, the phonetic segments in the telegraphic speech of Broca's aphasics are exaggerated and laboured, making the individual sounds of language more distinct from one another. These difficulties in speech produced by Broca's aphasics suggest a strategy that was adopted to make their speech clear to understand manifesting itself in the higher values of F3 and F4. Segment prolongation, vowels for instance, would stretch the acoustic space of the vowels leading to enhance the distinctive features that distinguish them. In light of these findings, we could conclude that vowel space expansion relates to variance in the listener's judgment and is correlated with individual speakers. Taking this into account, the aphasic patients display a highly expanded acoustic vowel space in order to produce the phonetic units with a high degree of articulatory precision. This serves as a significant predictor for efforts to make speech clear and intelligible.

In the present study, the aphasic subjects displayed generally more variable vowel formant patterns than those of the normal speakers. This variability could be interpreted in terms of a deficit in "realizing either the temporal or the geometric specifications of the required articulatory adjustments in the abnormal speech."[120] Furthermore, it may be important to consider the magnitude of deviations between the first four formants in utterances produced by Broca's aphasics. For example, as shown in table 18, it is clear that the deviations of F1 and F2 for the short vowel [a] exhibited a big magnitude contrasting to the one of F3 and F4. This observation would emphasize the fact that the first two formants apply to the vowel quality and F3 and F4 are related to the speaker.

[118] Cf. Bradlow, A., Torretta, G., & Pisoni, D. (1996): Intelligibility of Normal Speech: Global and Fine-grained Acoustic Phonetic Talker Characteristics, p. 255.

[119] Cf. Weismer, G., Jeng, J., Laures, J., Kent, R., & Kent, J. (2001): Acoustic and Intelligibility Characteristics of Sentence Production in Neuorgenic Speech Disorders, p. 15.

[120] Ziegler, W. (1987): Phonetic Realization of Phonological Contrast in Aphasic Patients, p. 175.

Formant	Minimum range	Maximum range	Mean average	Deviation
F1	563	884	585	321
F2	1532	1956	1687	424
F3	2980	3084	2989	104
F4	3901	4030	3913	129

Table 18: The formant values for the vowel [a] (Hz) including the minimum and maximum range, mean average and deviation as produced by the aphasic subjects.

These big deviations in the first two formants would suggest articulatory distortions of the vowels due to their articulatory positioning as will be discussed in the acoustic vowel space of Broca's aphasics in the current study.

To conclude, the results obtained from the formant frequencies indicate that the aphasic subjects in the present study are able to retain normal vowel output with a wide range of variability compared to the normal speakers. They also revealed clear variability in the formant frequencies by displaying increased F1 compared to the normal speakers. The results support the findings of several studies[121] that the aphasic patients produce vowels with high formant variability. All in all, there is a point of agreement between the studies[122] that the Broca's aphasics are more variable in their formant frequency as the case of the Palestinian aphasic patients. It is also worthy to note that Broca's aphasics in general use the ability to keep control of the acoustic features associated with supralaryngeal control despite its variability. Furthermore, the results will be discussed in terms of acoustic vowel space as will be shown in section 3.8.

[121] Cf. Ryalls, J. (1986), pp. 55-60.
[122] Cf. ibid., p. 60.

Vowel	F1	F2	F3	F4
[a]	575	1576	2777	3537
[a:]	540	1630	2644	3682
[u]	390	1010	2470	3461
[u:]	350	978	2610	3540
[i]	417	1727	2680	3666
[i:]	319	2049	2943	3782
[ɛ:]	485	1780	2465	3682
[o:]	560	1188	2770	3508

Table 19: The formant averages (Hz) for the vowels under study as produced by the normal speakers.

Vowel	F1	F2	F3	F4
[a]	585	1587	2989	3913
[a:]	645	1578	2984	3989
[u]	610	1826	2935	3941
[u:]	509	1743	3181	4186
[i]	517	1936	2985	3895
[i:]	473	1678	2831	4039
[ɛ:]	432	1792	2741	4239
[o:]	511	1450	2698	4079

Table 20: The formant averages (Hz) for the vowels under study as produced by the aphasic subjects.

3.3. Vowel duration

3.3.1. Introduction

Normal speech has received several systematic analyses and many investigations have been carried out on the durational measurements of normal speech. In fact, spoken language has different sounds that rapidly change in time and are required for precise articulation. In fact, speech perception and comprehension are associated with duration and temporal order.[123] However, disordered speech is widely investigated today particularly in the case of the

[123] Schirmer, A. (2004): Timing Speech: A Review of Lesion and Neuroimaging Findings, p. 269.

English language, but very little research has been done on Arabic. It is noteworthy to indicate that the amount of duration is an acoustic parameter that distinguished between long and short vowels.[124] In this sense, the long vowels have greater duration than the corresponding short vowels.

In fact, a number of studies have indicated different durational patterns of the vowels that correlate with several variables.[125] For example, it has been observed that low vowels are longer than high vowels.[126] Furthermore, it has been shown that vowels in open syllables are longer than those in closed syllables.[127] With respect to the effect of voicing and consonant category on vowel duration, it has been noticed, for instance, that vowels preceding voiced consonants are longer than those preceding voiceless consonants and those preceding fricatives are longer than those preceding stops.[128] Some effects of the utterance length and position of the vowels were observed on vowel duration. In this account, results obtained from different studies indicate that vowels in longer phrases are shorter than those in shorter ones and those that occupying the phrase-final positions are longer than non-final ones.[129] Basically, there are several factors that influence the vowel duration such as pitch accent, stress, number of preceding syllables and rate of speech.[130] For example, Magen and Blumstein[131] found that short vowels spoken at a slower rate are longer than those at faster rates. In fact, vowel duration is often language conditioned and those durational patterns might not be consistent across languages.

Vowel length in Arabic has been found phonologically significant. This means that quantity play an important role in the meaning of words. For example, the words [ka:l] 'weight' and [kal] 'tiredness' have different meanings indicating that vowel length is distinctive in Palestinian Arabic.

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[124] Cf. Lehiste, I. (1970): Suprasegmentals, pp. 30-35.
[125] Cf. Klatt, D. (1976): Linguistic Uses of Segment Duration in English: Acoustic and Perceptual Evidence, pp. 1210-1215.
[126] Cf. Lehiste, I. (1970), p. 18.
[127] Cf. Myers, S. (2005): Vowel Duration and Neutralization of Vowel Length Contrasts in Kinyarwanda, p. 428.
[128] Cf. House, A. (1961): On Vowel Duration in English, p. 1777.
[129] Cf. Cf. Myers, S. (2005), p. 433.
[130] Cf. Van Santen, J. (1992): Contextual Effects on Vowel Duration.
[131] Cf. Magen, H., & Blumstein, S. (1993): Effects of Speaking Rate on the Vowel Length Distinction in Korean, p. 387.

Thus, it can be seen that the quantity parameter is "physically indicated by sound duration and therefore, duration is a highly relevant feature to its phonology."[132] Furthermore, some attention has been given to the correlation between duration of vowels and gemination. For instance, Hassan[133] indicates that vowels preceding nongeminates are slightly longer than those preceding geminates. One of the phonological Arabic features is that long consonants can be preceded either by long or short vowels, e.g. [ha:m] 'important' and [ham] 'sadness.' The lengthening of the consonant affects the preceding vowel, but not to the degree to make it sound phonologically shorter. In light of this discussion it can be said that vowel length in Arabic is phonologically significant.

The Arabic phonological system consists of many types of syllables and it has been found[134] that the most dominant syllabic structure is the type of the sequence of CVCVCV [darasa] 'studied' and the most dominant post vocalic consonant cluster is the type (CVC) like [kam] 'how much', (CV:C) like [ta:m] 'complete' and (CVCC) such as [damm] 'blood.' The correlation between vowel and consonant duration has been an interesting issue for linguists and phoneticians in many languages including Arabic. Significantly, the temporal dimension is said to be language conditioned. In this account, empirical studies on English vowels, for instance, have demonstrated that tense vowels are relatively longer than lax vowels.[135] This is because of the fact that the time required to achieve the configuration of the tense vowels is longer than for the lax vowels.

In light of the finding that the durational differences are the result of configuration, we can assume that the durational behaviour of English vowels does not reflect tense-lax vowel behaviour in other languages. In this sense, vowel lengthening in Arabic is phonemic indicating that vowel quantity forms the basis of contrast and makes meaning differences. In the following example, the quantity contrast is clear: [ʕi:d] 'festival' and [ʕid] 'count.' In addition, Mitleb[136] concluded that lengthening of Arabic vowels increases their duration significantly. However, he[137] did not find an effect of voicing on vowel duration and

[132] Nenonen, S., Shestakova, A., Huotilainen, M., & Näätänen, R. (2005): Speech-Sound Duration Processing in a Second Language Is Specific to Phonetic Categories, p. 26.
[133] Cf. Hassan, Z. (2003): Temporal Compensation between Vowel and Consonant in Swedish & Arabic in Sequences of CV: C & CVC: And the Word Overall Duration, p. 46.
[134] Cf. ibid., p. 47.
[135] Cf. Chomsky, N., & Halle, M. (1968): The Sound Pattern of English, p. 324.
[136] Cf. Mitleb, F. (1984), p. 231.
[137] Cf. ibid., p. 229.

concluded that lengthening is particularly a characteristic of the consonant voicing contrast, whereas it is the opposite phenomenon in Arabic.

3.3.2. Neurolinguistic studies on vowel duration in aphasia

A number of studies have reported that aphasic patients exhibit longer vowel duration than normal speakers.[138] Furthermore, there are inconsistencies across studies about the magnitude and pattern of duration for aphasic patients. More generally, with respect to the number of syllables, patterns emerged from apraxic speakers indicate that vowel duration was longest for monosyllabic words, intermediate for disyllabic words and shortest for trisyllabic words.[139] This is relatively inconsistent with normal speakers. However, Collins et al.[140] replicated the results reported from the previous work by indicating that vowels were the longest with di- and trisyllabic words compared to words with one syllable. They also noticed across the non-fluent aphasics a clear-cut lack of syllable reduction from di- to trisyllabic words. In addition to segment prolongation, it might be that the speaking rate across speaker groups is a crucial issue, since it is associated with timing and temporal speech properties.

Furthermore, in a spectrographic study on a group of anterior aphasics, Ryalls[141] found that the word and sentence level were considerably longer for Broca's aphasics than for normal subjects. However, Duffy and Gawel[142] tested vowel duration before syllable preceding final voiced and voiceless stops in the CVC syllable type produced by English aphasics and patients with apraxia and indicated that vowel durations exhibited by the aphasics were relatively shorter than those of the normal speakers. In line with the same results, previous studies have indicated that vowel durations preceding voiced and voiceless final consonants vary based on the function of phonological differences in English. In this account, House[143] gave further evidence for this notion by addressing the duration of the vowel [i] in the word "bead" and "beat." In particular, he found that the duration of [i] in "bead" could be produced with a duration range estimated from 20-90% longer than the [i] in the word "beat."

[138] Cf. Schirmer, A. (2004), pp. 279-280.
[139] Cf. Caligiuri, M., & Till, J. (1983): Acoustical Analysis of Vowel Duration in Apraxia of Speech: A Case Study, pp. 226-232.
[140] Cf. Collins, M., Rosenbek, J., & Wertz, R. (1983): Spectrographic Analyses of Vowel and Word Duration in Apraxia of Speech, pp. 328-329.
[141] Cf. Ryalls, J. (1981), pp. 365-372.
[142] Cf. Duffy, J., & Gawle, C. (1984): Apraxic Speakers' Vowel Duration in Consonant-Vowel-Consonant Syllables, pp. 170-177.
[143] Cf. House, A. (1961), p. 1176.

Several studies have also reported abnormal durational patterns of the aphasics' speech. In such a case, Kent and Rosenbek[144] observed that speech of Broca's aphasics was characterized by abnormal rhythm and rate. In addition, Thai aphasics failed to maintain timing control of vowel duration due to longer utterances.[145] A general conclusion found in the literature is that Broca's aphasics display longer vowel duration than normal speakers. In light of the previous review, the purpose of the current section of the study is to investigate those durational features and patterns in the Palestinian Broca's aphasics by addressing the following questions:

1- Do Palestinian Broca's aphasics demonstrate the same behaviour of vowel duration found in non-Arabic aphasics?
2- If so, are the duration modifications comparable in magnitude and consistency to those made by other non-Arabic subjects?
3- Do Broca's aphasics demonstrate differences in their average duration of vowels compared to the normal speakers?
4- Do vowel durations preceding individual consonants vary between Broca's aphasics and the normal speakers?

3.3.3. Results

Figure 26 shows that, with respect to voiceless stop consonants, the aphasic subjects and the normal speakers followed the principle that low vowels are longer than high vowels in the same phonetic environment. In this case, the vowel [a] is longer in duration than the other two short vowels [i] and [u]. The normal speakers demonstrated a preference for shortening the short vowels [i] and [u] in comparison to the mean average of the short [a]. Furthermore, both groups produced the vowel [i] with the shortest duration. As in the normal group the mean average difference between the short vowel [i] and the lowest short vowel [a] among the aphasic patients seems to be large.

144 Cf. Kent, R., & Rosenbek, J. (1983), pp. 233-236.
145 Cf. Gandour, J., & Dardarananda, R. (1984b): Prosodic Disturbance in Aphasia: Vowel Length in Thai, p. 218.

Subjects	[a]	[u]	[i]
Normal speakers	123	73	66
Aphasic subjects	136	82	70

Table 21: Average vowel durations (msec) for the short vowels [a], [u] and [i] before voiceless stops as produced by the normal speakers and the aphasic subjects.

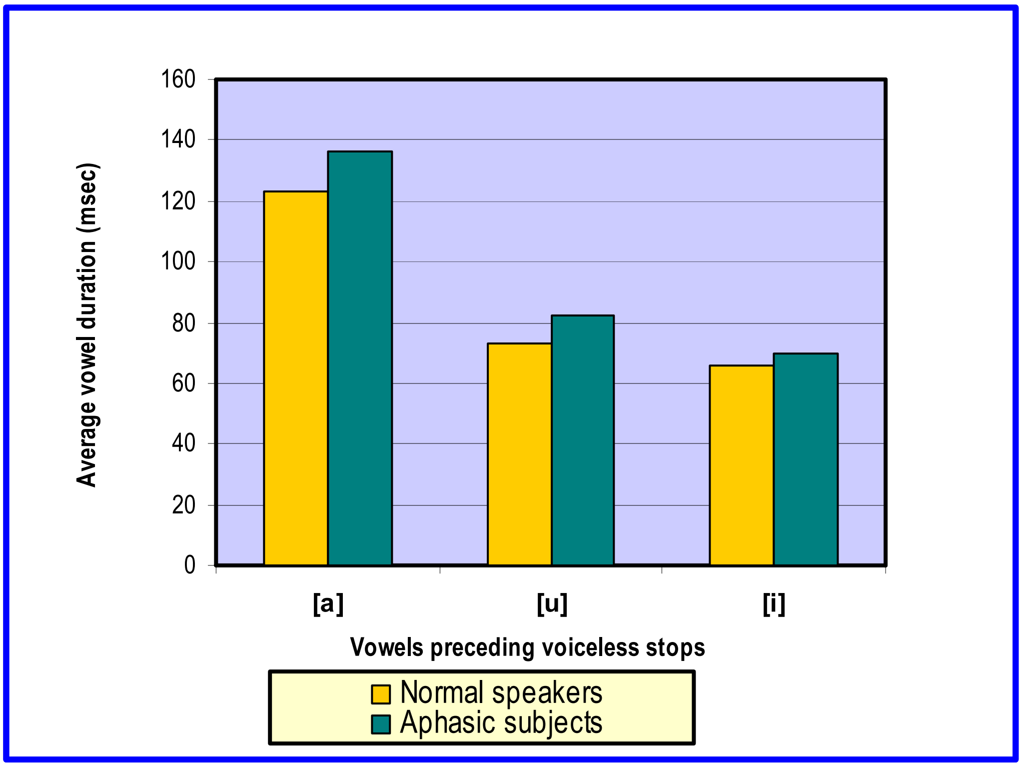

Figure 26: Average vowel durations (msec) for the normal speakers versus the aphasics for the short vowels [a], [u] and [i] before voiceless stops.

Subjects	[a:]	[u:]	[i:]
Normal speakers	165	174	160
Aphasic subjects	236	167	201

Table 22: Average vowel durations (msec) for the long vowels [a:], [u:] and [i:] before voiceless stops as produced by the normal speakers and the aphasic subjects.

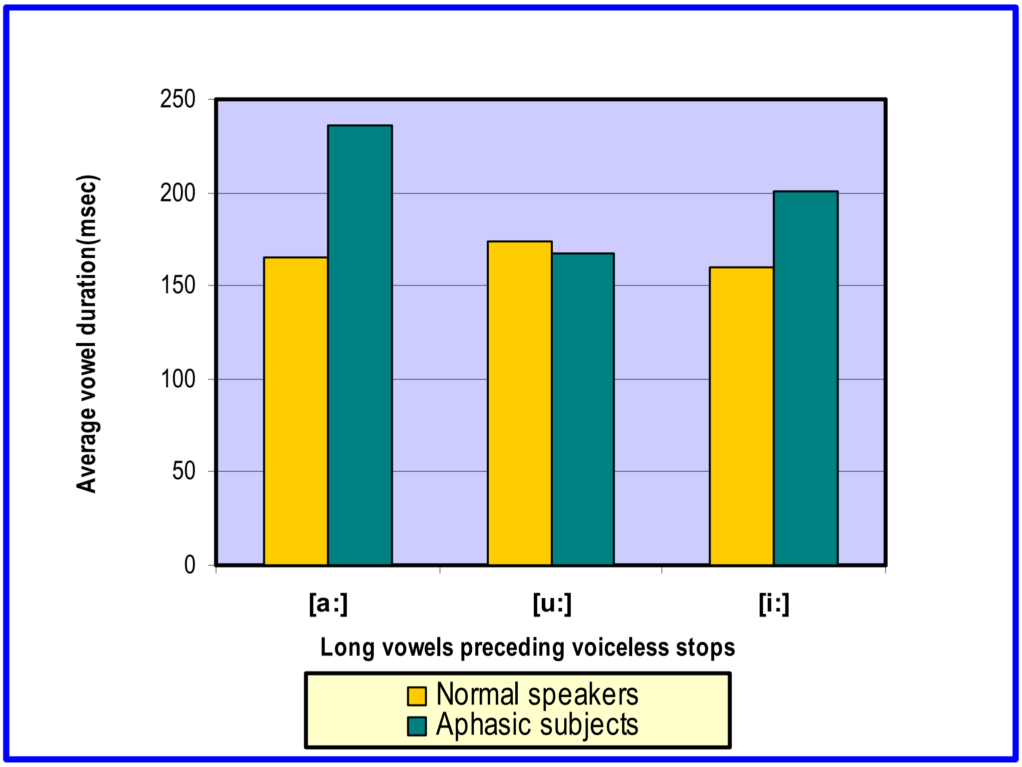

Figure 27: Average vowel durations (msec) for the normal speakers versus the aphasics for the long vowels [a:], [u:] and [i:] before voiceless stops.

As figure 27 indicates, different durational patterns in the speech of the aphasic subjects and the normal speakers can be noticed. For example, it took the aphasic subjects longer to produce the vowel [a:] than the other vowels. This was not the case for the normal speakers for whom the back vowel [u:] was the longest.

Subjects	[a:]	[u:]	[i:]
Normal speakers	185	170	174
Aphasic subjects	265	136	210

Table 23: Average vowel durations (msec) for the normal speakers versus the aphasics for the vowels [a:], [u:] and [i:] before voiced stops.

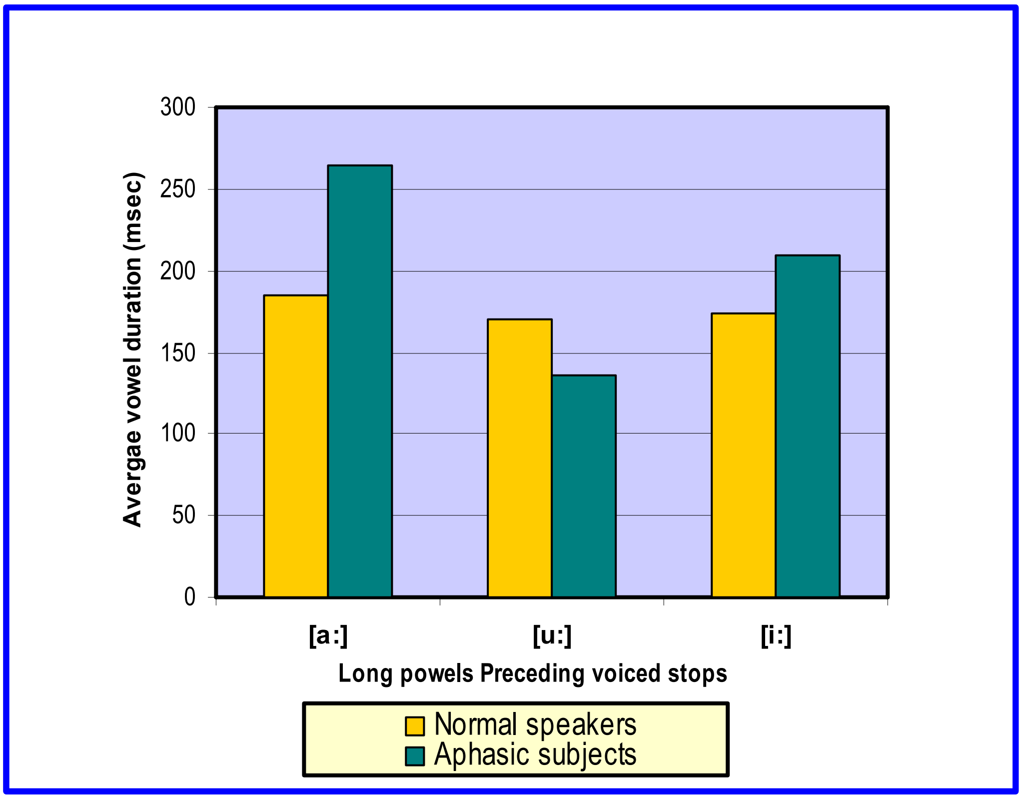

Figure 28: Average vowel durations (msec) for the normal speakers versus the aphasics for the long vowels [a:], [u:] and [i:] before voiced stops.

With respect to the long vowels adjacent to the voiced stops, it can be seen that Broca's aphasics and the normal speakers followed the principle of low vowels before the voiced stops. Therefore, as figure 28 displays, the low long vowel [a:] is longer than the high vowels. In contrast to the patterns exhibited with the voiceless stops, it was shown here that the normal speakers and Broca's aphasics indicated a kind of agreement with their durational pattern of the long vowel [i:] being longer than the vowel [u:] in the same phonetic environment.

Subjects	[a]	[u]	[i]
Normal speakers	97	70	86
Aphasic subjects	175	63	170

Table 24: Average vowel durations (msec) for the normal speakers versus the aphasics for the short vowels [a], [u] and [i] before voiced stops.

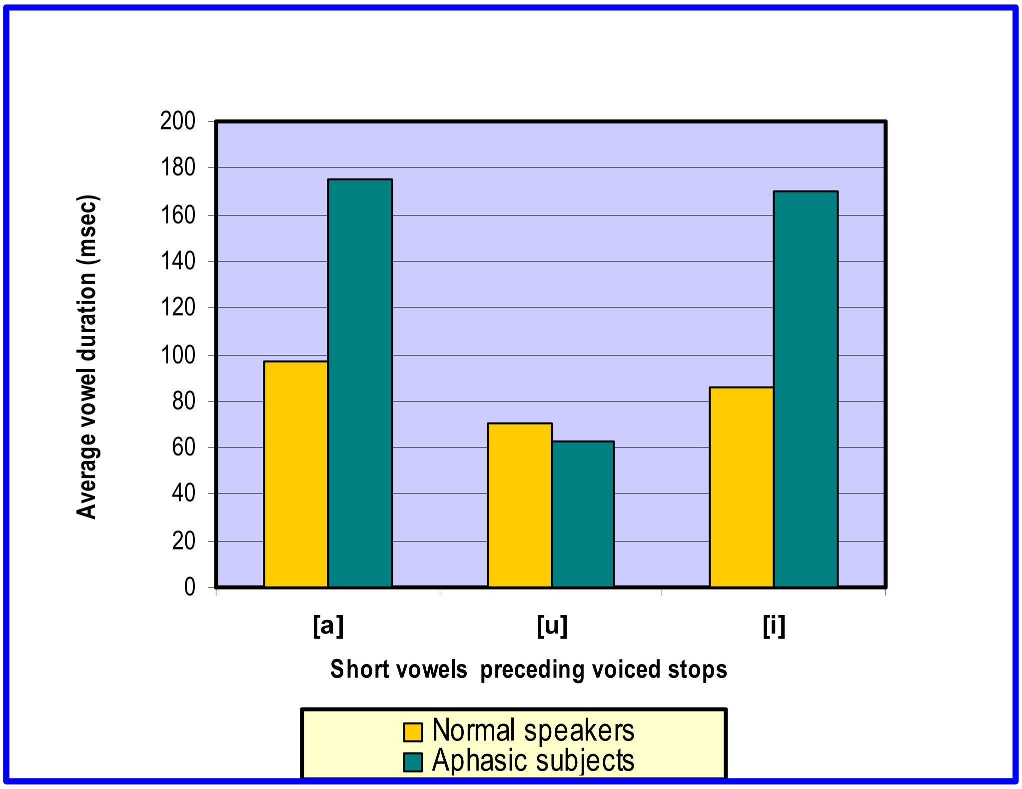

Figure 29: Average vowel durations (msec) for the normal speakers versus the aphasics for the short vowels [a], [u] and [i] before voiced stops.

When analyzing the average vowel duration of the short vowels [a] [u] and [i] before voiced stops, as seen in figure 29, the results indicate that the aphasic patients and the normal speakers follow the principle of low vowels by producing the vowel [a] longer than the high short vowels [i] and [u]. Unlike the normal speakers, the aphasic subjects displayed a longer overall average vowel duration. It is also noticeable that there is a presence of controversial durational averages between the two groups. This is manifested in shortening the duration of [u] among the control group compared to [i], whereas Broca's aphasics produce the vowel [i] notably longer than the short vowel [u]. However, it can be also generalized that Broca's aphasics produced [u] shorter than [i] in the same manner that the normal speakers did.

Subjects	[a]	[u]	[i]
Normal speakers	96	50	60
Aphasic subjects	60	75	89

Table 25: Average vowel durations (msec) for the normal speakers versus the aphasics for the vowels [a], [u] and [i] before voiced fricatives.

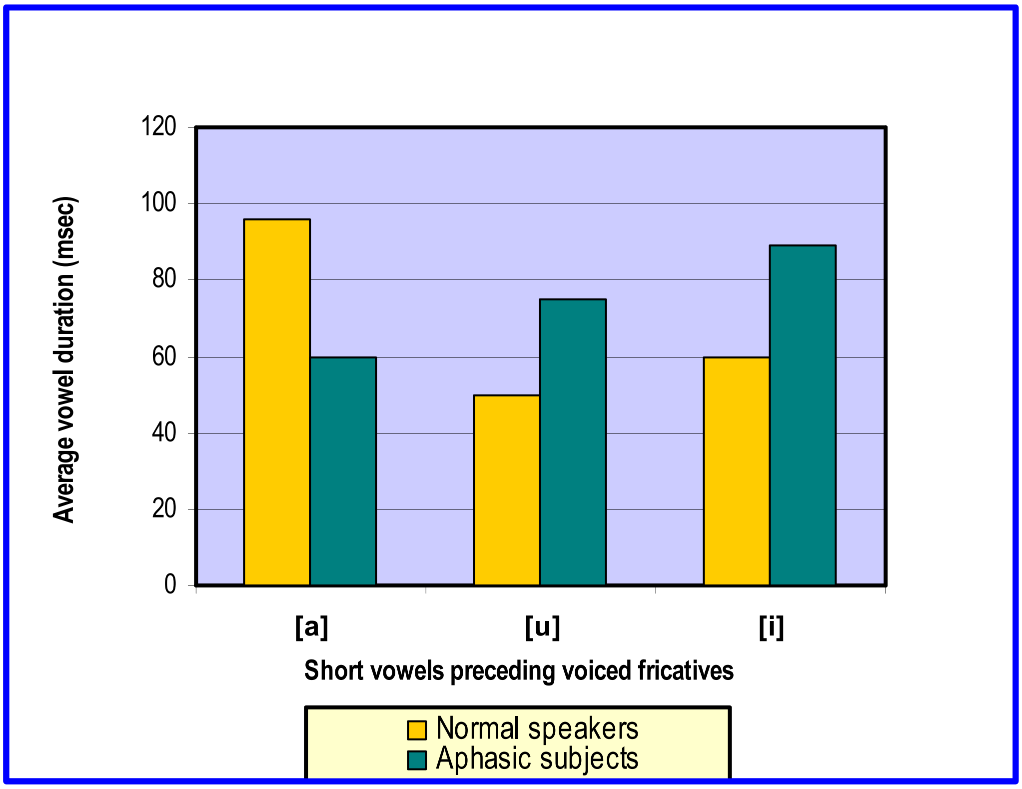

Figure 30: Average vowel durations (msec) for the normal speakers versus the aphasics for the short vowels [a], [u] and [i] before voiced fricatives.

Contrary to the initial effects of stop consonants on low vowel duration, no compliance with this rule preceding the voiced fricatives was noticed in the aphasic group. As can be seen from figure 30, the low vowel [a] was shorter than the vowel [u] and [i]. However, the duration of the vowel [u] was the shortest for the normal speakers. The performance of the two groups generally demonstrates different degrees in the amount of the durational variations. In light of this observation, the conclusion can be drawn that despite the similarities and differences of performance between Broca's aphasics and the normal speakers, Broca's aphasics produced their short vowels relatively longer than the normal speakers before voiced fricatives in the same phonetic context.

Subjects	[a:]	[u:]	[i:]
Normal speakers	157	159	127
Aphasic subjects	249	177	142

Table 26: Average vowel durations (msec) for the long vowels [a:], [u:] and [i:] before voiced fricatives as produced by the normal speakers and the aphasics subjects.

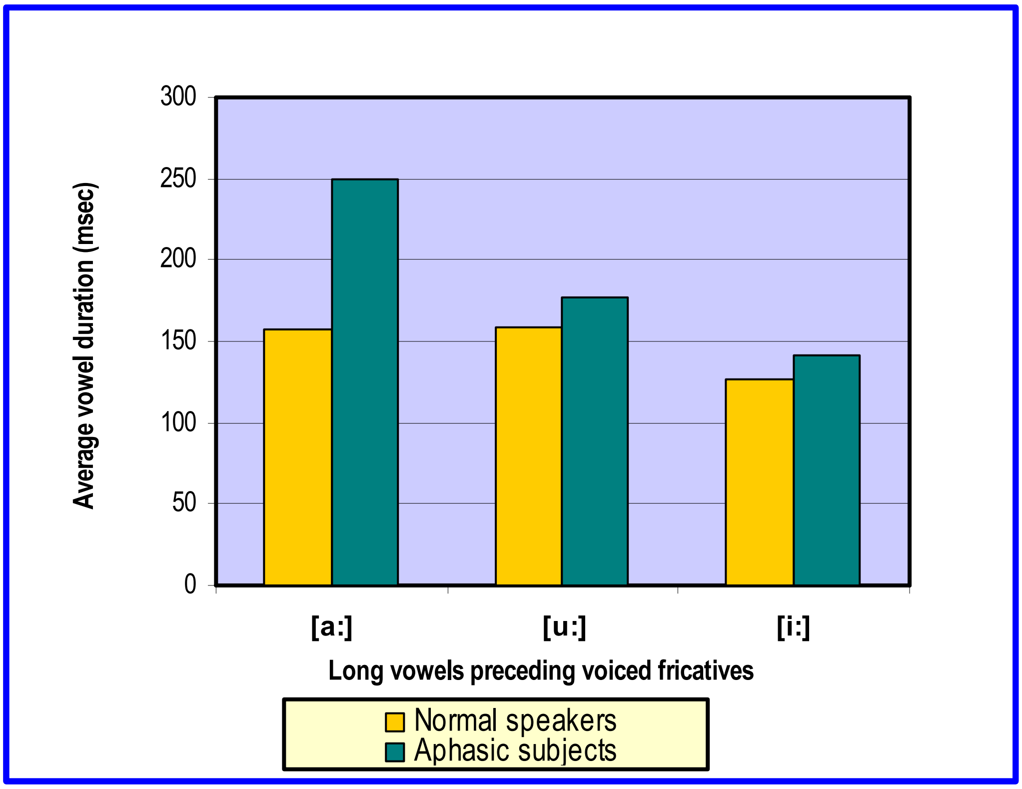

Figure 31: Average vowel durations (msec) for the normal speakers versus the aphasics for the long vowels [a:], [u:] and [i:] before voiced fricatives.

The primary observation, as figure 31 illustrates, is that Broca's aphasics demonstrated more variations between the vowels than the normal speakers having the longest duration for [a:] and the shortest one for [i:]. As just stated, these differences are held generally throughout the patterns of Broca's aphasics.

Subjects	[a]	[u]	[i]
Normal speakers	60	39	75
Aphasic subjects	142	230	266

Table 27: Average vowel durations (msec) for the normal speakers versus the aphasics for the short vowels [a], [u] and [i] before voiceless fricatives.

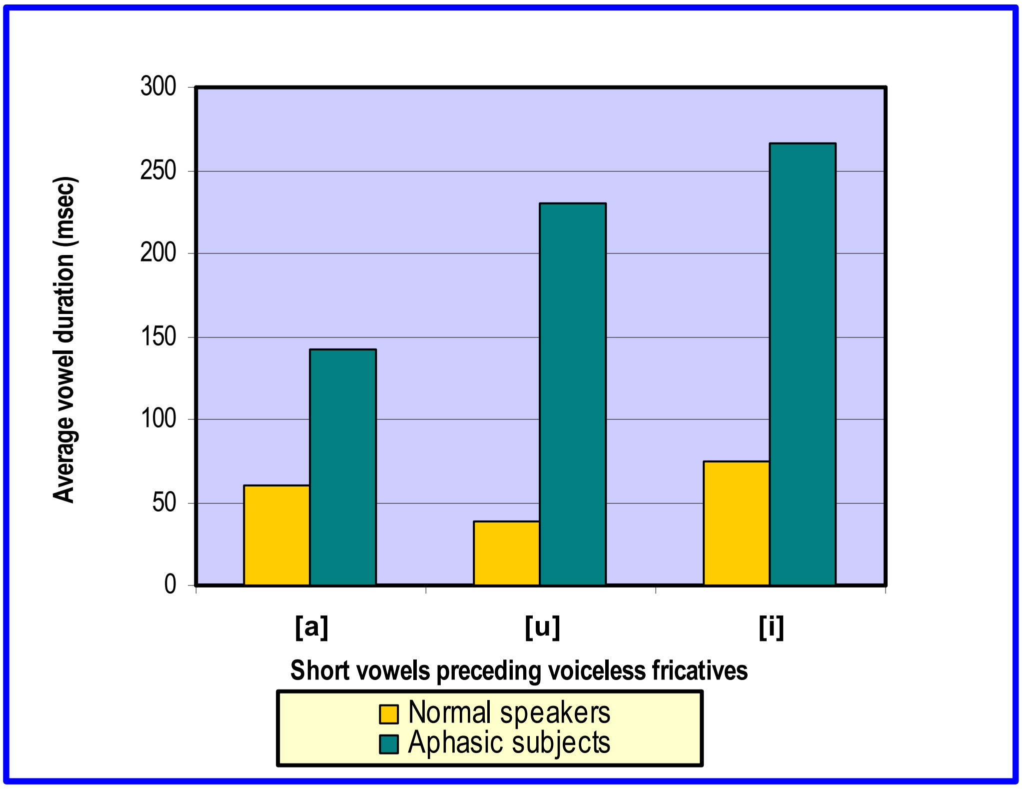

Figure 32: Average vowel durations (msec) for the normal speakers versus the aphasics for the short vowels [a], [u] and [i] before voiceless fricatives.

In the present acoustic analysis of the short vowel duration before voiceless fricatives, it can be noted that Broca's aphasics performed differently than the normal speakers. In this regard, figure 32 displays clearly that Broca's aphasics opposed the general trend of the low vowels being longer than other ones by producing the high vowel [i] with the longest duration that is also true for the normal speakers. In addition, even though the normal speakers displayed shorter durational average for the short vowel [u] than the low vowel [a], Broca's aphasics opposed this pattern by producing [a] shorter than [u]. Furthermore, considering the performance of Broca's aphasics on the high vowels, it can be observed that they demonstrated a longer average duration for the vowels [i] and [u] than that of the normal speakers under the same conditions corresponding to the same vowels.

Subjects	[a:]	[u:]	[i:]
Normal speakers	200	174	152
Aphasic subjects	250	231	227

Table 28: Average vowel durations (msec) for the normal speakers versus the aphasics for the long vowels [a:], [u:] and [i:] before voiceless fricatives.

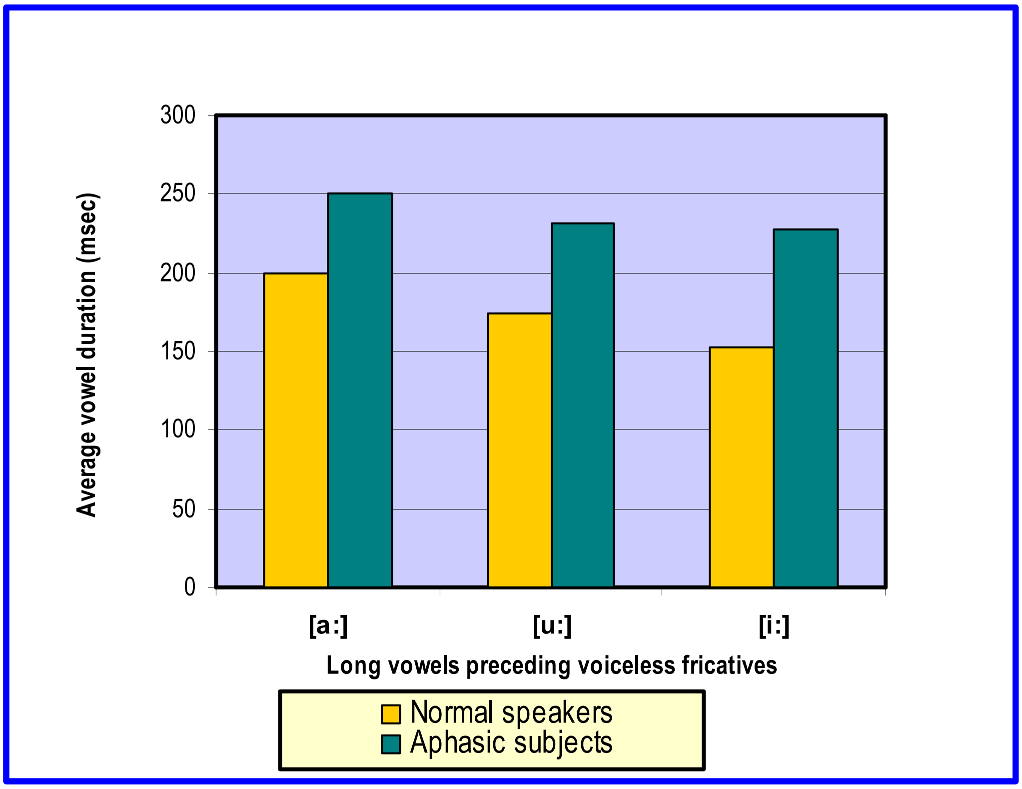

Figure 33: Average vowel duration (msec) of the normal speakers versus the aphasics for the long vowels [a:], [u:] and [i:] before voiceless fricatives.

Regarding the long vowels before voiceless fricatives, Broca's aphasics opposed the trend found for short vowels before the same consonant category in which they did not follow the low vowel rule, as figure 33 points out. Instead, Broca's aphasic subjects demonstrated a reversal pattern that complies with the low vowel rule being longer in duration than the high vowels. In general, the patterns obtained from the aphasic patients would indicate that they demonstrated longer average vowel durations for the high vowels compared to the normal speakers. However, the average vowel duration for the high vowel [i:] preceding both the voiced and the voiceless fricatives is found to be the shortest among Broca's aphasics. Interestingly, the same trend was noticed in the speech of the normal speakers.

3.3.4. Comparison of durational patterns based on individual differences

In fact, the normal speakers demonstrated compliance with the durational standards for the short vowels [a], [u] and [i] preceding the voiceless stops. All five of the normal speakers produced a longer [a] than the high vowels, as shown in figure 34. In such a production, they completely follow the principle of the low vowels, whereas 80% of Broca's aphasics displayed a compliance with the low vowels rule. On the other hand, only 40% of the normal speakers produced the long vowel [a:] longer than the high vowels, whereas 60% of Broca's aphasics showed compliance with the low vowels principle.

Subjects	Short vowels	Long vowels
Normal speakers	100	40
Aphasic subjects	80	60

Table 29: Percentage of the normal speakers and the aphasics following the durational standard that the short vowel [a] and the long vowel [a:] are longer in duration than the short vowels [i] and [u] and the long vowels [i:] and [u:] before voiceless stops.

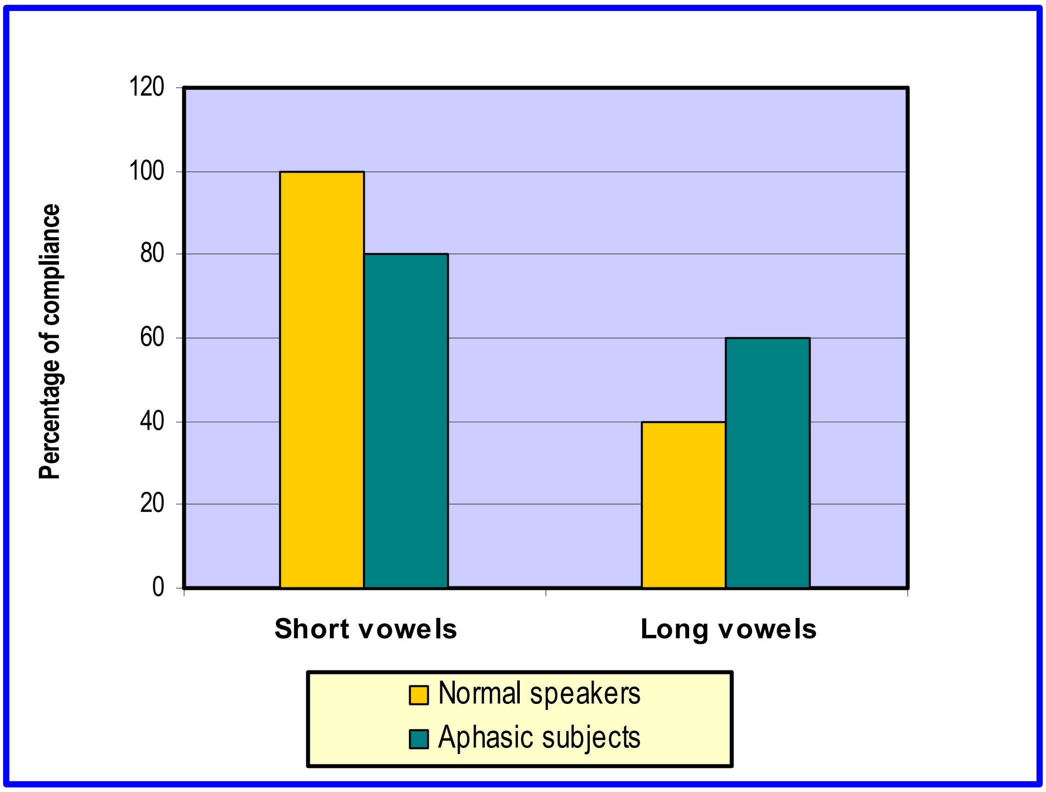

Figure 34: Percentage of the normal speakers and aphasics following the durational standard: The short vowel [a] and the long vowel [a:] are longer in duration than the short vowels [i] and [u] and the long vowels [i:] and [u:] before voiceless stops.

For the compliance with low vowel duration principle before the voiced stops, however, there was a difference in the degree of this duration between the aphasic group and the normal speakers. In this account, as figure 35 illustrates, only 20% of the normal speakers followed the rule, whereas 80% among Broca's aphasics did this. Once again, 80% of Broca's aphasics displayed this pattern for the long vowels.

Subjects	Short vowels	Long vowels
Normal speakers	20	40
Aphasic subjects	80	80

Table 30: Percentage of the normal subjects and the aphasics following the durational standard: The short vowel [a] and the long vowel [a:] are longer in duration than the short vowels [i] and [u] and the long vowels [i:] and [u:] before voiced stops.

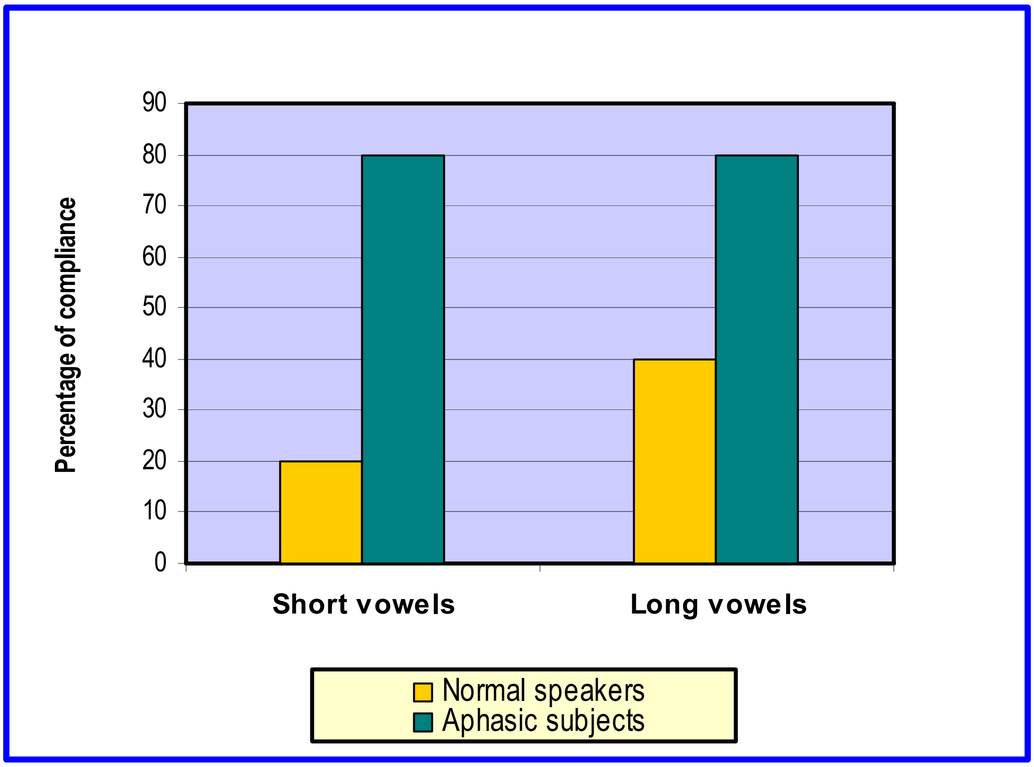

Figure 35: Percentage of the normal subjects and the aphasics following the durational standard: The short vowel [a] and the long vowel [a:] are longer in duration than the short vowels [i] and [u] and the long vowels [i:] and [u:] before voiced stops.

For both Broca's aphasics and the normal speakers there was also an obvious effect of voiceless fricative compliance with the low vowel duration to a greater degree in the performance of Broca's aphasics. In this sense, in the short vowel group, as figure 36 indicates, 20% of the normal speakers produced longer vowel [a] than the high ones, whereas 100% of the aphasic subjects showed this compliance. However, in fact, another trend was seen in the long vowels [a:], [u:] and [i:] within the same consonant category. In this regard, as figure 36 clearly shows, it has been found that 80% of the normal speakers achieved the principle, whereas only 60% of Broca's aphasics followed this trend.

Subjects	Short vowels	Long vowels
Normal speakers	20	80
Aphasic subjects	100	60

Table 31: Percentage of the normal speakers and the aphasics following the durational standard: The vowels [a] and [a:] are longer in duration than the vowels [i], [u], [i:] and [u:] before voiceless fricatives.

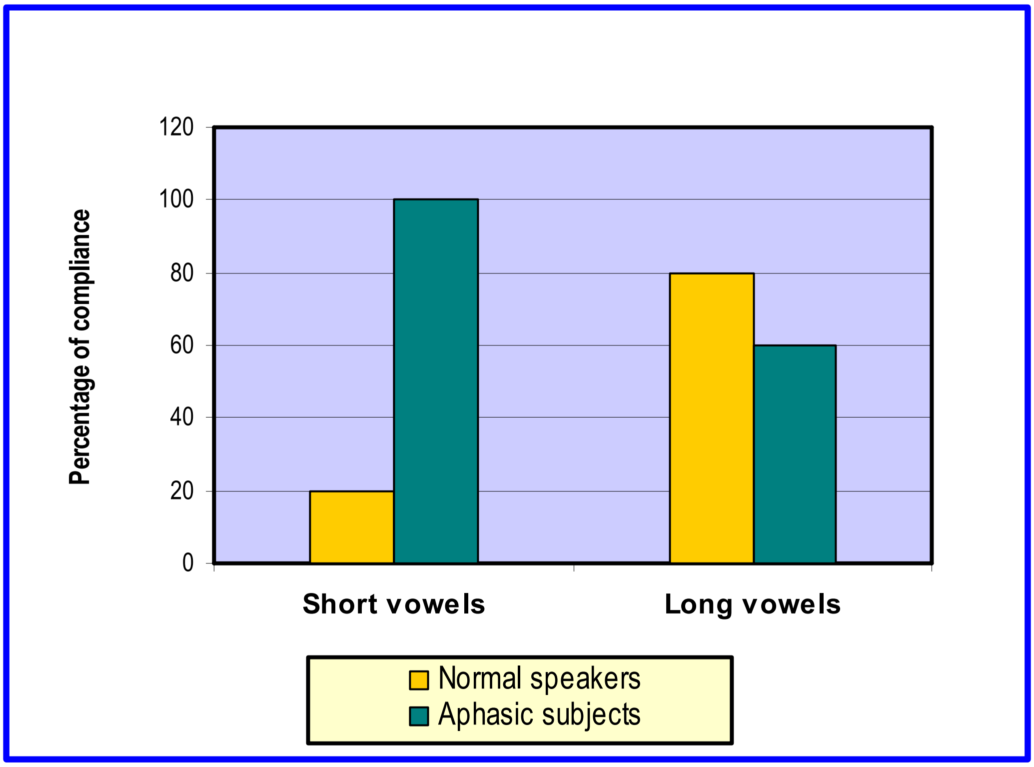

Figure 36: Percentage of the normal speakers and the aphasics following the durational standard: The vowels [a] and [a:] are longer in duration than the vowels [i], [u], [i:] and [u:] before voiceless fricatives.

Regarding the voiced fricatives, there was also a relative trend to follow the low vowel principle within the short vowels by the normal speakers and Broca's aphasics as well. Thus, 100% of Broca's aphasics completely followed the durational principle of low vowels. In contrast, only 80% of the normal speakers demonstrated this trend. With respect to the performance of both groups in the long vowels, the aphasic patients displayed a different pattern, as presented in figure 37. The low vowels were far longer than the other vowels. This was not the case with the normal speakers.

Subjects	Short vowels	Long vowels
Normal speakers	80	60
Aphasic subjects	100	100

Table 32: Percentage of the normal speakers and the aphasics following the durational standard: The vowels [a] and [a:] are longer in duration than the vowels [i], [i:], [u] and [u:] before voiced fricatives.

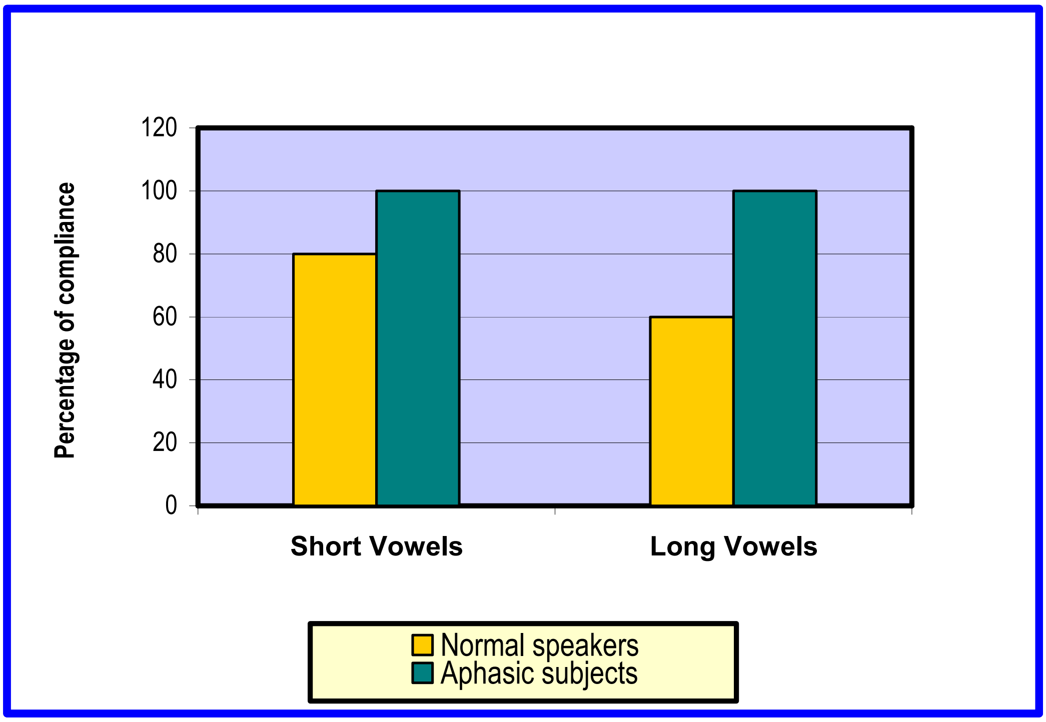

Figure 37: Percentage of the normal speakers and the aphasics following the durational standard: The vowels [a] and [a:] are longer in duration than the vowels [i], [i:], [u] and [u:] before voiced fricatives.

With respect to duration of [i] longer than [u] preceding the discussed consonant classes, the data presented in this section demonstrates that the aphasics and the normal speakers exhibit different average durational patterns. For instance, figure 38 shows that only 20% of the normal speakers produced [i] longer than [u] before voiced stops. In contrast, 100% of Broca's aphasics produced [i] longer than [u] within the same consonant class as shown in figure 38. Additionally, with the production of the vowel [i] and [i:] before the stop consonants, the results indicate a different way in which the normal speakers and the aphasic subjects interacted. 100% of Broca's aphasics showed a systematic trend in producing a long [i] before voiced and voiceless stops. On the other hand, none of the normal speakers produced a long [i] before the voiceless stops and only 20% of them displayed this trend before the voiced stops, as shown in figure 38. Broca's aphasics also produced [i] longer than [u] before voiceless fricatives. The normal speakers did not manifest such a result.

Consonant class	Normal speakers%	Aphasics subjects%
VL.F	0	80
V.F	40	40
VL.S	0	100
V.S	20	100

Table 33: Percentage of the normal speakers and the aphasics displaying the duration of [i] longer than [u] before the consonant classes of voiceless fricatives (VL.F), voiced fricatives (V.F), voiceless stops (VL.S) and voiced stops (V.S).

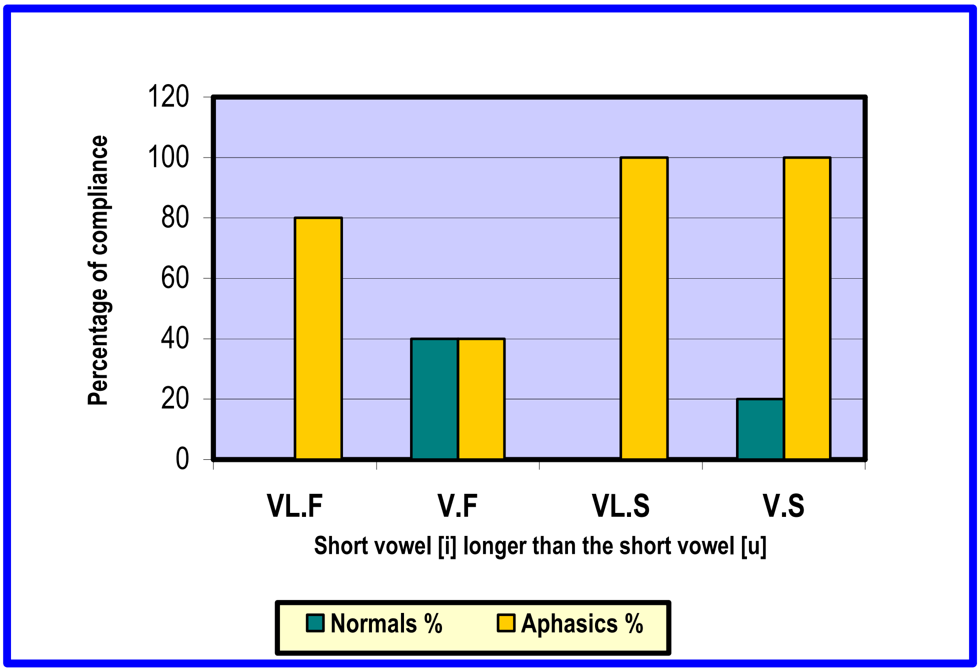

Figure 38: Percentage of the normal speakers and the aphasics displaying the duration of [i] longer than [u] before the consonant classes of voiceless fricatives (VL.F), voiced fricatives (V.F), voiceless stops (VL.S) and voiced stops (V.S).

Consonant class	Normal speakers %	Aphasic subjects %
VL.F	0	80
V.F	0	80
VL.S	20	20
V.S	40	100

Table 34: Percentage of the normal speakers and the aphasics displaying the duration of [i:] longer than [u:] before the consonant classes of voiceless fricatives (VL.F), voiced fricatives (V.), voiceless stops (VL.S) and voiced stops (V.S).

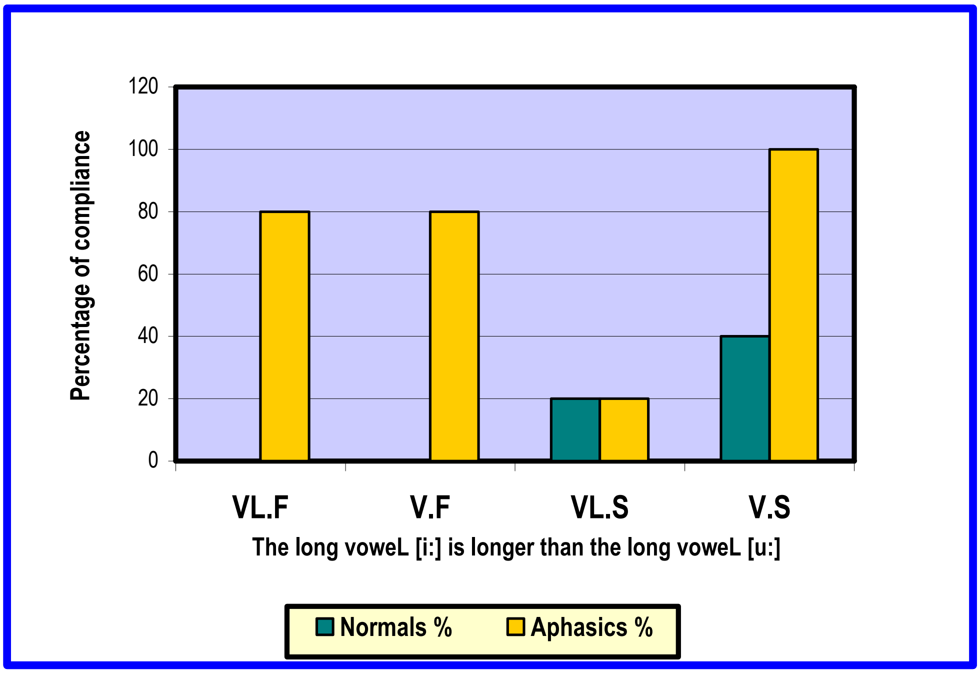

Figure 39: Percentage of the normal speakers and the aphasics displaying the duration of [i:] longer than [u:] before the consonant classes of voiceless fricatives (VL.F), voiced fricatives (V.F), voiceless stops (VL.S) and voiced stops (V.S).

With regard to the durational patterns for [i:] being longer than [u:] before the four consonant classes, noticeable differences between the normal speakers and the aphasic patients can be observed. For instance, the aphasic subjects and the normal speakers displayed similar patterns within the voiceless stops by producing shorter duration for [i:] than [u:], but this is not the case for the long vowels. In this case, Broca's aphasics and the normal speakers exhibited the same performance with 20% of each. On the contrary, all Broca's aphasics within the short vowels produced [i] longer than [u] before the same consonant category, as shown in figure 38. However, none of the normal speakers exhibited this pattern.

Based on figure 39, some trends clearly hold between the normal speakers and the aphasic subjects. For instance, the long vowel [i:] was longer in duration than the long vowel [u:] before the voiced stops in 100% of the aphasic's output. Figure 39 makes it clear that only 40% of the normal speakers demonstrated this durational pattern under the same phonetic conditions. However, with respect to the duration of [i:] longer than [u:] before voiced and voiceless fricatives, obvious findings were observed. Thus, significantly, whereas none of the normal speakers (0%) produced [i:] longer than [u:] before the two consonant classes, 80% of Broca's aphasics displayed this durational pattern. The normal speakers and the aphasic subjects displayed significant durational patterns seen by the short and the long vowels preceding the four consonant classes as shown in the figures above, representing several facts that can be summarized as follows:

1- The average vowel duration of Broca's aphasics was found to be relatively longer for [i], [a] and [u] compared to the normal speakers. However, the previous trend was found to be relatively changeable for the long vowels. Furthermore, with the exception of the voiced fricatives and stops, there were noticeable findings exhibited by Broca's aphasics with the short vowel [i] before the voiceless fricatives and the voiceless stops in contrast to the normal speakers.
2- Broca's aphasics revealed a compliance with the low vowel durational principle where particularly the short vowel [a] is longer in duration than the high vowels. However, at least to some degree, less compliance with the low vowel rule in the long vowel class was noticed compared to the one in the short vowels.
3- For the normal speakers and the aphasic subjects, a clear influence of the consonant class on the vowel duration was found. For instance, in the normal group and the aphasic patients the short vowel [i] before the voiceless stops was shorter than the others.

It must be noted that the aphasic subjects do not fully produce the long low vowel with the longest duration. For instance, it has been found that low vowels are relatively longer than the high vowels and this is found to be a general tendency in languages.[146] Thus, it can be assumed that the aphasic subjects generally responded to this durational rule by producing the low vowel longer than the high vowels before different consonant classes. According to Klatt,[147] this universal phonetic phenomenon could be attributed to the effect of jaw-lowering. The low vowels need a greater degree of lowering the jaw in order to be produced.

Figures 40 and 41 illustrate the average vowel duration for the vowels under study before the four consonant classes: voiced stops, voiceless stops, voiced fricatives and voiceless fricatives. These figures detect the way in which the vowels are increased. It can be seen in figure 40 that the lengthening of the short vowels takes place by starting from the longest to the shortest produced by Broca's aphasics in the following order:

Vowel before voiced stops
Vowel before voiceless stops
Vowel before voiced fricatives
Vowel before voiceless fricatives

Consonant class	Normal speakers	Aphasic subjects
V.S	75	117
VL.S	53	69
V.F	41	63
VL.F	65	62

Table 35: Average vowel duration (msec) of the short vowels [a], [u] and [i] preceding voiceless fricatives (VL.F), voiced fricatives (V.F), voiceless stops (VL.S) and voiced stops (V.S) for the normal speakers and the aphasics.

[146] Cf. Lehiste, I. (1970), p. 18.
[147] Cf. Klatt, D. (1976), pp. 1210-1214.

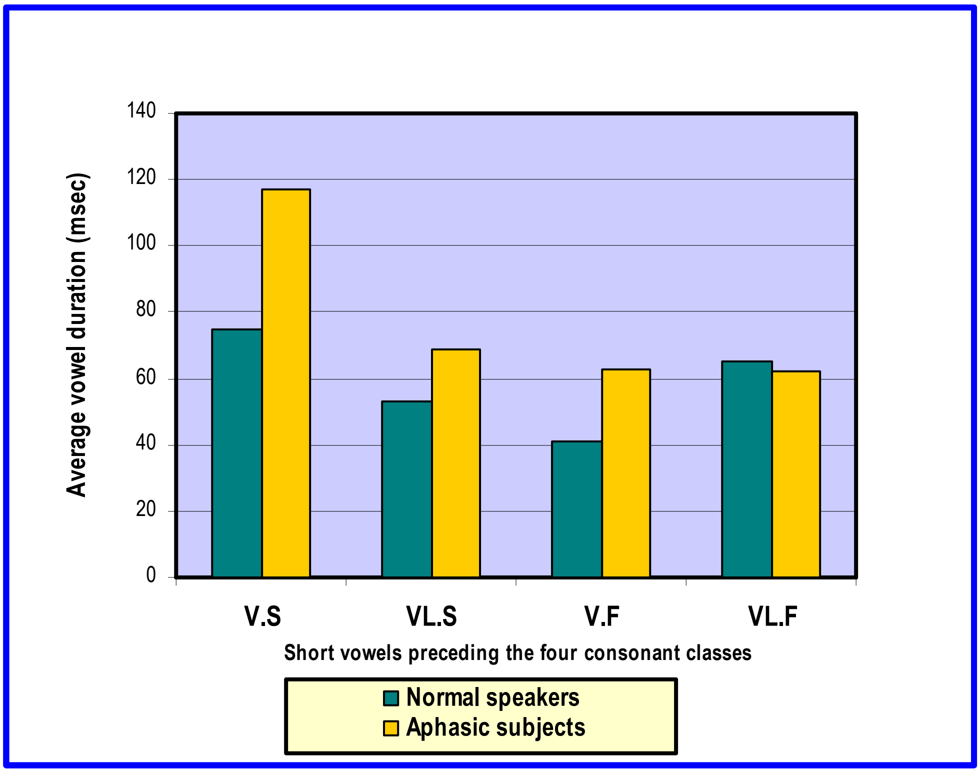

Figure 40: Average vowel duration (msec) of the short vowels [a], [u] and [i] preceding voiceless fricatives (VL.F), voiced fricatives (V.F), voiceless stops (VL.S) and voiced stops (V.S) for the normal speakers and the aphasic subjects.

In light of the previous results, it is thus evident that when the duration of the short vowels before the four consonant classes by the aphasic patients is addressed, it is higher than among the normal speakers. In the long vowels category, on the other hand, a comparison of the vowel's duration under the same consonant classes made by the two groups exhibited obvious differences according to the rank of order. In this regard, based on figure 41, Broca's aphasics displayed an in increase of their vowel durations before the consonant classes under study starting form the longest according to the following order:

Vowel before voiceless stops
Vowel before voiceless fricatives
Vowel before voiced stops
Vowel before voiced fricatives

Consonant class	Normal speakers	Aphasic subjects
V.S	176	200
VL.S	163	402
V.F	147	189
VL.F	175	236

Table 36: Average vowel duration (msec) of the long vowels [a:], [u:] and [i:] preceding voiceless fricatives (VL.F), voiced fricatives (V.F), voiceless stops (VL.S) and voiced stops (V.S) for the normal speakers and the aphasics.

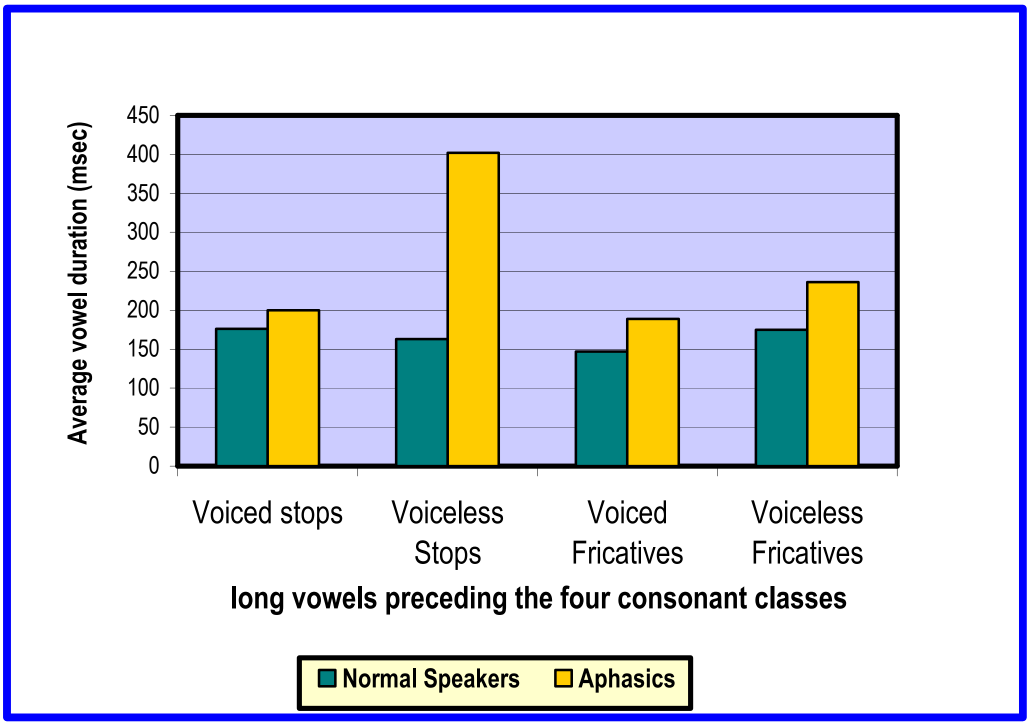

Figure 41: Average vowel duration (msec) of the long vowels [a:], [u:] and [i:] preceding voiceless fricatives (VL.F), voiced fricatives (V.F), voiceless stops (VL.S) and voiced stops (V.S) for the normal speakers and the aphasics.

Furthermore, when the mean averages of the aphasics' long vowel durations are grouped together, it can be noticed that they were larger than for the normal speakers. Figure 42 illustrates the interaction between the mean duration of the short vowel [a] preceding each consonant class among Broca's aphasics and the normal speakers.

Subjects	V.S	VL.S	VL.F	V.F
Normal speakers	70	123	60	96
Aphasic subjects	175	136	142	190

Table 37: Average vowel duration (msec) of the short vowel [a] preceding the consonant classes of voiced stops (V.S), voiceless stops (VL.S), voiceless fricatives (VL.F) and voiced fricatives (V.F) for the normal speakers versus the aphasics.

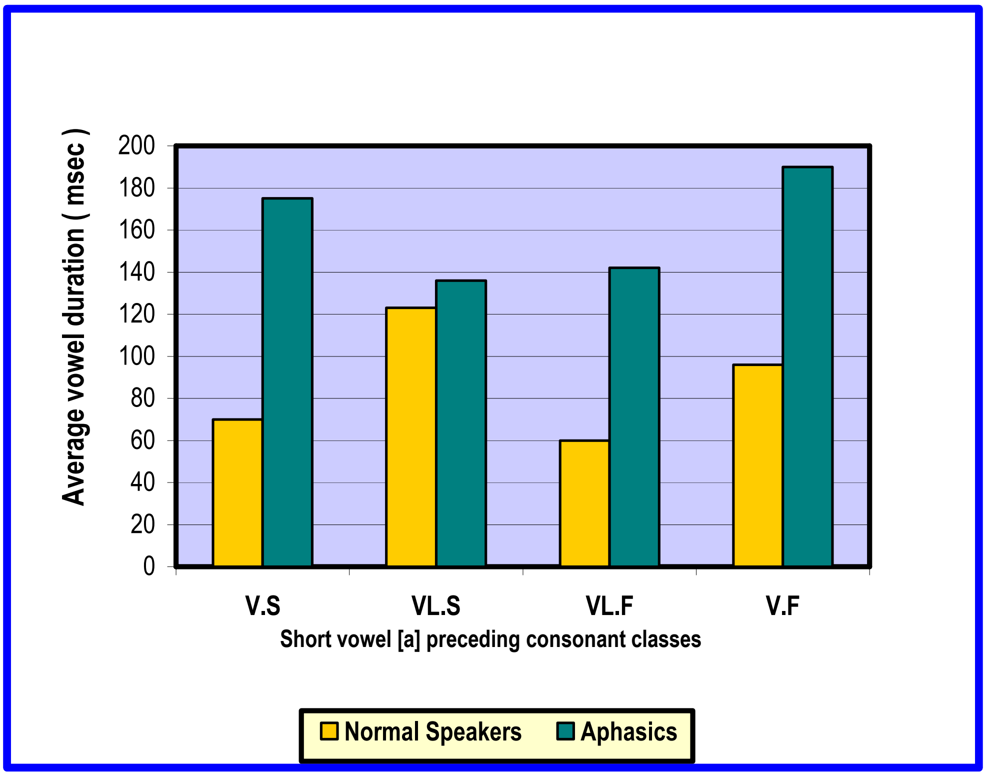

Figure 42: Average vowel duration (msec) of the short vowel [a] preceding the consonant classes of voiced stops (V.S), voiceless stops (VL.S), voiceless fricatives (VL.F) and voiced fricatives (V.F) for the normal speakers versus the aphasics.

This figure clearly shows that Broca's aphasics displayed the most increase in the duration of the short vowel [a] before voiced fricatives. However, the normal speakers displayed such increase before voiceless stops.

Subjects	V.S	VL.S	VL.F	V.F
Normal speakers	178	156	200	157
Aphasic subjects	256	236	250	249

Table 38: Average vowel duration (msec) of the long vowel [a:] preceding the consonant classes of voiced stops (V.S), voiceless stops (VL.S), voiceless fricatives (VL.F) and voiced fricatives (V.F) for the normal speakers and the aphasics

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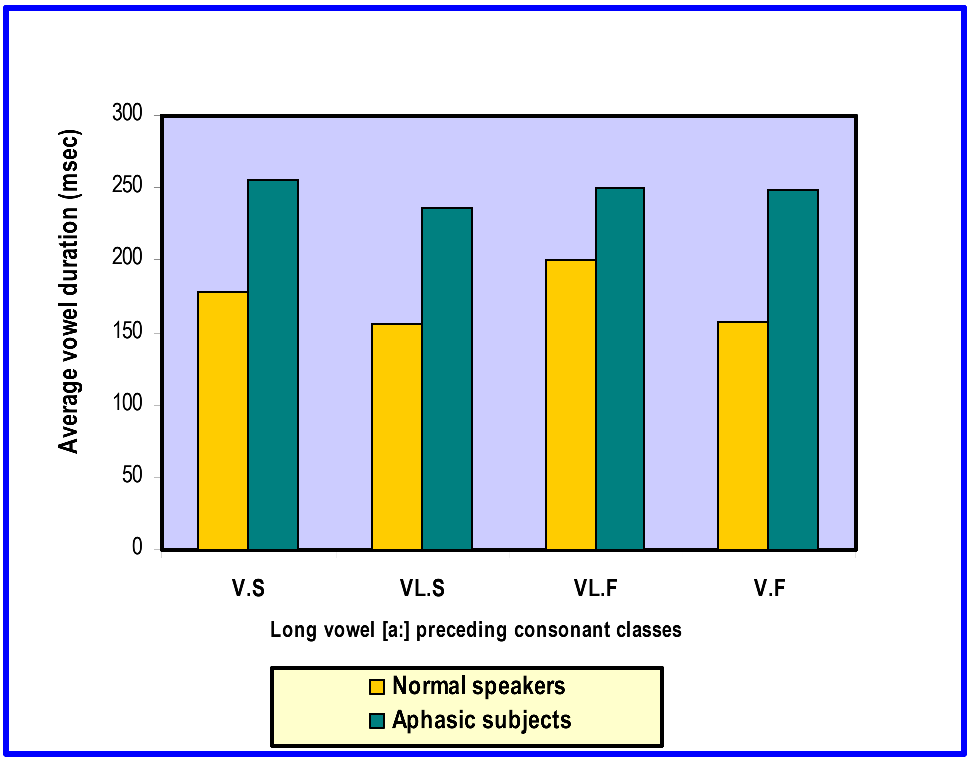

Figure 43: Average vowel duration (msec) of the long vowel [a:] preceding the consonant classes of voiced stops (V.S), voiceless stops (VL.S), voiceless fricatives (VL.F) and voiced fricatives (V.F) for the normal speakers versus the aphasics.

In the vowel [a:] preceding the four consonant classes, by contrast, a somewhat different durational pattern, as figure 43 indicates, can be noticed. In this account, the normal speakers displayed the most increase before voiceless fricatives, whereas the aphasic patients displayed that before voiced stops.

Subjects	V.S	VL.S	VL.F	V.F
Normal speakers	60	66	70	40
Aphasic subjects	175	70	45	80

Table 39: Average vowel duration (msec) of the short vowel [i] preceding the consonant classes of voiced stops (V.S), voiceless stops (VL.S), voiceless fricatives (VL.F) and voiced fricatives (V.F) for the normal speakers versus the aphasics.

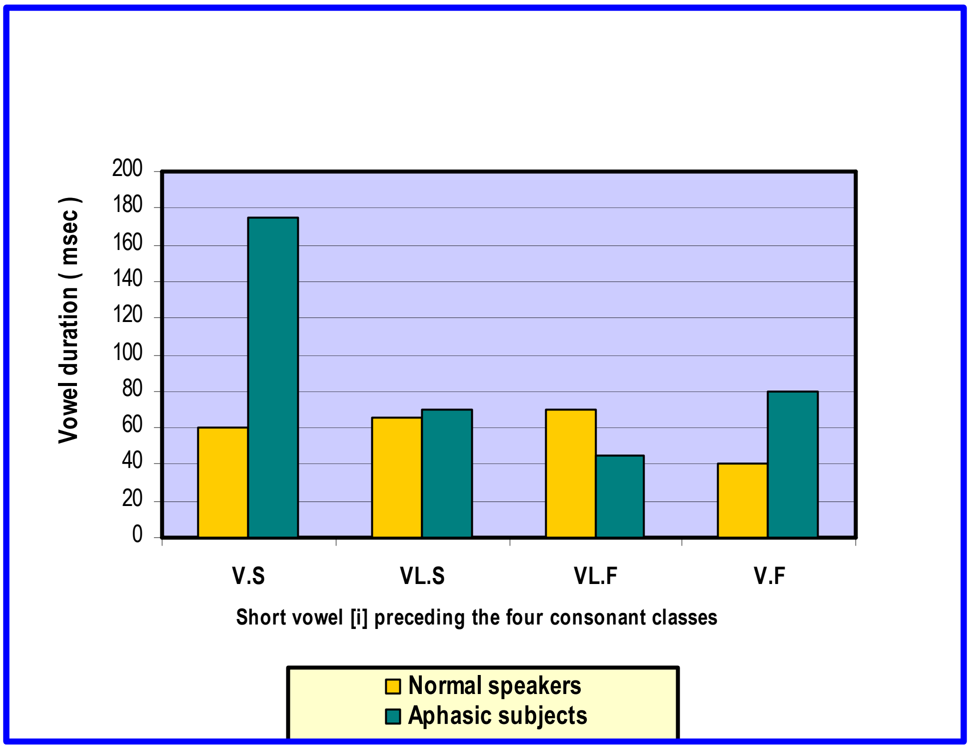

Figure 44: Average vowel duration (msec) of the short vowel [i] preceding the consonant classes of voiced stops (V.S), voiceless stops (VL.S), voiceless fricatives (VL.F) and voiced fricatives (V.F) for the normal speakers versus the aphasics.

Concerning the most increase in vowel duration in the case of the short vowel [i] preceding the consonant classes, as shown in figure 44, it can be seen that Broca's aphasics displayed such durational pattern before voiced stops, whereas the normal speakers displayed this trend before voiceless fricatives.

Subjects	V.S	V.L.S	VL.F	V.F
Normal speakers	174	180	152	127
Aphasic subjects	210	201	227	142

Table 40: Average vowel duration (msec) of the long vowel [i:] preceding the consonant classes of voiced stops (V.S), voiceless stops (VL.S), voiceless fricatives (VL.F) and voiced fricatives (V.F) for the normal speakers versus the aphasics.

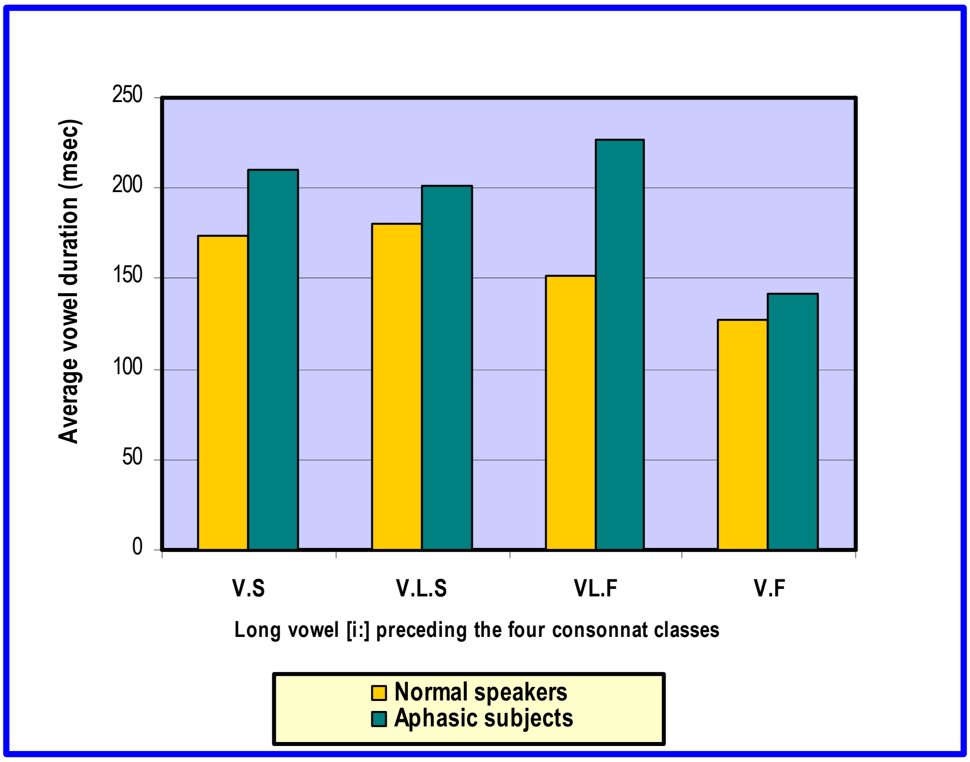

Figure 45: Average vowel duration (msec) of the long vowel [i:] preceding the consonant classes of voiced stops (V.S), voiceless stops (VL.S), voiceless fricatives (VL.S) and voiced fricatives (V.F) for the normal speakers versus the aphasics.

In addition to the previous patterns, Broca's aphasics displayed a different durational trend of the long vowel [i:] compared to the trend seen in the short vowel [i]. In this regard, the aphasic subjects exhibited the most increase before voiceless fricatives as is clearly seen in figure 45. Taken as a whole, this study indicates that the aphasics displayed the most increase in the vowel [i] before voiced stops and the normal speakers before voiceless fricatives. However, as shown in figure 45, for the long vowel [i:] the normal speakers displayed this before voiceless stops, whereas for the aphasic subjects it was before voiceless fricatives.

Subjects	V.S	VL.S	VL.F	V.F
Normal speakers	70	55	62	40
Aphasic subjects	60	80	70	22

Table 41: Average vowel duration (msec) of the short vowel [u] preceding the consonant classes of voiced stops (V.S), voiceless stops (VL.S), voiceless fricatives (VL.F) and voiced fricatives (V.F) for the normal speakers and the aphasics.

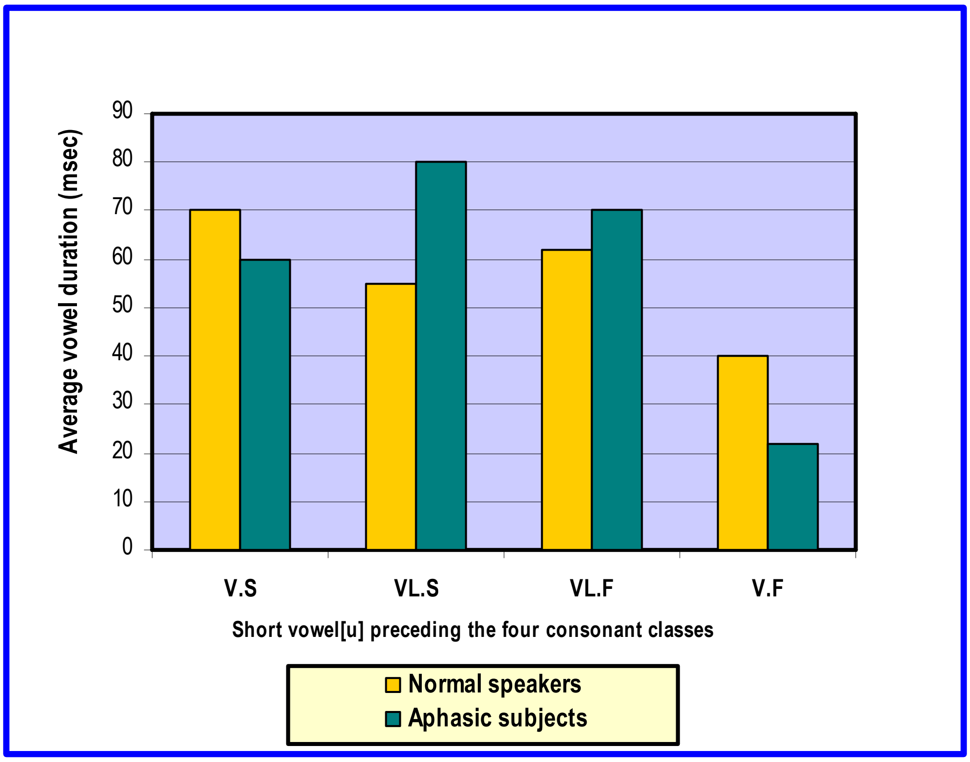

Figure 46: Average vowel duration (msec) of the short vowel [u] preceding the consonant classes of voiced stops (V.S), voiceless stops (VL.S), voiceless fricatives (VL.F) and voiced fricatives (V.F) for the normal speakers and the aphasics.

Regarding the average vowel duration of the short vowel [u] preceding the four consonant classes, Broca's aphasics demonstrated the longest duration of the short [u] before voiceless stops and it was for the normal speakers before voiced stops, as shown in figure 46.

Subjects	V.S	VL.S	VL.F	V.F
Normal speakers	185	174	159	173
Aphasic subjects	136	167	177	231

Table 42: Average vowel duration (msec) of the long vowel [u:] preceding the consonant classes of voiced stops (V.S), voiceless stops (VL.S), voiceless fricatives (VL.F) and voiced fricatives (V.F) for the normal speakers and the aphasics.

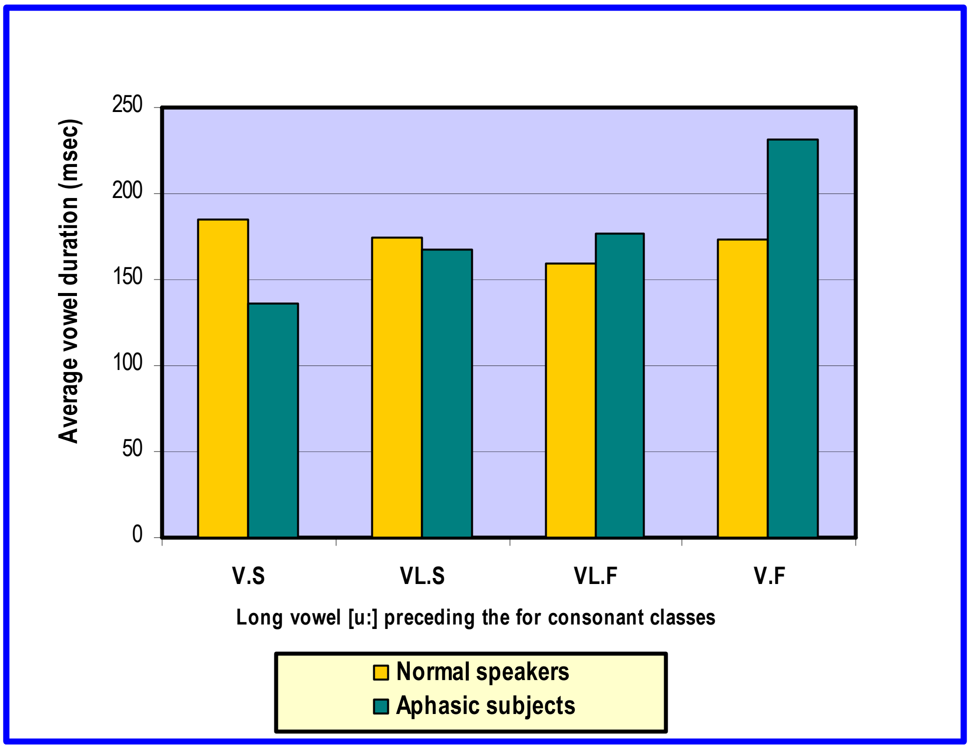

Figure 47: Average vowel duration (msec) of the long vowel [u:] preceding the consonant classes of voiced stops (V.S), voiceless stops (VL.S), voiceless fricatives (VL.F) and voiced fricatives (V.F) for the normal speakers and the aphasics.

Furthermore, as shown in figure 47, different durational trends also can be noticed in the long vowel [u:] preceding the consonant classes under study. For example, if we compare the durational patterns of the normal speakers and the aphasic subjects, it can be noticed that Broca's aphasics displayed the longest vowel durations before fricative consonants and the normal speakers before stop consonants.

Regardless of the standards and the rules being addressed in the current section of the study, a comparison was held between the averages of vowel durations of Broca's aphasics and the normal speakers preceding the consonant classes under the study of the long vowels [a:], [i:] and [u:] based on the judgment of whether the vowel is long, longer or the longest.

Consonant	Shortest	Longer	Longest
[s]	i:	u:	a:
[z]	u:	i:	a:
[ħ]	a:	i:	u:
[ʕ]	i:	u:	a:
[d]	u:	i:	a:
[t]	u:	i:	a:
[b]	u:	a:	i:
[k]	a:	i:	u:
[f]	i:	a:	u:

Table 43: The long vowels are judged as short, longer and longest before certain consonants as produced by the normal speakers.

Under the same phonetic environment, table 44 displays the results judged for Broca's aphasics.

Consonant	Shortest	Longer	Longest
[s]	u:	i:	a:
[z]	a:	u:	i:
[ħ]	i:	a:	u:
[ʕ]	i:	u:	a:
[d]	u:	i:	a:
[t]	u:	a:	i:
[b]	i:	u:	a:
[k]	u:	i:	a:
[f]	a:	i:	u:

Table 44: The long vowels are judged as short, longer and longest before certain consonants as produced by the aphasic subjects.

These two tables provide us with different results:

1- Broca's aphasics and the normal speakers showed a tendency to produce [a:] as their longest vowel before all the consonants addressed in this study.
2- The normal speakers placed [u:] in the middle position (longer) only two times, [i:] five times and [a:] two times, whereas Broca's aphasics under the same category

(longer) placed [i:] four times, [u:] three times and [a:] two times, displaying clear differences between the normal speakers and Broca's aphasics. However, both groups placed each vowel into the "shortest" position the same number of times. Once again, the picture is different with the "longest" position in which the normal speakers placed [a:] five times, [u:] three times and [i:] two times, while Broca's aphasics placed [a:] in the longest position five times, [i:] two times and [u:] two times.

3- The aphasics produced their shortest [a:] before [z] and [f]. This notion confirms the result that Broca's aphasics tend to produce [a:] within the ranks of longer or longest. In contrast, the normal speakers produced their shortest [a:] before] [ħ], [b] and [k]. It is also noticeable that Broca's aphasics produced their shortest [u:] before [s], [d], [t] and [k], whereas the normal speakers demonstrated this before [z], [d], [t] and [b]. Thus, both Broca's aphasics and the normal speakers shared this pattern before the consonants [d] and [t]. Furthermore, it can be observed that Broca's aphasics and the normal speakers have a preference to keep the vowel [i:] relatively within the middle position "longer."

4- The sequence of the long vowels [a:], [u:] and [i:] have six modalities of order:
[a:], [i:] and [u:]
[i:], [u:] and [a:]
[u:], [i:] and [a:]
[u:], [a:] and [i:]
[i:], [a:] and [u:]
[a:], [u:] and [i:]

In general, the normal speaker exhibited five of these modalities:

[a:], [i:] and [u:] before [ħ] and [k]
[i:], [u:] and [a:] before [ʕ] and [s]
[u:], [i:] and [a:] before [t], [d] and [z]
[u:], [a:] and [i:] before [b]
[i:], [a:] and [u:] before [f]

Interestingly, their productions exhibited no representation for the form [a:], [u:] and [i:].

However, the aphasics produced the 6 different forms of the vowel arrangements. These are:

[a:], [i:] and [u:] before [f]

[i:], [u:] and [a:] before [ʕ] and [b]

[u:], [i:] and [a:] before [s], [d] and [k]

[u:], [a:] and [i:] before [t]

[i:], [a:] and [u:] before [ħ]

[a:], [u:] and [i:] before [z]

4- The aphasics demonstrated the following order for the vowel [a:] from longest to shortest duration:

   [s], [ʕ], [d], [b], [k], [ħ], [t], [z] and [f]

On the other hand, the normal speakers exhibited the following order under the same phonetic environment:

   [s], [z], [ʕ], [d], [t], [b], [f], [ħ] and [k]

The following rank was found for both groups for the vowel [i:]:

Normal speakers: [b], [z], [ħ], [d], [t], [k], [s], [ʕ] and [f]

Aphasics: [z], [t], [s], [d], [k], [f], [ħ], [ʕ] and [b]

Furthermore, it can be seen by examining the durational results for the vowel [u:] that this vowel followed the rank order from the longest to the shortest as follows:

Normal speakers: [k], [ħ], [f], [s], [ʕ], [z], [d], [t] and [b]

Aphasics: [ħ], [f], [z], [ʕ], [b], [s], [d], [t] and [k]

In general, our data show that the durational trends of the aphasic patients in terms of ranking were inconsistent with those for the normal speaker.

3.3.5. Conclusion

Important differences in vowel duration between the performance of Broca's aphasics and the normal speakers were found. In general, the mean vowel duration was longer for the aphasic subjects than for the normal speakers. It is also worth noting that the durational patterns of the aphasics were highly variable due to the absence of systematic trends. Furthermore, the findings obtained from the current section are also in support of previous results that Broca's aphasic patients produce vowels that are longer than normal speakers.

With respect to the increase of vowel duration, different patterns of performance between the aphasic subjects and the normal speakers were noticed. For instance, in the aphasic group, when the mean duration of each vowel was grouped according to the consonants that follow, we can see that the longest durational pattern of the short vowel [u] was before voiceless stops, whereas for the normal speakers it was before voiced stops. Furthermore, the results indicate that the aphasic patients demonstrated the longest overall vowel duration for [i], whereas it was [a] for the normal speakers. However, the normal speakers and the aphasic subjects produced [a:] with the longest duration. In general, the aphasic subjects displayed inconsistent durational patterns and were indeed different from the patterns of the normal speakers, but there was some consistency between the two groups in increasing the duration of [a] and [a:] before the consonant classes.

Furthermore, interesting results come from ranking the vowels based on the consonant classes that followed them. For example, the normal speakers and the aphasic subjects increased the vowel duration of the short and long vowels in the same way before voiced stops according to the following rank: [a], [i] and [u], and [a:], [i:] and [u:]. Furthermore, both groups share the same pattern for the short vowels before the voiceless stops: [a], [u] and [i]. It must be noted, though, that the two groups have some similar rank order as shown with some consonant classes, there is clear evidence that the rank order of the short and the long vowels before the other constant classes displayed obvious differences between both groups. Thus, based on the consonant class, the following order was for the vowel duration increase starting from the longest to the shortest:

Normal subjects, short vowels, voiceless fricatives [i], [a] and [u]
Aphasic subjects, short vowels, voiceless fricatives [i], [u] and [a]
Normal subjects, short vowels, voiced fricatives [a], [i] and [u]
Aphasic subjects, short vowels, voiced fricatives [i], [u] and [a]
Normal subjects, long vowels, voiced fricatives [u:], [a:] and [i:]
Aphasic subjects, long vowels, voiced fricatives [a:], [u:] and [i:]
Normal subjects, long vowels, voiceless stops [u:], [a:] and [i:]
Aphasic subjects, long vowels, voiceless stops [a:], [i:] and [u:]

Regarding the durational principles preceding the consonant classes under question, when the vowel durations of three short vowels were grouped together, the aphasics displayed the following order of increase starting from the longest to the shortest: vowel before voiced stops, vowel before voiceless stops, vowel before voiced fricatives and vowel before voiceless fricatives, whereas for the long vowels the following rank was observed: vowel before voiceless stops, vowel before voiceless fricatives, vowel before voiced stops and vowel before voiced fricatives. In fact, the results obtained from the current section would suggest that voiced consonants would contribute to the length of the previous vowel, particularly where the consonant is a stop reflecting a stop-voicing effect on vowel duration. This effect was clear in the aphasics and the normal speakers. For example, as the results indicate it appears that voicing operates on the low short vowel [a] being longer than the other vowels in both groups. Thus, in the aphasic and normal groups, it was noticed that vowels before voiced stops were longer than before voiceless stops keeping to the linguistic rules established across languages. On the other hand, lengthening of the vowels before voiced stops more than with voiced fricatives provides some evidence that the effect of the voiced stop is different from the effect of the voiced fricative. Nevertheless, more investigation is needed to understand the operation of voicing effect on vowels in Arabic in general.

These findings are in accordance with results obtained from different investigations which indicate that vowels were longer and more variable for the aphasic subjects. The intra-speaker variabilities and the differences between average vowel durations of the normal speakers and the aphasic subjects could be interpreted in terms of impaired articulatory implementation at the phonetic-motoic level. This implies articulatory control and timing deficits, but with applying the phonological knowledge between the long and short vowels.

3.4. Vowel reduction by the normal speakers and the aphasic subjects

3.4.1. Introduction and definition

Vowel reduction is a phonological phenomenon. In fact, it is considered to be a prominent feature that characterizes languages and particularly the heavy stress ones. In normal speech production, a clear relationship is already established between vowel duration and word length.[148] In this account, it has been noticed that the duration of stressed vowels is usually decreased as the number of syllables increases.

Importantly, vowel reduction is a rule-governed phonological pattern indicating a linguistic knowledge.[149] Furthermore, this phenomenon could refer to “the non-neutralizing changes in the way in which both stressed and unstressed are being pronounced.”[150] Accordingly, vowel reduction can be realized by a quality change that can be influenced by stress or phonemic vowel length. Furthermore, this phenomenon can be seen as a sloppy pronunciation of vowels with less distinction when the vowels are part of an unstressed syllable or when speaking style is informal.[151]

3.4.2. Vowel reduction in Arabic

Vowel reduction in Arabic takes place whenever the stem is lengthened by adding suffixes that shift the stress to the right edge of the word causing primary stress. In addition, the possessive suffixes that start with consonants are subject to reduction. Abu Salim[152] indicated that vowels are reduced in unstressed open syllables in Palestinian Arabic, in heavy syllables that consist of a long vowel or ended with consonant cluster [mabsu:tˤ] 'happy' and [darasat] 'studied', and in penultimate syllables that have long vowel or closed syllable. In this account, Abu Salim hypothesized that “the vowels are being shortened whenever they are dominated by weak nodes.”[153] Based on this hypothesis, vowels should occur in unstressed open syllables in order to be reduced. Significantly, it must be noted that the long vowels are reduced only under a condition where they are “immediately dominated by weak nodes.”[154] As a result, this indicates that the position of vowels affects their reduction. On this view, one could conclude that a long vowel is shortened whenever it is immediately dominated by a weak node. Thus far, this subsection of the study will try to predict the behaviour of the aphasics with respect to open unstressed syllables in trisyllabic words from an acoustical point of view.

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[148] Cf. Lehiste, I. (1970), pp. 41-52.
[149] Cf. Bergem, D. (1995): Perceptual and Acoustic Aspects of Lexical Vowel Reduction, a Sound Change in Progress, p. 330.
[150] Crosswhite, K. (2001): Vowel Reduction in Optimality Theory, p. 3.
[151] Cf. Harvey, M., & Baker, B. (2005): Vowel Harmony, Directionality and Morpheme Structure Constraints in Warlpiri, pp. 1460-1470.
[152] Cf. Abu Salim, I. (1986): Vowel Shortening in Palestinian Arabic, pp. 225-230.
[153] Ibid., p. 228.
[154] Ibid.

3.4.3. Neurolinguistic studies on vowel reduction in aphasia

Numerous investigators have addressed the question of vowel reduction in speech produced by aphasics. Considerable evidence indicates that the aphasics reduce their vowel duration in disyllabic and trisyllabic words more than monosyllabic ones.[155] However, based on acoustic data, other results indicate that the aphasic subjects produce vowels that are longer than normal duration in polysyllabic utterances, but not necessarily in monosyllabic utterances. For example, in their study on duration of vowels among apraxic speakers, Collins et al.[156] indicated that vowels are longer in words with more than one syllable. Furthermore, they noticed among the non-fluent aphasics a clear-cut lack of syllable reduction from di- to trisyllabic words. On the other hand, in the normal group, it was clearly noticed that polysyllabic words were produced with shorter word stem vowel duration than monosyllabic words. In general, a number of studies have reported abnormal durational patterns and in particular a tendency to produce longer vowel duration than those of normal speakers. Based on these observations, we will test whether the Arabic aphasics are able to maintain the temporal rule that vowel duration decreases as the number of syllables increases and if they do, we will examine whether the duration patterns are comparable in magnitude and consistency to those of the normal speakers.

3.4.4. Results

Across the aphasic group, based on figure 48, vowel duration of trisyllabic words exhibited a remarkable vowel reduction. Overall, vowels in monosyllabic words were produced with greater vowel duration than those in polysyllabic words.

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[155] Cf. Baum, S., Blumstein, S., Naeser, M., & Palumbo, C. (1990): Temporal Dimensions of Consonant and Vowel Production: An Acoustic and CT Scan Analysis of Aphasic Speech, pp. 50-54.
[156] Cf. Collins, M., Rosenbek, J., & Wertz, R. (1983), p. 328.

Word syllable type	[a]	[u]	[i]
Monosyllabic words	170	112	283
Disyllabic words	159	100	270
Trisyllabic words	90	50	60

Table 45: Average vowel durations (msec) for the short vowels as produced by the aphasics from mono to disyllabic and to trisyllabic words.

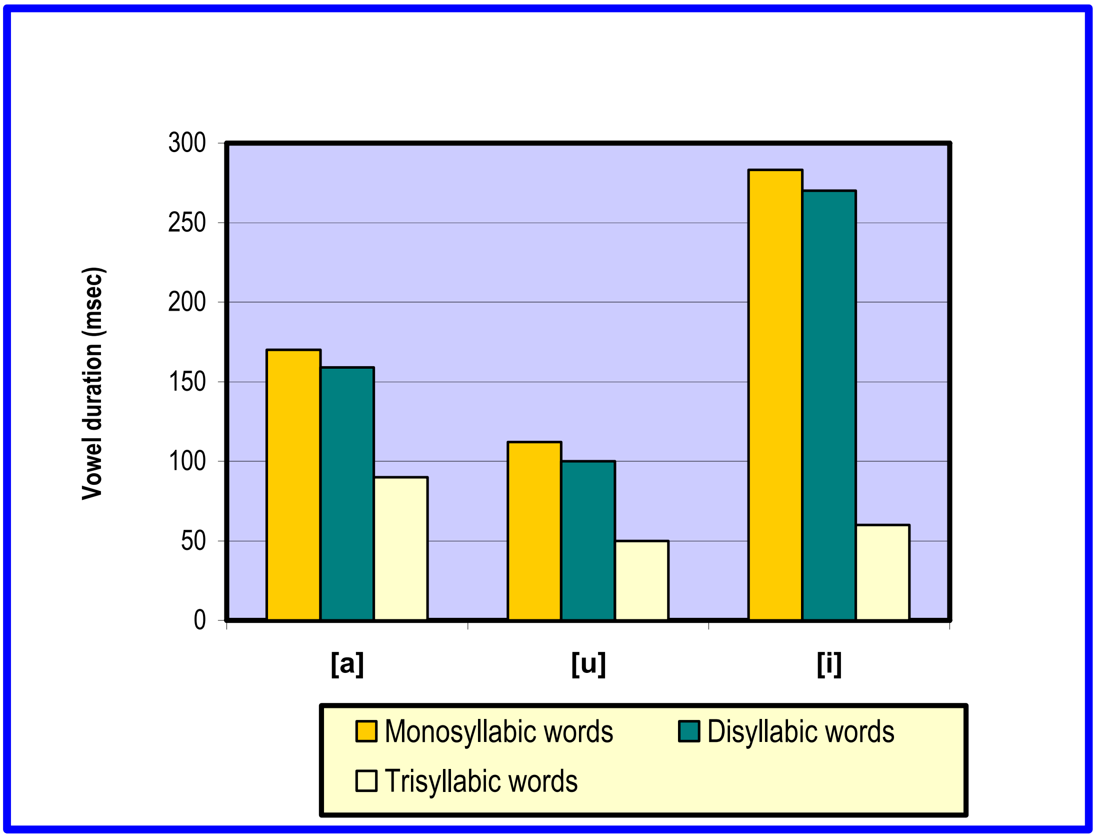

Figure 48: Average vowel durations (msec) for the short vowels as produced by the aphasics from mono to disyllabic and to trisyllabic words.

Basically, there was a vowel duration decrease from di- to trisyllabic words. The results are also very consistent with observations reported by Baum[157] and Gandour et al.[158] Furthermore, a decrease in vowel duration in the monosyllabic words to polysyllabic ones was noticed with longer vowel durations in the disyllabic words than trisyllabic ones. The

[157] Cf. Baum, S. (1992): The Influence of Word Length on Syllable Duration in Aphasia: Acoustic Analyses, pp. 501-511.

[158] Cf. Gandour, J., Ponglorpisit, S., Khunadorn, F., Dechongkit, S., Boongird, P., & Boonklam, R. (1992): Timing Characteristics of Speech after Brain Damage: Vowel Length in Thai, p. 338.

percentage of reduction for the short vowels produced by the aphasics is computed, as table 46 exhibits.

[a]	[u]	[i]
47	55	79

Table 46: The percentage of reduction from mono- to trisyllabic words for short vowels showed by the aphasics.

With regard to the magnitude of reduction, as table 46 illustrates, the short vowel [i] is the most reduced, yet it was the longest among the di- and monosyllabic words, whereas for the other short vowels the magnitude was clearly low.

Word syllable type	[a:]	[u:]	[i:]
Monosyllabic words	208	179	200
Disyllabic words	200	175	191
Trisyllabic words	169	154	136

Table 47: Average vowel duration (msec) of the long vowels displayed by the aphasics from mono and disyllabic to trisyllabic words.

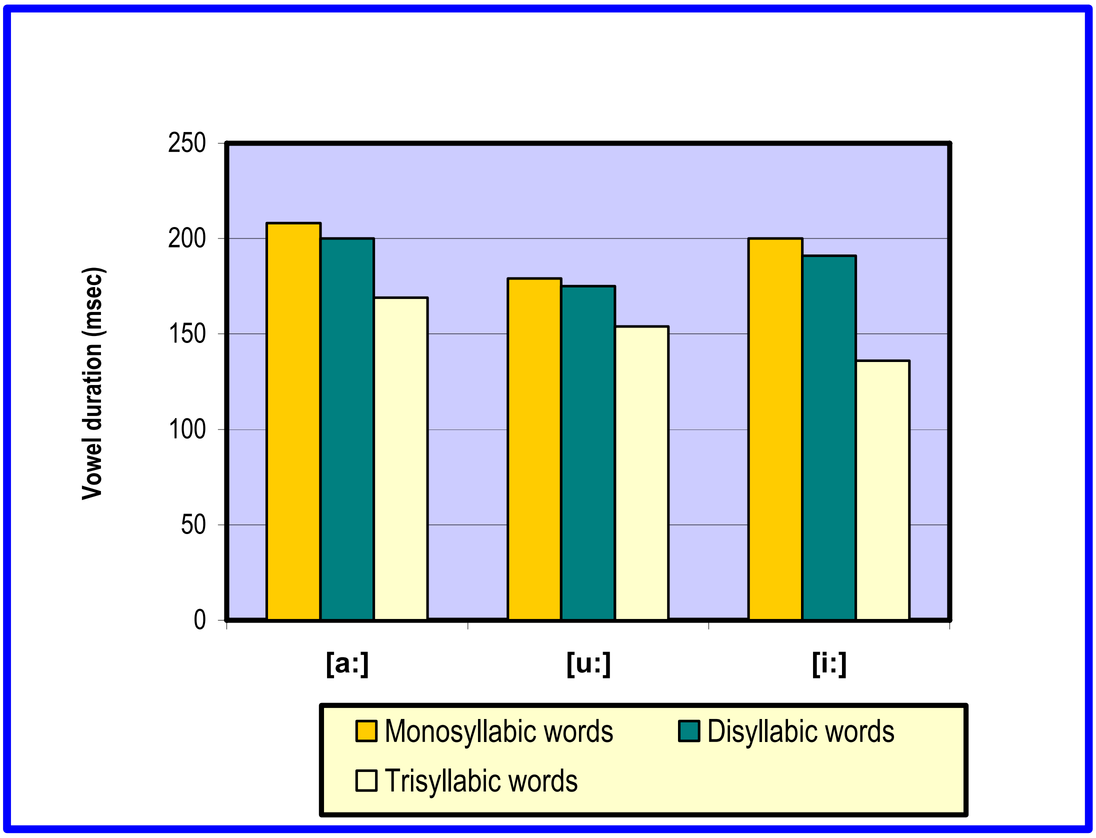

Figure 49: Average vowel durations (msec) for the long vowels displayed by the aphasics from mono and disyllabic to trisyllabic words.

In the long vowels category, based on figure 49, it is apparent that the absolute vowel duration of the aphasic subjects gradually decreased as the word duration increased regardless of the number of syllables in the target word. Notably, this study has found evidence that the aphasic subjects display a systematic tendency of reducing vowels as the word duration increased indicating that they retained this phonological rule, but with a different magnitude of reduction. In general, the vowel duration across the Arabic normal speakers is found to decrease as the length of the word increased.[159]

Overall, these findings indicate that Broca's aphasics were able to keep the above mentioned phonological temporal rule. As a result, the syllables (CVV) were shortened because they are followed immediately by a weak nod (CVVC, CVC). Furthermore, they did not perform the vowel reduction on the final vowels because they occupy strong positions. The implementation of these phonological rules suggests that they exhibit phonological encoding abilities. The preserved phonological encoding would suggest that the deficit might be in the

[159] Cf. Hassan, Z. (2003), p. 47.

implementation level. For example, with increasing the number of syllables in the word, as figure 50 shows, a gradual decrease in vowel duration relative to word duration can be noticed. Furthermore, the aphasics implement the vowel reduction rule on trisyllabic words and they exhibit long vowel durations for mono and disyllabic words.

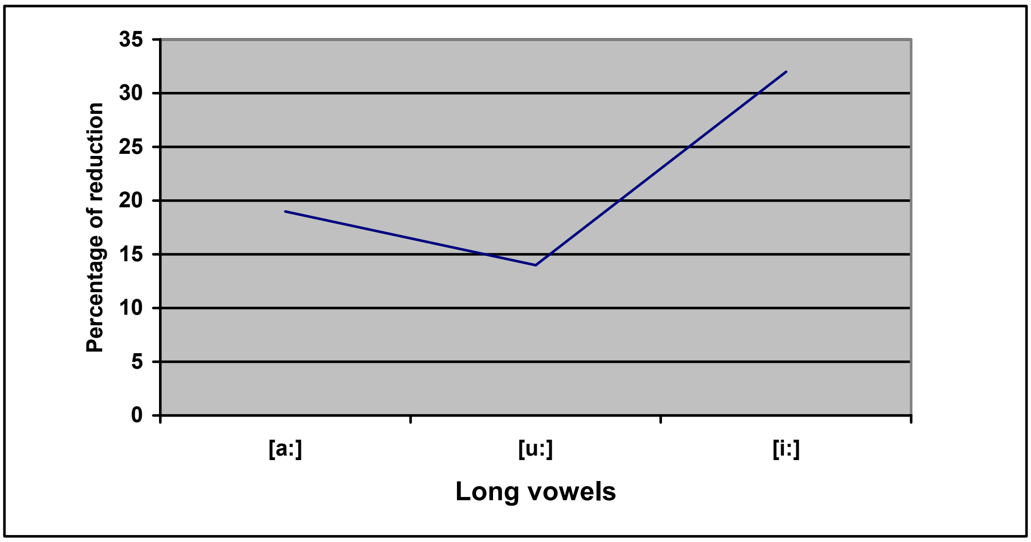

Figure 50: Percentage of reduction for long vowels from mono and disyllabic to trisyllabic words as exhibited by the aphasic subjects.

With respect to the magnitude of reduction, as figure 50 shows, it can be observed that the magnitude of the vowel reduction of the long vowel [i:] is remarkably decreased compared to the short vowel [i] amounting to about a 47% difference. The results from the present study indicate that Broca's aphasics maintain the vowel duration reduction rule unlike other investigations that have reported from an increase in vowel duration as the word length increased in some apraxic and Broca's aphasic subjects.[160] In this regard, figures 51 and 52 display a precise picture of the durational patterns of Broca's aphasics compared to the normal group.

[160] Cf. Collins, M., Rosenbek, J., & Wertz, R. (1983), pp. 326-329.

Subjects	[a]	[u]	[i]
Normal speakers	60	40	50
Aphasic subjects	90	50	60

Table 48: An illustration of vowel reduction (msec) of the short vowels for the normal speakers versus the aphasics in trisyllabic words.

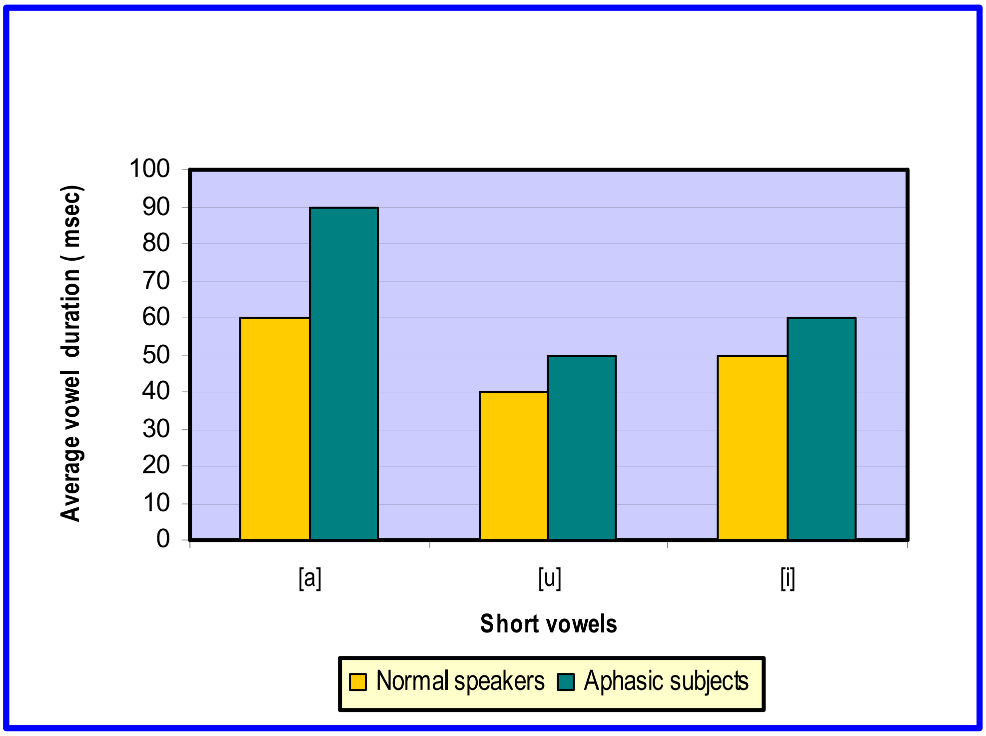

Figure 51: An illustration of vowel reduction (msec) of the short vowels for the normal speakers versus the aphasics in trisyllabic words.

Subjects	[a:]	[u:]	[i:]
Normal speakers	109	114	126
Aphasic subjects	169	154	136

Table 49: An illustration of vowel reduction (msec) of the long vowels for the normal speakers versus the aphasics in trisyllabic words.

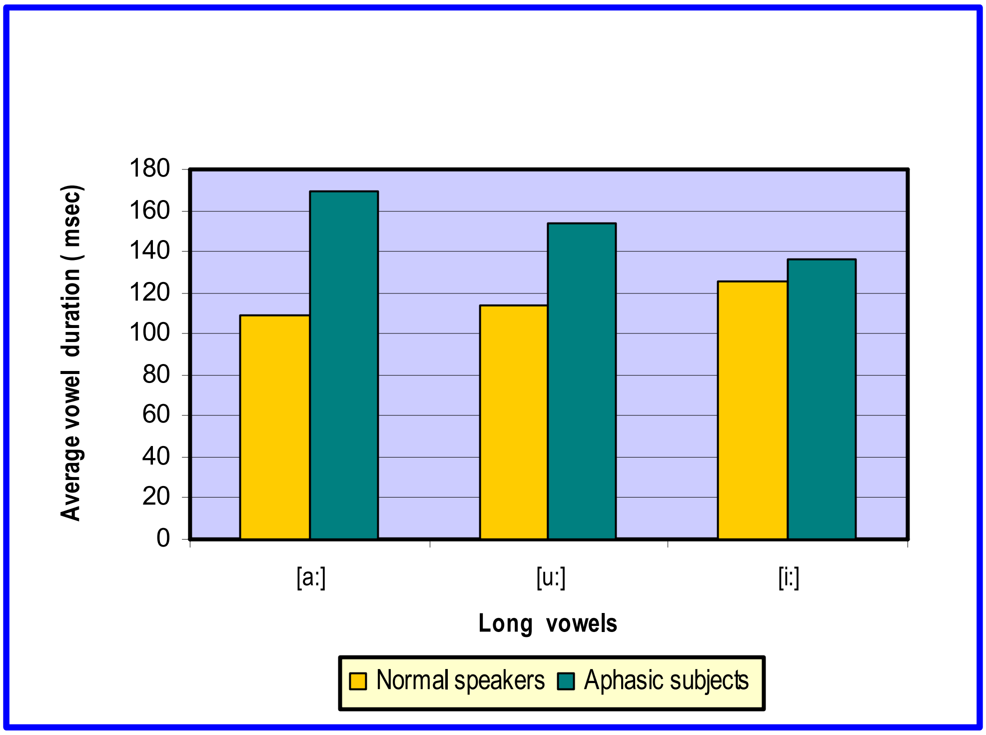

Figure 52: An illustration of vowel reduction (msec) of the long vowels for normal speakers versus the aphasics in trisyllabic words.

For the aphasic subjects and the normal speakers, as it can be seen in figures 51 and 52, there was a clear reduction in vowel duration from monosyllabic and disyllabic to trisyllabic words. However, taken as a whole, this study exhibits that the vowel durations are higher for the aphasics than for the normal speakers. This trend can be noticed especially in the long vowels. Clearly, based on these figures, it is true for the aphasic subjects and the normal speakers that they reduce vowel duration in trisyllabic words, but the magnitude of the reduction was smaller for the aphasics than for the normal speakers. With regard to the results from the present study, there was a consistency with findings reported from other investigations.[161]

3.5. Syllable duration

Many researchers have reported on timing deficits across the aphasics, especially in large-sized linguistic units.[162] In light of these observations, this section aims to explore the timing relations of the intra-syllabic among our aphasics and whether the Palestinian Broca's aphasics exhibit specific durational patterns that are demonstrated by aphasics whose native language is not Arabic. In addition, the current section will address whether the aphasic

[161] Cf. Baum, S., Blumstein, S., Naeser, M., & Palumbo, C. (1990), p. 33.
[162] Cf. Murai, K., Tanaka, Y., & Miyazaki, M. (2005): Acoustic Analysis of Speech Output in Broca's Aphasia and Parkinson's Disease, pp. 217-218.

subjects produce shorter syllable duration in polysyllabic conditions than those in isolation environment compared with the normal speakers.

As figure 53 shows, the aphasics produce longer monosyllabic words than the same syllables produced within disyllabic or trisyllabic words. Thus, this indicates that the aphasics produced the embedded syllable in polysyllabic words longer than the same syllable under isolation condition. Clearly, this pattern is inconsistent with those of the normal speakers. These results in the present study obtained from the aphasic performance are inconsistent with those reported from other studies. For example, Baum[163] indicated that his English aphasics produced longer monosyllabic words in isolation condition than the same syllables that embedded in polysyllabic words particularly in the disyllabic ones.

Subjects	Monosyllabic words	Disyllabic words	Trisyllabic words
Normal speakers	219	229	125
Aphasic subjects	255	244	342

Table 50: Average duration (msec) of the syllable (maz) as produced by the normal speakers and the aphasics in monosyllabic and polysyllabic words.

[163] Cf. Baum, S. (1990): Acoustic Analysis of Intra-Word Syllabic Timing Relations in Anterior Aphasia, p. 321.

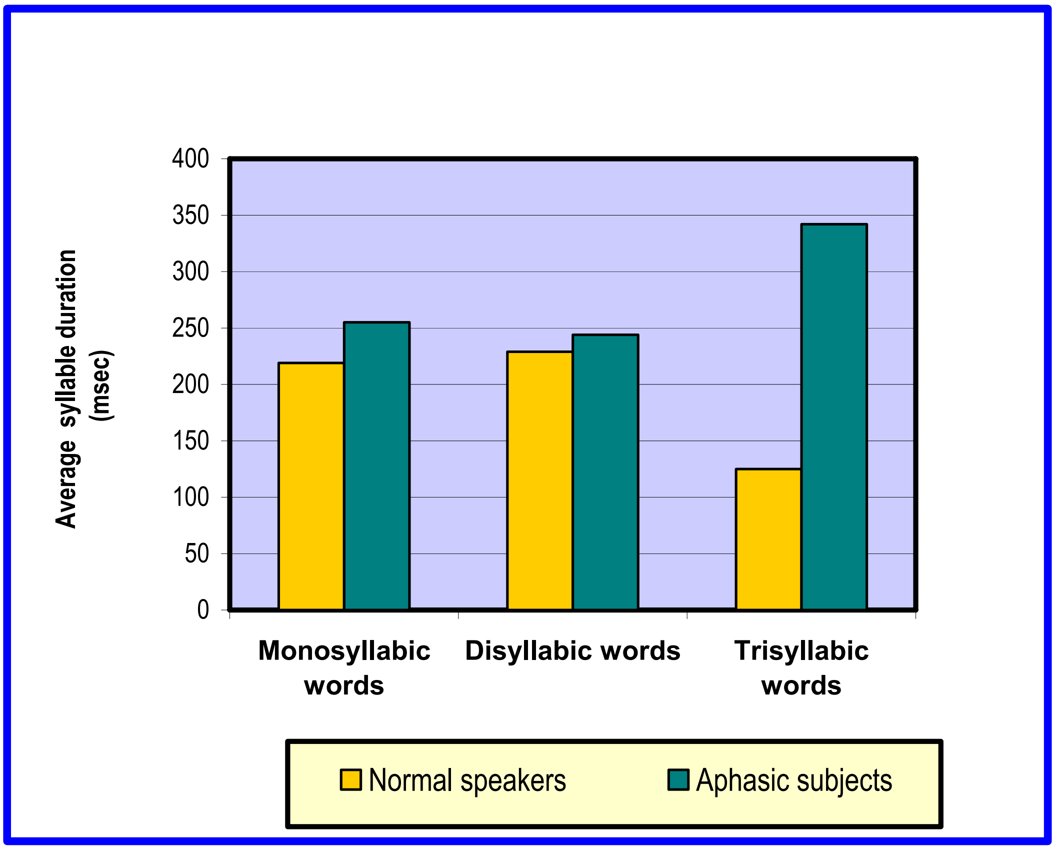

Figure 53: Average duration (msec) for the syllable (maz) as produced by the normal speakers and the aphasics in monosyllabic and polysyllabic words.

With regard to the root syllable in trisyllabic words, Broca's aphasics displayed a notable increase in its duration in trisyllabic words compared to the duration of the same root embedded in disyllabic or monosyllabic words, as shown in figure 53. The amount of increase from monosyllabic to trisyllabic words was 87msec. This is, however, found to be completely different from the normal speakers who decreased the duration of the same root syllable in trisyllabic words to 125msec. In general, it appears that Broca's aphasics displayed across the trisyllabic words a different durational pattern than the normal speakers did. It follows that they did not reduce the duration of the syllable as the normal speakers perform. In their study on apraxia, Kent and Rosenbeck[164] reported on three sorts of syllabic breakdowns that might be responsible for prolongation of syllables. First, "articulatory prolongation" is defined as the lengthening of the input's of speech flow. Second, "syllable segregation" is defined as increasing silent pauses among syllables. Finally, "syllable dissociation" is characterized by a large isolation of syllables within temporal parameters. Applied to the observations being

[164] Cf. Kent, R., & Rosenbek, J. (1983), p. 233.

noticed in the current part of the study, we would argue that the aphasics prolonged the element of the speech by increasing the intra-syllabic duration. However, another questionable issue is determining whether the temporal deficit of maintaining temporal control in the trisyllabic words is a result of temporal programming deficits or implementation impairments. On the ground of the findings of previous studies and of the current findings, one would suggest that the aphasics were able to program and to carry out timing relations across disyllabic words.

3.6. Word duration

In this part of the study, we will explore the pattern of word duration across the aphasics in order to have a comprehensive picture of the correlation between word duration and increasing the number of syllables. With increasing number of syllables in a word, as figure 54 shows, important differences between the normal speakers and the aphasic subjects can be noticed. Thus, while the number of syllables increased, the word duration of the normal speakers decreased, particularly in trisyllabic words. However, the aphasic subjects displayed a significant increase in word duration as the number of syllables increased. Furthermore, the magnitude of the word duration increase was relatively greater for the aphasics than for the normal speakers mainly in trisyllabic words. In this regard, the comparisons confirmed that the aphasics produced longer word durations than the normal speakers for both disyllabic and trisyllabic words. Support for this result came from Thai aphasics who exhibited systematic increase in word duration as the stem word length increased.[165]

Subjects	Monosyllabic words	Disyllabic words	Trisyllabic words
Normal speakers	219	489	570
Aphasic subjects	248	530	838

Table 51: Mean word duration (msec) as exhibited by the aphasics and the normal speakers.

[165] Cf. Gandour, J., Dechongkit, S., Ponglorpisit, S., Khunadorn, F., & Boongird, P. (1993): Intraword Timing Relations in Thai after Unilateral Brain Damage, p. 161.

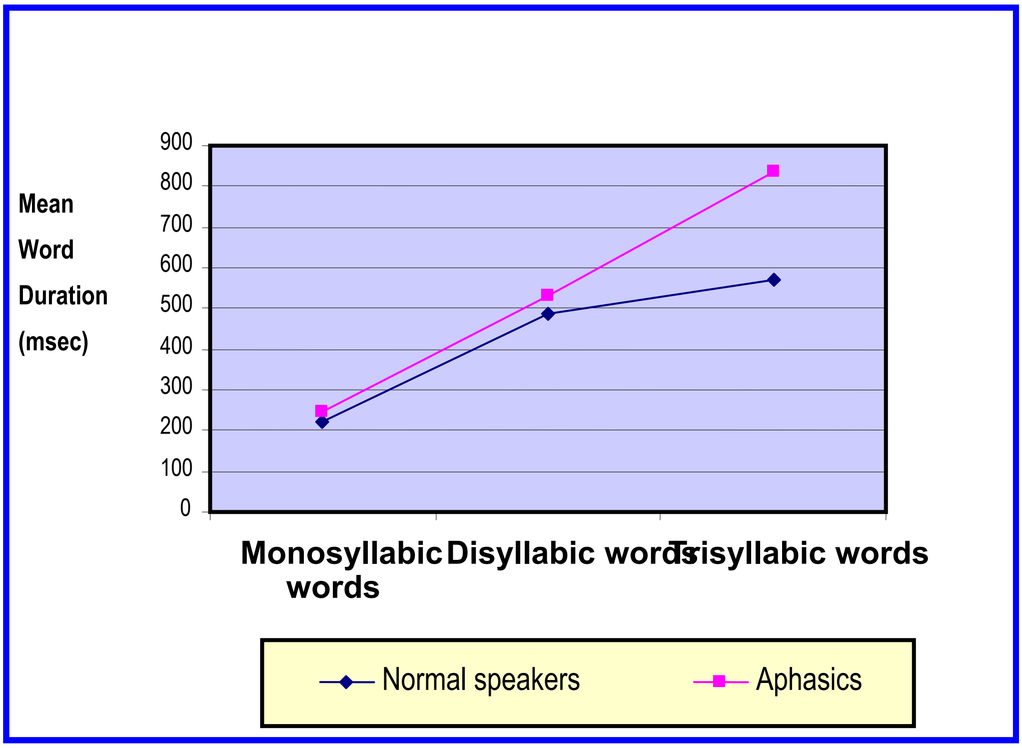

Figure 54: Mean word duration (msec) for words as produced by the aphasics and the normal speakers.

3.7. Discussion and conclusion

In general, the aphasics in the current study displayed a decrease in vowel duration as the word's length increased particularly in trisyllabic words, but with a different magnitude of reduction in comparison to the normal speakers. This would suggest that they might tend to reduce the duration of muscle activity in order to maintain the sensitivity to the phonological encoding of vowel duration that decreases as the word's length increases. In light of these observations, it is reasonable to argue that the aphasic subjects systematically tend to decrease the time needed to end muscle activity as word length increased resulting in deviated durational patterns. Notably, a general tendency was noticed in the performance of the aphasic subjects that the mean vowel duration decreased and the mean word duration increased as the number of syllables increased. It must be noted that the mean vowel duration and word duration for the aphasics were longer than those of the normal speakers giving evidence for motor timing impairments.

In fact, the results obtained from the aphasic subjects show that their absolute vowel and word durations were longer than those for normal speakers. In addition, they simultaneously decreased the vowel duration as word duration increased regardless of the number of syllables reflecting coarticulatory effects. It is of further interest to point out that the systematic tendency of reducing vowels as word duration increases is an obvious indication that the aphasics retained this phonological rule, but with a different magnitude of reduction. This was clear in some spared durational correlations particularly in vowel reduction patterns as the word length increased. The results indicate that the production of polysyllabic words seems to be particularly difficult for the aphasic subjects due to the increase of articulatory complexity.

In addition, it has been concluded from most of the acoustic studies that polysyllabic words are difficult to plan and execute because the need for more coarticulatory possibilities leads to breakdowns at the temporal and production levels by the aphasic patients. Consequently, this leads to a remarkable reduction of speaking rate compared to normal speakers. For example, the duration of [i] was found to be the most reduced in the words under study. This reduction of duration is a strong indication for the implementation of phonological rules, giving evidence of the phonological knowledge of the aphasics and their accessing ability concerning the number of syllables in the word. Thus far, it appears that the aphasics displayed primarily motor deficits in speech production rather than phonological ones. In fact, increased duration for Broca's aphasics could likely be due to slow rate of speech associated with struggled production. Furthermore, it has been often pointed out that the overall sentence durations are longer for aphasics than for normal speakers, indicating a clear decrease in speaking rate compared to normal subjects.[166] With respect to syllable duration, the data demonstrates that the aphasic patients tend to reduce syllable duration in disyllabic words, while they increase it in trisyllabic words. In spite of the preservation of this phonological rule, at least within disyllabic words, there is a considerable lack of reduction in syllable duration from di-to trisyllabic words among the aphasic subjects.

In general, our aphasics exhibited durational patterns that are characterized by lengthening the temporal components. Many factors might contribute to these patterns such as stress and syllable position. However, other factors also come into play such as segmental content of the word, number of syllables in an utterance and lexical familiarity.[167] Utterance length difficulty that requires performing ordered articulatory sequences is found to be challenging for Broca's

[166] Cf. Gandour, J., & Dardarananda, R. (1984b), p. 206.
[167] Cf. Stenneken, P., Bastiaanse, R., Huber, W., & Jacobs, A. (2005): Syllable Structure and Sonority in Language Inventory and Aphasic Neologisms, pp. 288-291.

aphasics in addition to the stress pattern, particularly in the production of initial unstressed syllables.[168] With respect to the correlation of vowel duration with word duration, the aphasic subjects displayed systematic and consistent patterns in reducing vowels as the normal speakers revealed, but with other magnitude of reduction.

It should be briefly addressed that the performance of Broca's aphasics on vowel reduction confirms the preservation of phonological rules. In this account, as one would expect, the overall duration of the word displays a notable increase as the number of syllables increases. However, since the percentage of time devoted to vowel production systematically decreases as words become longer, significant differences in the magnitudes of decrease may appear between the normal speakers and the aphasic subjects that are usually found to be less for the aphasics. Importantly, the results also address the question of the nature of deficit in Broca's aphasia that is considered to be phonetic due partially to impairments in the neuromotor control commands. In general, the speech of our Broca's aphasics is characterized by relative centralization of vowels, slowness and inaccuracy of movement of the articulators. This leads to an increase in vowel durations for the aphasics compared to the normal speakers. In addition to these findings, the mean vowel and word durations were longer for the aphasics than for the normal speakers giving evidence for motor timing impairments. Among the normal speakers, monosyllabic words were produced with greater word stem vowel duration than polysyllabic words. These results would suggest that normal speakers systematically tend to decrease the time needed to end muscle activity as word length increases. Thus, the general pattern emerging from this study indicates that Broca's aphasics are more impaired in temporal and articualtory aspects than in phonological ones.

3.8. The acoustic vowel space of the aphasic subjects and the normal speakers

Vowel inventories widely differ from one language to another. However, cross-linguistic studies exhibit that vowel configuration is preferred. Consequently, this section of the present study will shed some light on this issue in terms of comparison between the patterns of the normal speakers and Broca's aphasics. Figures 55 and 56 express the acoustic vowel space of the long and short vowels produced by the aphasic subjects and the normal speakers.

[168] Cf. Balan, A., & Gandour, J. (1999): Effect of Sentence Length on the Production of Linguistic Stress by Left- and Right-Hemisphere-Damaged Patients, p. 88.

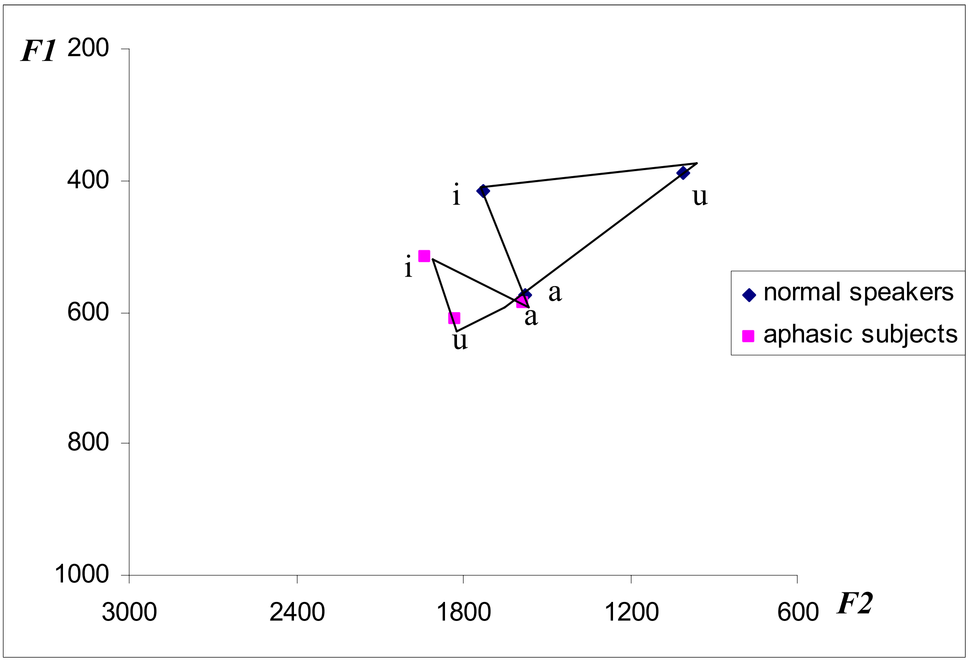

Figure 55: Acoustic vowel space for short vowels as produced by the aphasic subjects and the normal speakers.

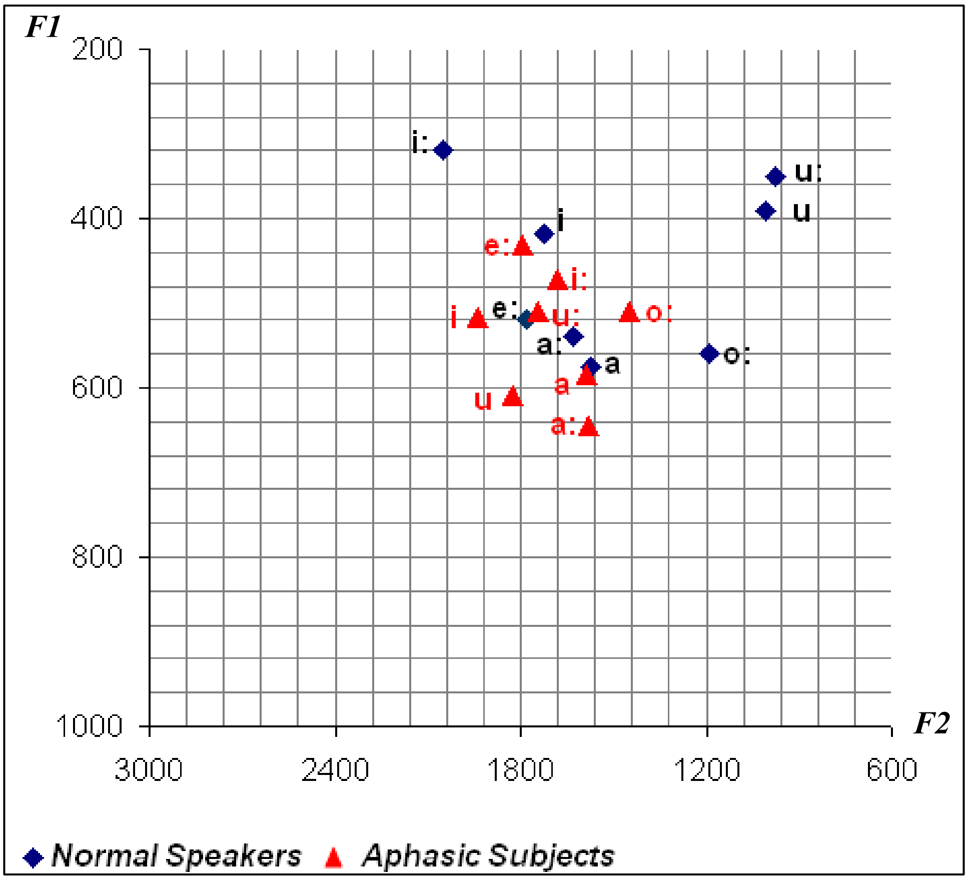

Figure 56: Vowel distribution in the acoustic vowel space for the long and short vowels [a, a: u, u, i, i:, ɛ:, o:] as produced by the aphasic subjects and the normal speakers.

Concerning the general picture of all vowels, the results indicate that the F1 and F2 of both long and short vowels in speech produced by the aphasic subjects are located lower than those of the normal speakers. Furthermore, it can be noted that the aphasic's vowel space moves relatively downwards in comparison to the normal speakers. It is also noteworthy to indicate that the aphasic's vowel space is narrower and smaller than the vowel space of the normal speakers. In addition, the short vowels lie in two separate zones for the aphasic subjects and the normal speakers. In the long vowels category, these speakers reversed the pattern by showing a kind of overlapping between their productions, as shown in figure 56. For example, in figure 56, the aphasic subjects showed that the closest vowel to the vowel [i:] is not the short vowel [i] but rather the long vowel [u:]. Interestingly, the results from the normal speakers indicate that lax vowels are lower than their tense cognates as can be clearly seen in the cases of [i] and [i:].

Based on the values of F1 and F2 obtained from Broca's aphasics, the results would indicate that vowels usually tend to be centralized suggesting a deficiency in the motoric coordination and the reduction in muscular activity. This would emphasize a motor deficit in Broca's aphasia. It may be important to point out that this form of acoustic space, in general, indicates that the production of vowels requires more effort than in the case of the normal speakers. Therefore, it is possible that Broca's aphasics display remarkable problems with maintaining the maximal frequency range of the vowel distribution in the acoustic space, reflecting some difficulties either in the front/back or in the open/close direction.

There is further evidence for this difficulty coming from the back vowels, where the short [u] and the long [u:] have higher F2 values than the vowels produced by the normal speakers due to the fact that F2 conveys information about the front/back tongue positioning. Consequently, this would indicate a difficulty with enough and precise movement of the back of the tongue in the vocal tract. In addition, some evidence from F1 data whose value is higher than in the case of the normal speakers indicates a deficit in placing the tongue in the velar region of the vocal tract.

Interestingly, as figure 57 illustrates, the formant frequencies of the long and the short vowels, as displayed by the normal speakers, are overlapped. Consequently, the vowel triangle formed by the short vowels is relatively contained within the vowel triangle established by the long vowels. In addition to short and long vowel overlapping, the reduction of the vowel triangle size for short vowels in comparison to the long vowels demonstrated a kind of centralization relative to long vowels.

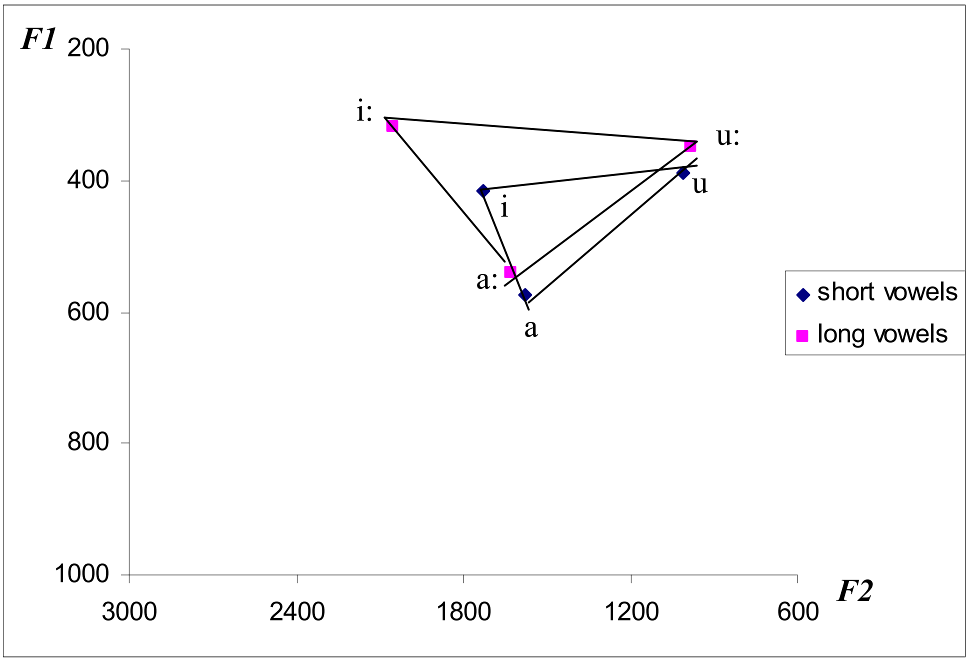

Figure 57: Acoustic vowel space of the long and short vowels as produced by the normal speakers.

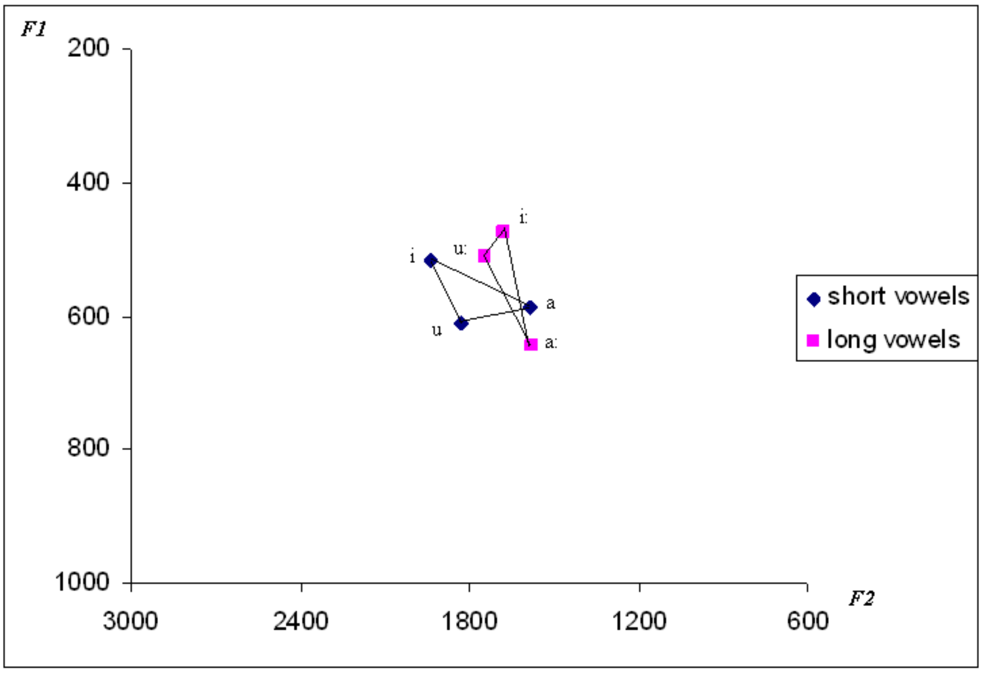

Figure 58: Acoustic vowel space of the long and short vowels as produced by the aphasics.

In contrast, as shown in figure 58, it is clear that the acoustic vowel space of the long and short vowels produced by Broca's aphasics is smaller than that of the normal speakers, reflecting extreme reduction and centralization of vowels. Furthermore, the ranges of the vowel formant frequencies of short low vowels produced by the aphasic patients had the highest F1. However, trends were different for the high front vowels [i:] and [i], which had the lowest F1 frequencies. In general, the aphasic subjects tended to have more compressed vowel spaces than the control speakers did, indicating that they suffer from limitations in the musculature apparatus movement. This affects tongue movement, tongue displacements and the direction of the movement. In general, this finding indicates that the compressed vowel acoustic space would refer to a deficit in the acoustic contrast among vowels accompanied by a loss in word distinctiveness in either single words or sentences.

In conclusion to this section, it can be said that the acoustic vowel space of the aphasics is remarkably narrower than the one of the normal speakers. Furthermore, the short vowels are somewhat centralized relative to distinctively long vowels. The long vowels are extremely reduced indicating motoric limitations in the mobility of the musculature.

4. CONSONANT PRODUCTION BY THE APHASIC SUBJECTS AND NORMAL SPEAKERS

4.1. Voice onset time (VOT) in stop sounds

4.1.1. Introduction and definition

A lot of attention was focused on voice onset time (VOT) because of its critical attribution to the voiced-voiceless phonetic distinction. Basically, it clarifies the timing relation between the release of the stop consonant and the onset of voicing as schematically illustrated in figure 59. In this account, VOT is defined as the temporal delay between consonant release and the first glottal pulse.[169] In their study, Lieberman and Blumstein[170] pointed out that this phenomenon refers to the timing between the onset of phonation and the release of the primary occlusion of the vocal tract. A similar point has been made by Lisker and Abramson,[171] who considered VOT as the temporal relation between the onset of glottal pulsing and the release of the initial stop consonants. Furthermore, many investigations indicate that VOT cues are processed in the "left auditory cortex in right-handed subjects with left-hemispheric dominance for language."[172]

[169] Cf. Taehong, C., & Ladefoged, P. (1999): Variation and Universals in VOT: Evidence from 18 Languages, p. 209.
[170] Cf. Lieberman, P., & Blumstein, S. (1990), p. 215.
[171] Cf. Lisker, L., & Abramson, A. (1967): Some Effects of Context on Voice Onset Time in English Stops, p. 2.
[172] Cf. Fonseca, A., Giraud, K., Badier, J., Chauvel, P., & Liégeois-Chauvel, C. (2005): Hemispheric Lateralization of Voice Onset Time (VOT) Comparison between Depth and Scalp EEG Recordings, p. 12.

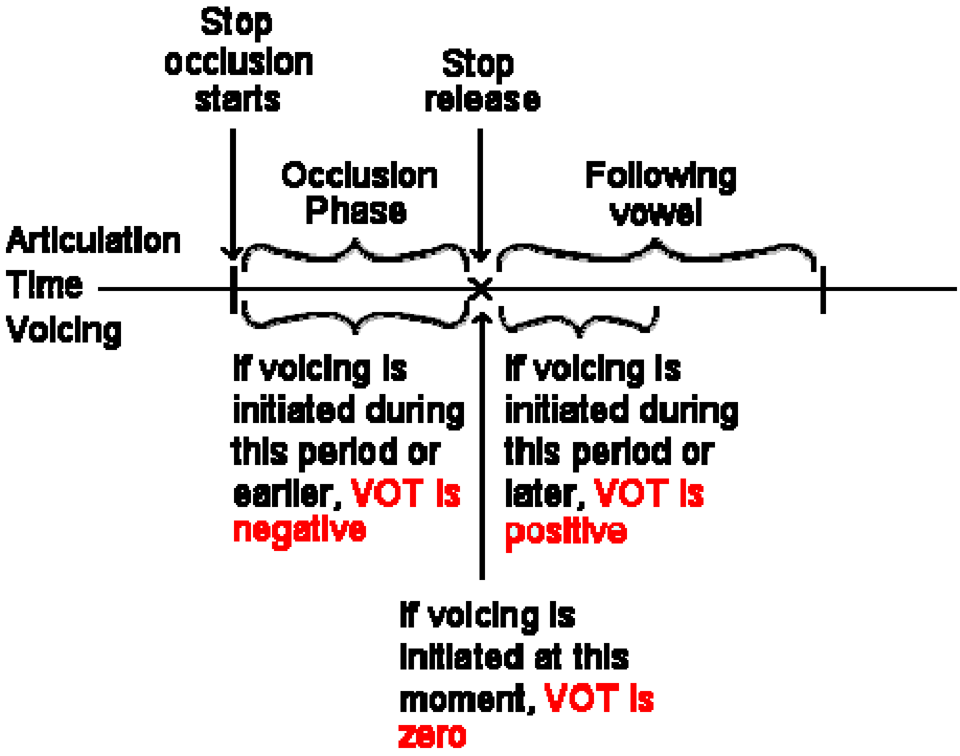

Figure 59: Schematic representation of the VOT production for voiced and voiceless stops (Adapted from Robert Mannell Speech Hearing and Language Research Centre Department of Linguistics 2000-2004, Macquarie University).

In fact, the production of the stop sounds is carried out through many phases as clearly seen in the figure above. It is obvious that this schematic representation clarifies the VOT for syllable-initial stops. It is noteworthy, however, to indicate that the term "voiced" relates to the periodicity caused by the vibration of the vocal cords. On the other hand, voiceless sounds did not exhibit such periodicity. Furthermore, phonation can take place in different phases. In such a case, it might be produced simultaneously with the release of the stop sound after or before its release. In the case of the temporal relationships of stop consonants, as figure 60 points out, it can be indicated that voicing starting after the release called voicing lag has a positive VOT value, while before the release voicing lead has a negative value or zero relating to the timing of stop release burst.

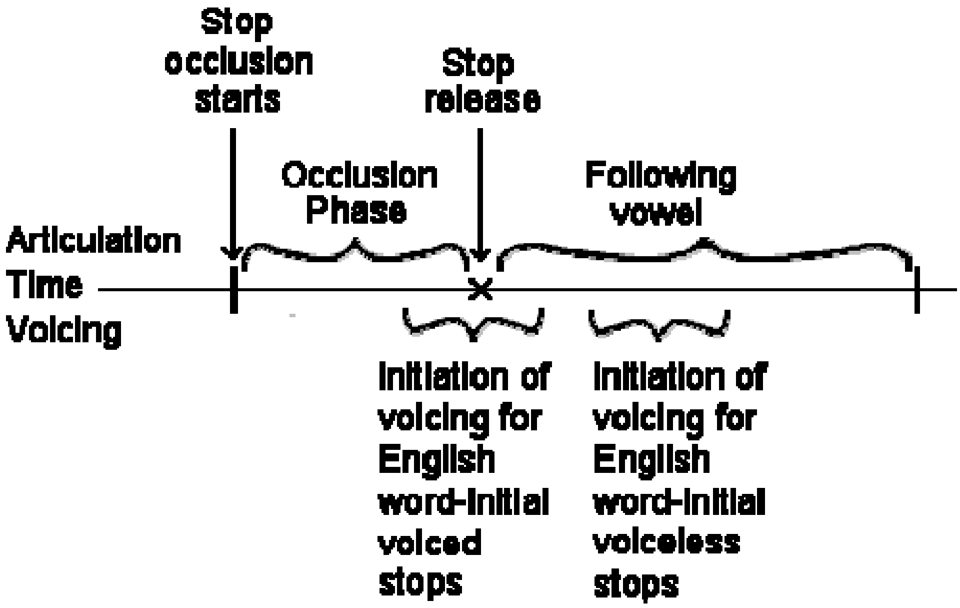

Figure 60: Schematic representation of the VOT production for voiced and voiceless stops (Adapted from Robert Mannel Speech Hearing and Language Research Centre Department of Linguistics 2000-2004, Macquarie University).

Nevertheless, it is also noteworthy to indicate that phonation shows language specifics that may be partly due to the fact that time intervals could vary from one language to another.[173] Several investigations have been carried out in order to study the voice onset time's reliability as a main acoustic parameter in production and perception of stops in many languages.[174] The results found in these investigations attest a significant correlation between the place of articulation of stop consonants and VOT. For instance, it was found that the frontal voiceless stops exhibited shorter lag.[175] However, one possible explanation of this is that these observations might be language conditioned rather than a kind of rule manipulated from the articulation gestures of plosives. Taehong and Ladefoged[176] emphasize the role of the voluntary initiation of gestures in a speaker's VOT in terms of realisation of timing for glottal pulsing.

In their study, they define VOT as "the difference in time between the initiation of the articulatory gesture and the initiation of the laryngeal gesture."[177] Furthermore, it plays a key

[173] Cf. Taehong, C., & Ladefoged, P. (1999), p. 222.
[174] Cf. Cho, T., & Ladefoged, P. (1997): Variations and Universals in VOT: Evidence from 17 Endangered Languages, pp. 12-38.
[175] Cf. Henton, C., Ladefoged, P., & Maddieson, I. (1992): Stops in the World's Languages, p. 79.
[176] Cf. Taehong, C., & Ladefoged, P. (1999), pp. 211-214.
[177] Cf. Cho, T., & Ladefoged, P. (1999), p. 226.

role in both speech production and perception, since it conveys information about the coordination between laryngeal and supralaryngeal mechanisms.[178] In general, as an acoustic cue, VOT serves as "an inferential estimate of speech motor control, requiring fine motor coordination of the respiratory, phonatory and articulatory structures."[179]

In normal speech production, it was noticed that there was no existence of overlapping voicing contrast in homorganic word-initial stops.[180] It must be noted that VOT is a distinguishable cue between homorganic stops. There is some evidence for other crucial cues like burst intensity, presence of turbulent noise and rate of spectrum change.[181] Thus, an issue of considerable interest is the relationship between these factors, giving the suggestion that the distinction and the identification of stop consonants is a function of several acoustic parameters based on complex articulatory gestures. In spite of this, there is some evidence to suggest that VOT values are determined to some extent by the place of articulation. Therefore, many acoustic rules have been established across language studies[182] such as:

1- The further back the closure is, the longer the VOT.
2- The increase in the degree of contact area leads to longer VOT values.
3- The increase in the movement of the articulator leads to shorter VOT.

Other acoustical rules[183] have been established for VOT within consonant categories, but with some exceptions because of the existence of language-specific variations such as:

1- Velar stops always have longer VOT.
2- VOT is shortened before bilabial stops.
3- VOT is intermediate before alveolar stops.

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[178] Cf. Whiteside, S., Dobbin1, R., & Henry, L. (2003): Patterns of Variability in Voice Onset Time: A Developmental Study of Motor Speech Skills in Humans, p. 29.
[179] Robb, M., Gilbert, H., & Lerman, J. (2005): Influence of Gender and Environmental Setting on Voice Onset Time, p. 125.
[180] Cf. Modarresi, G., Sussman, H., Lindblom, B., & Burlingame, E. (2005): Locus Equation Encoding of Stop Place: Revisiting the Voicing/VOT Issue, p. 102.
[181] Cf. Stevens, K., & Klatt, D. (1974): Role of Formant Transitions in the Voiced-Voiceless Distinction for Stops, p. 658.
[182] Cf. Henton, C., Ladefoged, P., & Maddieson, I. (1992), pp. 65-98.
[183] Cf. Lisker, L., & Abramson, A. (1964): A Cross-Language Study of Voicing in Initial Stops, pp. 385-420.

4.1.1.1. VOT in Arabic

Languages show variations in VOT patterns. In English, for example, a particular pattern was observed for VOT that differed from Arabic. In this sense, getting a cue for voicing in English for word-initial stops did not depend mainly on glottal pulsing. In fact, cue for voicing "can be obtained not from the presence or absence of glottal pulsing during the production of the stops, but from the timing differences between glottal and supraglottal events."[184]

On the other hand, Arabic exhibits a binary system in terms of glottal vibration during the closure period of the stop consonant.[185] Thus, differences between the distribution of VOT values in Arabic and English are predictable.[186] In this account, based on figure 61, a comparison of VOT distribution made by speakers in the two languages demonstrates that the VOT range for Arabic voiceless stops lay within the range of voiced stops in English, whereas the voiced Arabic stops and voiceless English stops occupy the end of the continuum.

English Stops

- [b d g] [p t k]

____________________________|____________________________+

Lead voicing 0 short lag long lag

Arabic Stops

[-b d g] [t k] +

_____________________________|_____________________________________

Lead voicing 0 short lag long lag

Figure 61: Schematic representation of the VOT continuum showing the relationship between the English and Arabic stops. (Adapted from Deuchar & Clark, 1995, p. 25 and from Khattab 2000, p. 96).

Regarding the stops inventory in Arabic, as it can be seen in table 52, two of them are emphatic, [dˤ] and [tˤ], three are voiced [b], [d] and [dˤ], while the other four are voiceless: [tˤ], [t], [q] and [k]. Furthermore, two pairs of them are contrasted in voicing [d, t] [dˤ, tˤ], whereas three have no voiced counterparts: [k], [g] and [b]. Importantly, in Arabic, the

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[184] Ladefoged, P., & Maddieson, I. (1996): The Sounds of the World's Languages, p. 50.
[185] Cf. Khattab, G. (2000): VOT Production in English and Arabic Bilingual and Monolingual Children, p. 95.
[186] Cf. ibid., p. 97.

differences between voiced and voiceless stop consonants contrast. The following minimal pairs exhibit this phonemic contrast:

[dam] 'blood' [dˤam] 'join'

[tam] 'complete' [tˤam] 'spread'

Consonant	Place of articulation	Voicing
[d]	alveolar	voiced
[t]	alveolar	voiceless
[b]	bilabial	voiced
[tˤ]	alveolar emphatic	voiceless
[dˤ]	alveolar emphatic	voiced
[q]	uvular	voiceless
[k]	velar	voiceless

Table 52: The stop consonants in Arabic.

4.1.1.2. Neurolinguistic VOT studies on aphasia

Neuropathological changes in patients, particularly those with strokes, would affect the ability to establish voicing discriminations.[187] In this account, numerous investigations have been conducted on the place of articulation of stops and voicing contrasts in aphasia. Blumstein et al.[188] indicate that Broca's aphasics performed better than all the other aphasic groups on voicing discrimination tasks, but they exhibited overlapping patterns between voiced and voiceless stops. In contrast, Wernicke's aphasia is distinguished by phonemic deficit. In fact, studies on aphasia have demonstrated a wide range of speech characteristics that specify this language disorder by indicating that Broca's aphasic patients exhibit phonetic errors, while Wernicke's aphasics reveal phoneme mistargeting.[189]

[187] Cf. Harel, B., Cannizzaro, S., Cohenc, H., Reillya, N., & Snyder, P. (2004): Acoustic Characteristics of Parkinsonian Speech: A Potential Biomarker of Early Disease Progression and Treatment, p. 441.

[188] Cf. Blumstein, S., Cooper, W., Goodglass, H., Hstatlender, S., & Gottlieb, J. (1980): Production Deficits in Aphasia: A Voice-Onset Time Analysis, p. 162.

[189] Cf. Gandour, J., & Dardarananda, R. (1984a): Voice Onset Time in Aphasia: Thai II. Production, p. 179.

Furthermore, in accordance with the patterns found across Broca's aphasics, studies conducted on apraxic[190] patients demonstrated overlapping patterns between the voiced and voiceless stops and their VOT values were longer than for normal speakers. Similar results were made by Gandour and Dardarananda,[191] who found that the apraxic subjects in the production of stop sounds made voiced and voiceless overlapping and their voicing lag was longer than the normal speakers. In particular, a number of investigations have demonstrated that anterior aphasics show impaired VOT productions and overlapping between the stop sounds. For example, Gandour and Dardaranada drew the conclusion that the deficit lies in coordinating between the "abductory and adductory forces at the larynx with upper articulatory events."[192] We would predict, on this basis, that those patients would display timing deficits. In contrast to the previous findings, Shewan et al.[193] indicate that Broca's subjects produce short VOT lead and lag.

In the light of the previous results, the purpose of this section is to address this issue in Arabic in order to get a picture of the Palestinian aphasic patterns in terms of exhibiting the similarities and differences that might appear compared to normal speakers and non-Arabic aphasics. In general, we would predict that the VOT values would show significant differences between the aphasics and the normal speakers and that VOT duration is a crucial cue in voiced/voiceless distinction. Thus, the following questions will be addressed:

1- Do Arabic aphasics exhibit similar VOT patterns to those found among normal speakers?
2- If they do not, what are their VOT patterns that they produced?
3- What are the durational patterns of their VOT values?

[190] Cf. Itoh, M., Sasanuma, S., Tatsumi, I., Murakami, S., Fukusako, Y., & Suzuki, T. (1982): Voice Onset Time Characteristics in Apraxia of Speech, p. 207.
[191] Cf. Gandour, J., & Dardarananda, R. (1984a), pp. 191-193.
[192] Ibid., p. 202.
[193] Cf. Shewan, C., Leeper, H., & Booth, J. (1984): An Analysis of Voice Onset Time (VOT) in Aphasic and Normal Subjects, pp. 200-215.

4.1.2. Results

4.1.2.1. The patterns of the normal speakers

Significantly, as shown in figures 62, 63 and 64, the normal speakers exhibited no overlapping between all the places of articulations of the stop consonants. This fact is further evidence that these speakers show full voicing lead for the voiced stops and voicing lag for the voiceless stops. In addition to these results, table 53 exhibits that the patterns of the normal speakers are in accordance with the acoustic universal rules. In this sense, for example, the high VOT value of the voiceless stop [k] refers to the fact that as the place of articulation of the stops moves back in the oral cavity the VOT increases. Similarly, the same behaviour has been observed for the voiced stop [g]. Thus, the results also indicate that normal Arabic speakers comply with the universal rules by exhibiting that, for instance, velar stops always have longer VOT and VOT is shortened before bilabial stops. Furthermore, intermediate values have been noticed for the alveolar stops. The mean VOT for the voiceless stops is higher than that for voiced stops.

Subjects	[t]	[k]	[b]	[d]	[g]
Normal speakers	20	28	9	10	20

Table 53: VOT average duration (msec) for the normal speakers.

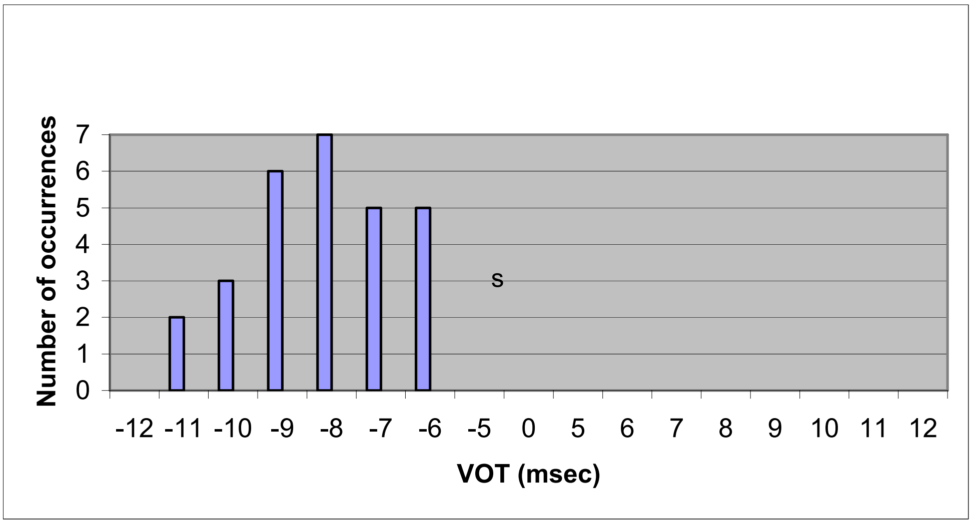

Figure 62: Distribution of VOT productions for the bilabial stop [b] in word initial position for three normal speakers.

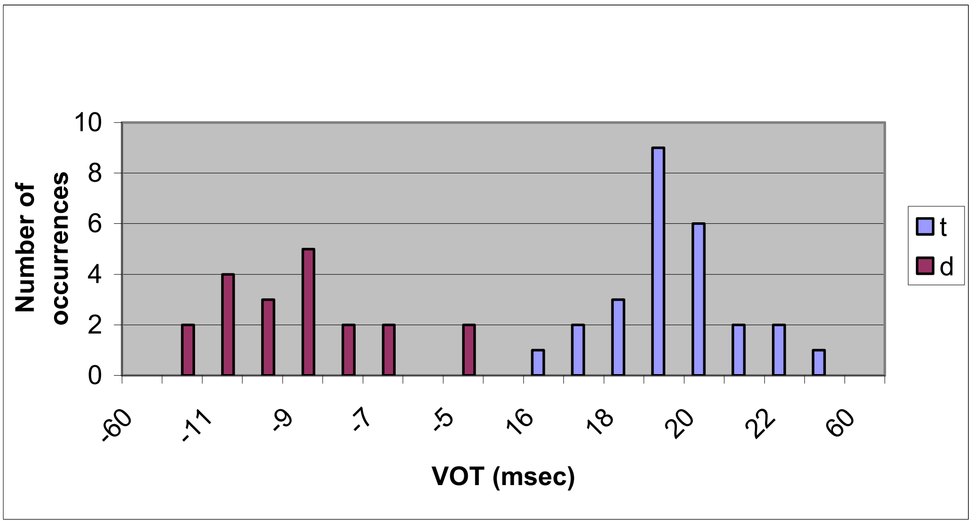

Figure 63: Distribution of VOT productions for the alveolar stops [t] and [d] in word initial position for three normal speakers.

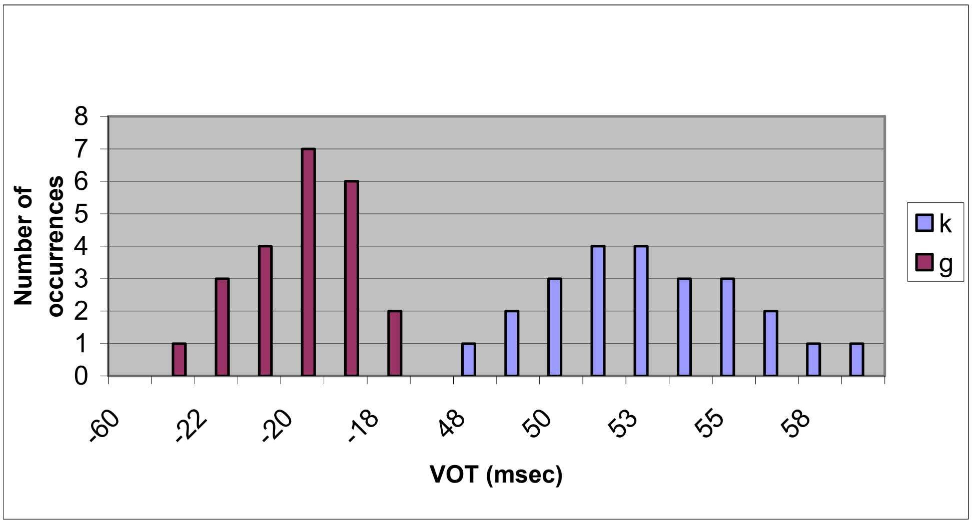

Figure 64: Distribution of VOT productions for the velar stops [g] and [k] in word initial position for three normal speakers.

In the present acoustic analysis, it was noted that the VOT values of the normal speakers exhibited no overlapping at any place of articulation of the stops. In addition, the VOT values for [b, d, g] lay in the voicing lead region, whereas the voiceless stops [t, k] occupied the voicing lag. It was clear that VOT increased as the place of articulation moved back in the oral cavity for the voiceless stops. It would seem reasonable to assume that voice onset time is a specific feature of the plosive consonants. In spite of this, VOT is considered to be only one of the primary cues for the correct identification of voiceless stops.

4.1.2.2. The patterns of the aphasic subjects

Contrary to the results of the normal speakers, as figure 65 exhibits, some productions of the stop [b] by the three aphasics are in the voicing lag region. The three aphasic subjects produced longer mean VOT value for the stop sound [b] (25msec) than the normal speakers (9msec).

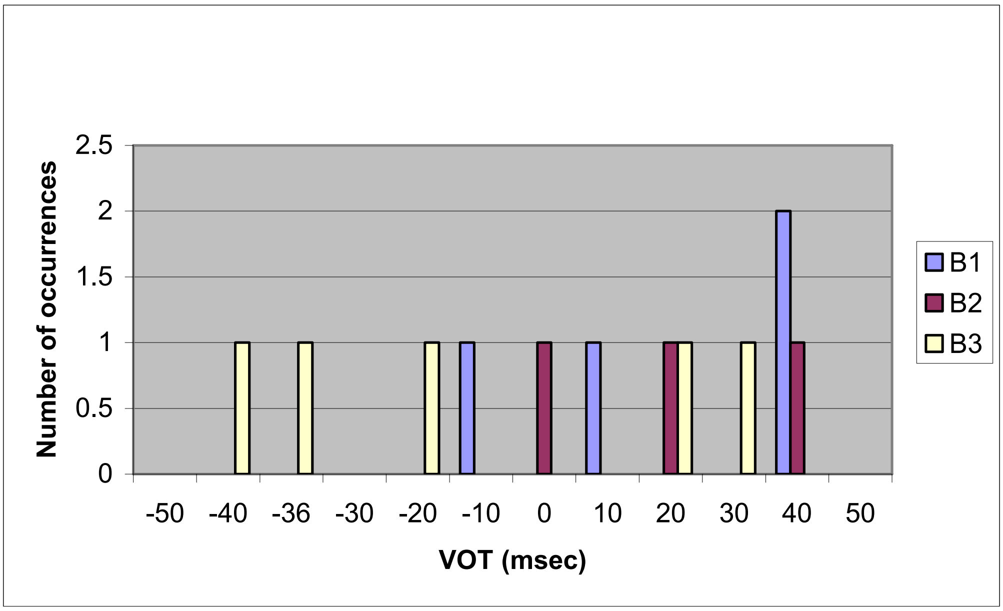

Figure 65: Distribution of VOT productions for the bilabial stop [b] in word initial position for three Broca's aphasic subjects.

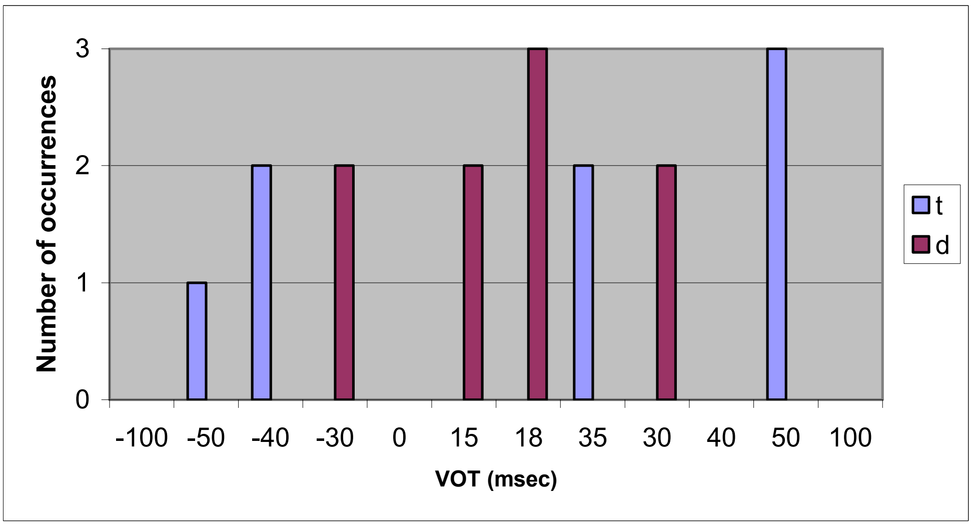

Figure 66: Distribution of VOT productions for the alveolar stops [t] and [d] in word initial position for each of the Broca's aphasic subjects (B1).

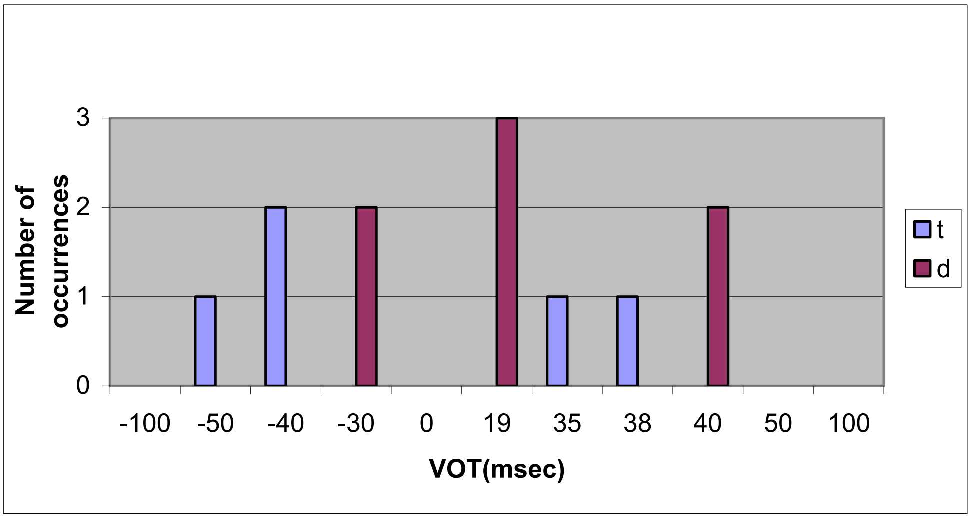

Figure 67: Distribution of VOT productions for the alveolar stops [t] and [d] in word initial position for each of the Broca's aphasic subjects (B2).

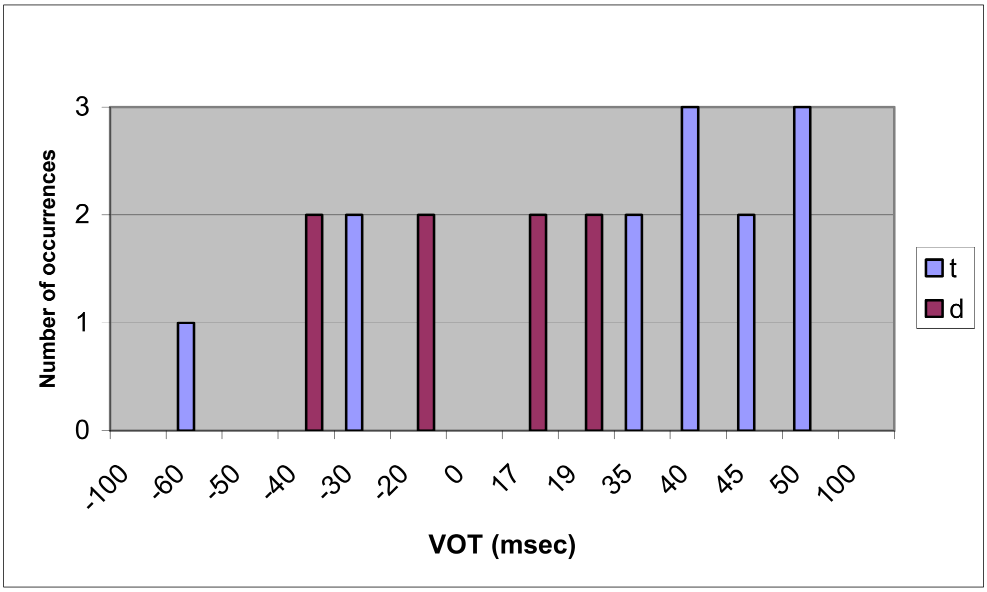

Figure 68: Distribution of VOT productions for the alveolar stops [t] and [d] in word initial position for each of the Broca's aphasic subjects (B3).

The figures 66 and 68 display two consonants that differ only in voicing feature [t, d]. The former is mostly aspirated and it is dialect-conditioned, while the latter is not aspirated. Therefore, we will first explain the patterns of each consonant separately and then will hold an inter-comparison. Looking at these figures, we can see that Broca's aphasics displayed overlap between [t] and [d]. For example, for the aphasic B3, the VOT values for [t] and [d] overlapped with each other. Therefore, some of his productions of [t] were in the voicing lead and those of [d] in the voicing lag. In addition, the same patterns of overlapping can be seen respectively in B2. As a result, the productions of [d] lie in the voicing lag, while the productions of [t] overlap by occupying mostly the voicing lead. Typically, it would appear that a high incidence of overlapping characterizes speech production of Broca's aphasics. In this regard, B1 exhibits a pattern that is found to be overlapped for [d], which is produced within the voicing lag region, whereas [t] is within the normal lag region. Significantly, they revealed longer mean VOT values than those of the normal speakers. In addition to overlapping, they not only exaggerated with aspiration of the voiceless stop [t], but also produced it with higher VOT value.

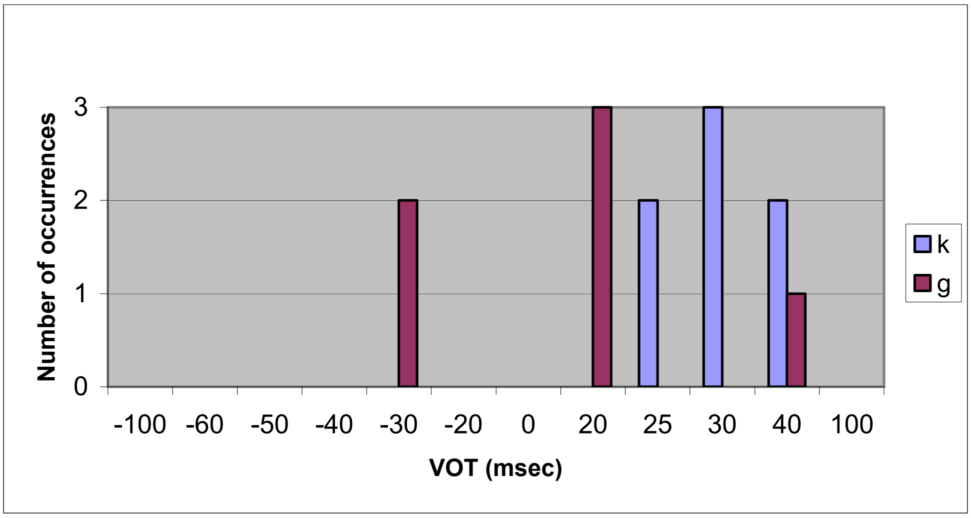

Figure 69: Distribution of VOT productions for the velar stops [k] and [g] in word initial position for each of the Broca's aphasic subjects (B1).

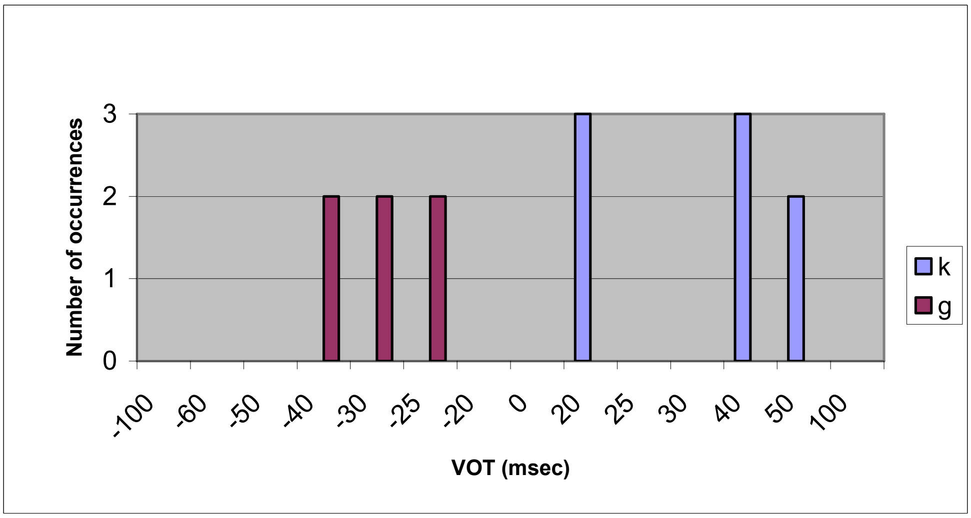

Figure 70: Distribution of VOT productions for the velar stops [k] and [g] in word initial position for each of the Broca's aphasic subjects (B2).

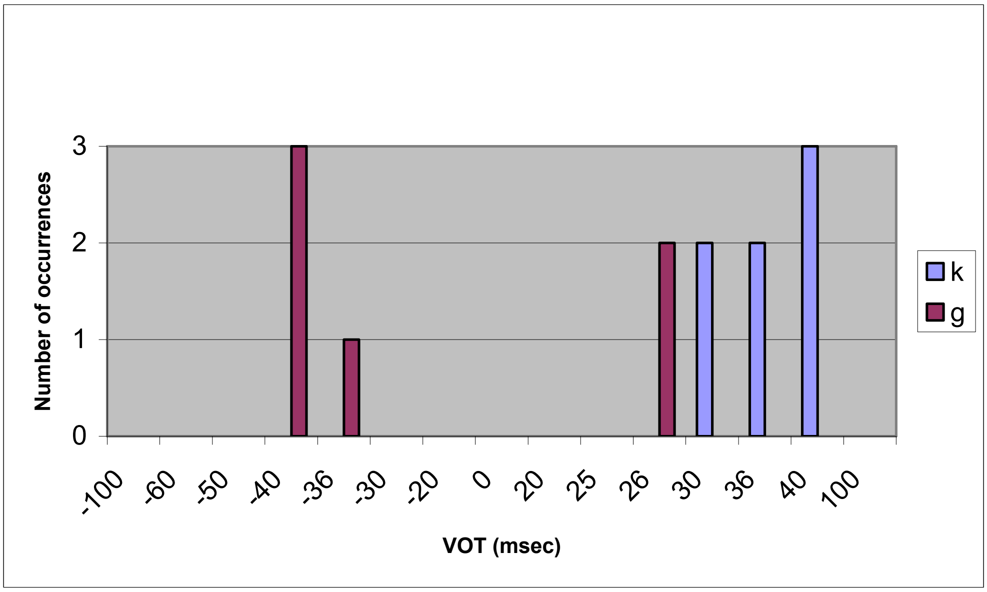

Figure 71: Distribution of VOT productions for the velar stops [k] and [g] in word initial position for each of the Broca's aphasic subjects (B3).

In the velar stops, as figures 69 and 71 illustrate, it can be noticed that the VOT values of B1 and B3 of [g] and [k] overlap within the voicing lag and the voicing lead regions. Notably, a striking result comes from the aphasic patient (B2), who exhibited no overlapping between the velar stops, whereas he shows overlapping in the alveolar and labial stops, as figure 70 shows. Furthermore, for the aspirated voiceless stop [k], it is also apparent that the aphasics produced a longer voicing lag than the normal speakers did. In general, the findings display longer VOT value (35msec) for Broca's aphasics than for the normal speakers (28msec). Significantly, our aphasic patients reversed the pattern found in other studies[194] where the VOT of Broca's aphasics for voiceless aspirated stops is shorter than for the normal speakers by producing long VOT for these consonants in the current study.

4.1.3. Comparison between the normal speakers and the aphasic subjects based on the place of articulation

With regard to the present findings, the normal subjects were able to show full normal VOT distributions for voiced and voiceless stops indicating a control of time programming and planning for production of the targeted phonemes. In contrast, Broca's aphasics revealed impaired VOT productions in terms of overlapping between the places of articulation of the consonants under study. This would suggest that the deficit of Broca's aphasia is phonetic rather than phonological reflecting patterns of timing difficulties as well. In other words, they

[194] Cf. Blumstein, S., Cooper, W., Goodglass, H., Hstatlender, S., & Gottlieb, J. (1980), pp. 166-167.

were unable to maintain a timing control between the laryngeal and supralaryngeal articulatory sequences. In general, similar findings to the current study come from different investigations[195] that indicate that Broca's aphasics are distinguished by overlapping between voiced and voiceless stops.[196] Nevertheless, opposite results were reported from other languages and investigations. For instance, Itoth et al.[197] indicate that the aphasic and apraxic subjects produce shorter voicing lead for the fully voiced stops, while our aphasics exhibit longer voicing lead. Furthermore, Blumstein et al.[198] indicate that the performance of the aphasics on the voiceless aspirated English stops shows no definite trends by producing sometimes shorter voicing lag, while others produced longer voicing lag. In contrast, our aphasics produced longer voicing lag for [t] and [k] compared to the normal speakers. Moreover, this is inconsistent with the results obtained from Gandour and Dardarananda, who indicate that: "there is definite tendency for voiced and voiceless stops to be produced with a shorter voicing lead and voicing lag, respectively, when compared to normal VOT productions."[199] Despite the overlapping patterns and deviant VOT values by exhibiting mean longer VOT for the velar stops [g, k], our aphasics were able to maintain the generalized rule found across languages that the further back the closure, the longer the VOT.[200]

To sum up, our Broca's aphasic subjects exhibited remarkable deficits in their VOT productions compared to the normal speakers. Their VOTs are in general higher than those of the normal speakers. Furthermore, overlapping between the voicing lags and voicing leads was notable. Some of the results of this study have replicated or confirmed previous studies. However, in spite of some consistency with other studies, the Palestinian aphasics displayed particular patterns that are not found in other languages.

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[195] Cf. Shewan, C., Leeper, H., & Booth, J. (1984), pp. 199-217.
[196] Cf. Baum, S., Blumstein, S., Naeser, M., & Palumbo, C. (1990), p. 41.
[197] Cf. Itoh, M., Sasanuma, S., Tatsumi, I., Murakami, S., Fukusako, Y., & Suzuki, T. (1982), p. 207.
[198] Cf. Blumstein, S., Cooper, W., Zurif, E., & Caramazza, A. (1977): The Perception and Production of Voice-Onset Time in Aphasia, pp. 373-380.
[199] Gandour, J., & Dardarananda, R. (1984a), p. 201.
[200] Cf. Henton, C., Ladefoged, P., & Maddieson, I. (1992), pp. 65-98.

4.1.4. The nature of errors as exhibited by the aphasic subjects

A problem of considerable interest is whether the aphasic errors are phonetic or phonological in nature. In particular, it has been suggested that Broca's aphasic patients are characterized by phonetic errors that are realized in terms of articulatory deficits, while Wernicke's aphasics exhibit phonological errors. According to the author's knowledge, there are no published studies that have been conducted on the VOT of the Arabic aphasics and the type of their errors. Therefore, this subsection aims to investigate this issue to highlight their patterns by adopting Blumstein's methods as will be discussed later in method and stimuli. Blumstein et al.[201] conducted a pioneer acoustic study on English aphasic subjects by implementing VOT measurements in order to distinguish between phonetic and phonological errors.

4.1.4.1. Stimuli and procedure

For the purpose of this part of the study, we adopt Blumstein's definition for phonetic and phonological errors. In this case, phonetic errors are VOT values that are not produced by normal subjects in which their productions fall between VOT categories, whereas phonemic errors are regarded as substitutions with VOT values falling acoustically within the opposite voicing category for normal subjects. The same three Broca's aphasics took part in this part of the study. As this study was conducted on spontaneous aphasic speech, the same words which were used in the previous VOT analysis were selected here.

4.1.4.2. Results and discussion

Based on the VOT values of our Broca's aphasics, their productions were classified in three categories: correct productions, phonemic errors and phonetic errors. Because there is no comprehensive study on ranges of VOT values in Palestinian Arabic, we will adopt the range of VOT values of the normal speakers obtained from our study. The following table reveals the VOT ranges for the voiced and voiceless stops. Note, however, the consonant [b] was excluded because it has no voiceless counterpart in Arabic.

[201] Cf. Blumstein, S., Cooper, W., Goodglass, H., S., & Gottlieb, J. (1980): Production Deficits in Aphasia: A Voice-Onset Time Analysis, pp. 159-168.

Place of articulation	Voiced-voiceless range
Alveolar	10-20
Velar	20-28

Table 54: Range of VOT values (msec) displaying voicing phonetic categories.

As the table indicates, the range of the alveolar stops is between 10-20msec representing the shortest values in contrast to the velar consonants whose range is between 20-28 msec. At the individual level, the analysis of the data indicates individual differences between the subjects in their types of errors. For example, B1 exhibited no error in producing [t], whereas 60% of his errors in [d] were phonetic in nature and 40% were phonemic errors. In contrast, B2 demonstrated errors in both [t] and [d]. With regard to his nature of errors, 100% of the errors for [t] were phonemic and for [d] his errors were 50% phonetic and 50% phonemic. Furthermore, for B3, the errors in [t] were phonemic 100% of the time as the same as in B2, whereas for [d] 69% of the errors were phonetic and 31% phonemic.

In general, the results indicate that the errors of Broca's aphasics were divided equally between phonemic and phonetic. Surprisingly, it was noticed that the aphasic subjects exhibited neither phonetic errors nor phonemic in producing [k], but they displayed long voicing lag compared to normal subjects. Clearly, the results exhibit different trends based on the place of articulation. It is of further interest to point out that the performance of the aphasic subjects on alveolar stops revealed no preference for phonetic or phonemic errors because they were equally divided for both kinds of deficit at 50% each. This result contradicted what has been reported from Thai aphasics whose errors for alveolar stops were phonetic rather than phonemic.[202] As a group, the aphasics exhibited a consistent pattern of phonemic errors for [t], whereas errors for [d] were phonetic rather than phonemic. However, they demonstrated phonetic errors in producing velars. Once again, this finding is inconsistent with other investigations.[203] Apart from the differences found between the places of articulation, we find by calculating the percentage of the phonemic and phonetic errors from the total number of errors that our Broca's aphasics produced phonetic errors more than phonemic ones 63% of the time. Taken in its whole, these results agree with those reported from other languages. For instance, the results are in support of previous findings made by

[202] Cf. Gandour, J., & Dardarananda, R. (1984a), pp. 184-189.
[203] Cf. ibid., pp. 181-200.

Blumstein et al.,[204] who indicated that Broca's aphasic patients are distinguished by producing the greatest number of errors that are phonetic in nature. However, there were individual variations as some subjects tend to produce phonemic errors and others exhibit predominantly phonetic errors.

Taken together, in the present study, it was noted that Broca's aphasics were unable to maintain the category distinction between voiced and voiceless stops manifested in overlapping between the stop categories. Furthermore, it is obvious from the previous analysis that Broca's aphasics exhibited a mixture of phonetic and phonemic errors with a predominance of phonetic errors. Therefore, one would argue that the origin of the error seems likely to be obscure. In the light of these mixed errors many questions emerge:

1- Is the classical hypothesis that deficits of Broca's aphasics could be due to timing problems convincing in light of the existence of phonemic errors?
2- Is it possible to explain the phonemic errors of Broca's aphasics in terms of motor sequencing hypothesis by considering these as a result of an impaired neuromotor program?
3- Can we say that Broca's aphasics exhibit both phoneme selection and motor programming deficits in trying to explain their phonetic and phonemic errors?
4- Can we consider the substitution errors (phonemic errors) as a kind of distortion errors?

In order to answer the questions, we will adopt Levelt's model of speech production. The following part sheds light on this model by giving interpretations of the aphasic disorders.

4.1.5. Stages of language processing: Levelt's model of speech production

Speech production, in general, is one of the most complex skills that require interaction between many different components at different levels such as the cognitive, motoric and sensory. In fact, many models have been proposed in order to account for the speech production mechanism. Those models are based on different concepts like neural, motoric and vocal tract approaches. Levelt's investigations are considered as basic ground for research on disfluencies in spontaneous speech. His model emphasizes the concept of hierarchy in

[204] Cf. Blumstein, S., Cooper, W., Goodglass, H., S., & Gottlieb, J. (1980), p. 153.

spontaneous speech production. Thus, it would seem reasonable to point out that speech control emerges when all the components are precisely carried out. However, speech fluency disorders appear when any deficit happens in any level in this hierarchical system. In this account, Level's model consists of many stages as the figure below exhibits. As a whole, as we can see in figure 72 many processes and subprocesses are involved in speech production. The following discussion presents an introduction for its components and its relation to the deficits among aphasics.

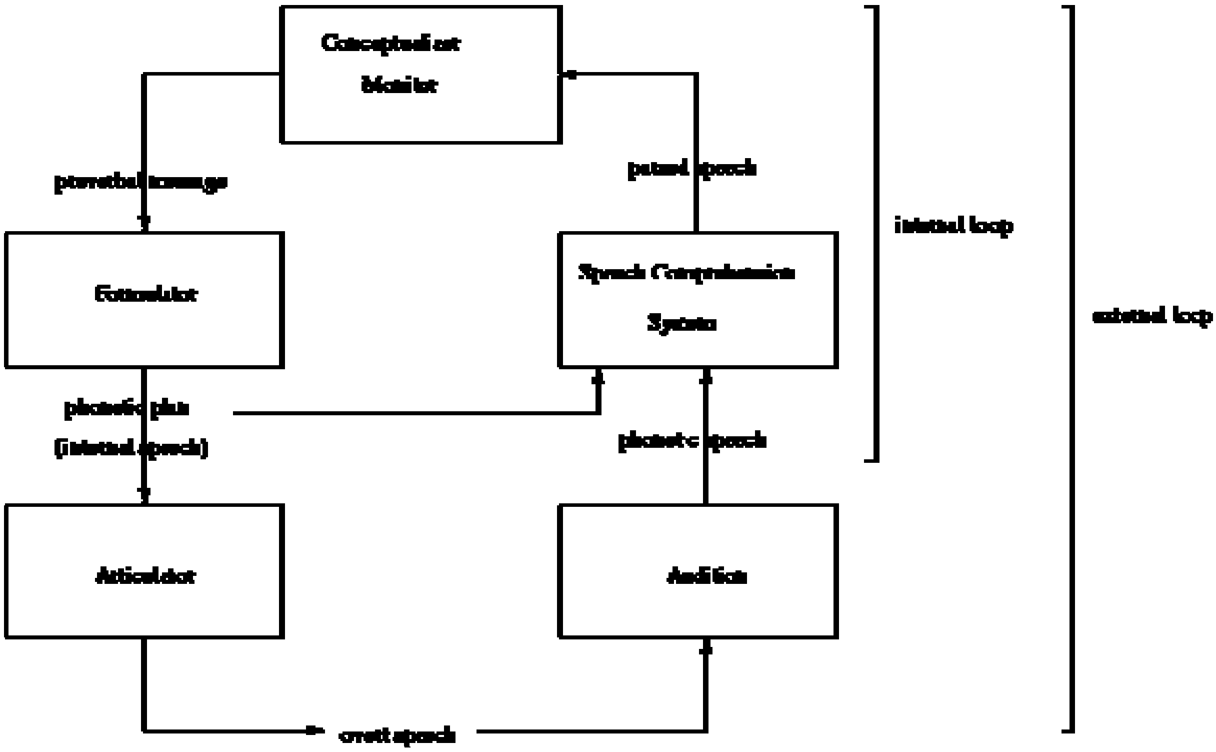

Figure 72: Schematic presentation of speech production adapted from Levelt's model.

- The conceptualization stage

This phase involves the activation of the lexical concept that represents the meaning of the word. Importantly, constant attention is considered to be the core of this stage for gathering information that could be implemented later in the process of expression. This concept is influenced by pragmatics, context-dependent considerations and the activation of the visual analysis of the presented stimulus. In general, the semantic-complexity effect would lead to a difficulty in accessing words with more complex features than simpler ones. Thus, the message can be deposited in the so called working memory.[205] All information currently accessible to the speaker is found in the working memory like all the information "that can be processed by message-generating procedures or by monitoring procedures."[206]

To summarize, according to Levelt, two parts in the planning of a preverbal message at this stage can be distinguished: macroplanning and microplanning.[207] Regarding the performance of Broca's aphasics in this stage, based on the results of the current study, it is clear that in the macroplanning stage they were able to access the retrieval phase to order the message to be carried out. The same capability was found during the microplanning stage in which the aphasics succeeded in carrying out the expected form of this information.

- Lexical selection

Having activated the chosen concept, the following step begins in which lemma is ordered from the mental lexicon involving the syntactic characteristics of a word. By such activation of a lemma, it is possible to carry out additional grammatical encodings in order to put the words in their appropriate syntactic form. Consequently, an appropriate sentence is produced consisting of its all correct syntactical elements concerning tense, mood, gender and word category.

- Morphophonological encoding

The phonological-articulatory stage is activated after the lemma-selection process and the conceptual phase are selected. Interestingly, in this stage a specific type of breakdown of the speakers is realized in terms of difficulties of selecting a particular word form. Therefore, this would suggest that during such a stage the syntactic features of a word are accessed. In this stage of the theory, as Levelt indicated, the activation of the word form includes accessing the morphological make-up in which the morphological properties of the structure of the word involving its root and suffixes are activated. Furthermore, the metrical and segmental make-up is being carried out at this level as the theory indicates. Here, the number of syllables that the word should have and the place of the stress pattern are determined and defined. However, according to this theory, at this level no presence of syllables is available. As a result, the formation process of syllables takes place at a later stage that requires a previous

[205] Cf. Baddeley, A. (1986): Working Memory, pp. 33-75.
[206] Levelt, W. (1989): Speaking: From Intention to Articulation, p. 10.
[207] Cf. ibid., p. 11.

representation of phonological environment. It is noted that the existence of phonemes is based on the activation of labelled links in order to determine their correct ordering. The output of this stage is called a phonological word. With the exception of Broca's aphasics, impairments like substitutions, omissions, additions and syllable deletions might emerge at this level.

- Phonetic encoding

In fact, phonetic encoding involves the execution of the articulatory gestures at different levels including the oral, nasal, pharyngeal and lip cavity. At this level, the program of articulation is being executed by determining "how the planned utterance should be articulated."[208] According to this model, there are two kinds of phonetic encoding: the direct and the indirect ones. Direct phonetic encoding includes direct access to a hypothetical mental store or 'phonetic' 'mental syllabary,'[209] whereas the indirect route involves on-line sub-syllabic encoding. In addition, the direct phonetic encoding has abstract 'gestural scores.' After this abstract phase, information is passed on to an articulatory network that is responsible for coordinating the motor system that includes feedback mechanism.

- Articulation

Articulation is a stage in which the phonetic plan is achieved during the carrying out of articulatory movements and the sub- and supralaryngeal system. According to Levelt, in order to articulate, it is necessary that "the phonetic plan can be temporarily stored."[210] At this level, motor coordination between the muscles should be available in order to execute well timed and precise gestures. The product of this phase is "overt speech."[211]

- Self-monitoring

The internal speech or the phonetic plan is the ability of the speaker to monitor his productions and the ability to detect the errors that might occur. This means that the speaker controls both his phonetic plan "internal speech" and his overt speech. According to Levelt, the performance of these skills requires an auditory processing component. The activation of

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[208] Levelt, W. (1989), p. 12.
[209] Cf. ibid., pp. 13-18
[210] Ibid., p. 12.
[211] Ibid., p. 13.

this stage is where the person understands, interprets and judges what happened by the so-called “speech-comprehension system.”[212]

4.1.6. Aphasic symptoms within stages of speech production

- Conceptual impairments

As mentioned in the previous discussion, the activation of a lexical concept is considered the first step of producing speech. In this regard, there is a kind of understanding across the scholars that aphasia could be described as a conceptual impairment. Support for the cognitive impairments also come from Kohn and Smith,[213] who reported that aphasics display a kind of deficiency in the analytical isolation and hold impaired relations between concepts. However, it should be very careful in dealing with such an assumption because some deficiencies in performance are related in one way or another to some vague concepts. Taking paraphasias as an example, we can see that the productions of the aphasics are closely related to concepts during spontaneous speech. This appeared in some productions like instead of saying <spoon>, they said <fork>.

In general, the aphasics exhibit lexical semantic processing impairments in semantic judgment or picture naming tasks. However, some investigations have emphasized that there might be a relation between processing one word and the preceding word sharing similarities in the semantic categories. An obvious example for this type of processing is that when one wants to name the word <fork>, this is accomplished faster and easier when it is preceded by <spoon>, whereas this could be slower if it is preceded by the word <dog>, which is unrelated to the same semantic category. This could be presumably due to the fact that the presentation of the prime word <fork> activates not only the lexical entry for <fork>, but also its lexical semantic network. This indicates the importance of the categorization stage in the production process.

This finding would draw the conclusion that aphasics would be capable of storing intact lexical concepts while having a deficit in accessing these representations and performing imprecise cognitive judgments like analytical isolation.

[212] Levelt, W. (1989), p. 13.
[213] Cf. Kohn, S., & Smith, K. (1994): Distinctions between Two Phonological Output Deficits, pp. 77-84.

This would emphasize that Broca's aphasics display lexical processing deficits distinguished by a general reduction in lexical activation.[214]

- Phonological impairments

Research has shown that the aphasic's speech is characterized by a number of different types of phonological errors such as phoneme substitution, simplification, addition and insertion. Furthermore, these errors differ from one syndrome to another. In other words, the errors are related to phonemic deficits in Wernicke's aphasia and phonetic in Broca's aphasia. However, it is then apparent that the questionable issue is the interpretation of paraphasias. In their study, Gagnon et al.[215] indicated that the aphasic's behaviour is attributed to lexical substitutions at a level of the retrieval system that is found to be responsible for word frequency and grammatical class.

- Phonetic impairments

With regard to the nature of deficits among Broca's and Wernicke's aphasics, there is agreement among studies that errors arise on this level are found to be phonetic among Broca's aphasics, while Wernicke's aphasics exhibited phonemic ones. However, it is worthy to note that manner of articulation of the consonants is perceived better than the place of articulation by normal speakers.[216] The results further indicate that the productions of Broca's aphasics particularly exhibit timing difficulties which clearly appeared from the VOT measurements reflecting programming and planning impairments. Support for this result came from Blumstein, who pointed out that: "phonological planning is relatively intact and it is the ultimate timing or coordination of the articulatory movements that is impaired."[217] Furthermore, it has been argued that phonetic errors are in fact distortions as a result of deficits that arise at the level of gesture programming.

[214] Cf. Misiurski, C., Blumstein, S., Rissman, J., & Berman, D. (2005): The Role of Lexical Competition and Acoustic-Phonetic Structure in Lexical Processing: Evidence from Normal Subjects and Aphasic Patients, p. 64.

[215] Cf. Gagnon, D., Schwartz, M., Martin, N., Dell, G. and Saffran, E. (1997): The Origins of Formal Paraphasias in Aphasics' Picture Naming, p. 470.

[216] Cf. Warner, N., Smits, R., McQueen, J., & Cutler, A. (2005): Phonological and Statistical Effects on Timing of Speech Perception: Insights from a Database of Dutch Diphone Perception, p. 68.

[217] Blumstein, S. (1995): The Neurobiology of the Sound Structure of Language, p. 922.

Nevertheless, one would interpret such errors as allophones of neighbouring phonemes and not of the target phoneme. Monoi et al.[218] distinguished three origins of substitution errors among the non-fluent aphasics:

1- Errors that take place at the level of programming exhibiting errors that are realized as phonetic distortions substituting only one phonetic feature.
2- Errors that arise at the phoneme level producing real substitutions that are perceived acoustically and perceptually as substitutions.
3- Multiple-feature errors in both the programming and phonological level.

In conclusion to this section, it can be said that the results of the current analysis, in general, are consistent with those reported from Blumstein et al. [219] and Itoh et al.[220] in which Broca's aphasics exhibited impaired temporal coordination of laryngeal and supralaryngeal movements and phonetic errors are predominant.

Taken as a whole, the results of the acoustic data display that Broca's aphasics were unable to implement the voicing distinction. In other words, it is apparent that they were unable to coordinate the articulatory gestures required to carry out the different acoustic parameters involving voicing in stop consonants. However, it is of considerable importance to point out that Broca's aphasic impairments do not seem to reflect a general global weakness of the articulator's musculature. Rather, articulatory disabilities appear to be best characterized as affecting two independent articulators in terms of coordinating vocal fold vibration with the tongue tip release of stop consonants. Consequently, there is a notable overlap between the voiced and voiceless stops. Thus, Broca's aphasic patients demonstrated a disability in maintaining the normal voicing distinction for Arabic stop consonants by overlapping between the production of voiced and voiceless stop consonants. In addition, they revealed different patterns of distribution of their VOTs with the tendency to make greater pre-voicing for voiced stops.

[218] Cf. Monoi, H., Fukusako, Y., Itoth, M., & Sasanuma, S. (1983): Speech Sounds Errors in Conduction and Broca's Aphasia, p. 190.
[219] Cf. Blumstein, S., Cooper, W., Goodglass, H., Hstatlender, S., & Gottlieb, J. (1980), pp. 167-169.
[220] Cf. Itoh, M., Sasanuma, S., Tatsumi, I., Murakami, S., Fukusako, Y., & Suzuki, T. (1982), pp. 204-208.

4.2. Fricative sounds

The Arabic fricative sounds are distributed over the whole vocal tract with the tendency to occupy relatively back positions including the uvular, pharyngeal and glottal areas. In fact, Arabic has thirteen fricative sounds including: [θ], [ħ] [χ], [ð] [z], [s], [ʃ], [sˤ], [ðˤ] [ʕ], [ɣ] [f] and [h]. It will be recalled that consonants are produced with an obstruction achieved somewhere along the vocal tract while expelling the airstream from the lungs. In the case of fricatives, in general, an incomplete obstruction and a narrowed passage is achieved allowing for the air to go out in a continuous way accompanied by a friction between the airstream and the speech organs.[221]

In fact, errors in sound realization and production of words are common to all classical aphasic types. In this sense, a huge body of research has focused on the phonetic and phonemic errors that are displayed by the aphasics. Several investigations have reported that Broca's aphasics exhibit impairments in producing the fricative sounds, affecting the parameters of the sound including the place and the manner of articulation in addition to voicing feature.[222] This simultaneously affects the acoustic features of those sounds. In this regard, numerous investigations have addressed the nature of the errors in the speech production of the aphasic patients whether they arise at the phonetic or the phonological level. As a result, there are suggestions that have related these deficits to be either impairments in selecting and planning of speech production or deficits in the articulatory implementation of the speech segments.

Review of the literature indicates that Broca's aphasics display deficits in the production of voicing in fricative consonants, particularly by exhibiting devoicing impairments.[223] Those investigations have emphasized the fact that Broca's aphasics show deficits in coordinating vocal cord vibration and supralaryngeal articulatory gestures. As noted earlier in the VOT analysis, Broca's aphasics also reveal impaired productions by exhibiting overlapping between voiceless and voiced stops. It must be noted that Broca's aphasics exhibit remarkable

[221] Cf. Lieberman, P., & Blumstein, S. (1990), p. 192.
[222] Cf. Baum, S. (1996): Fricative Production in Aphasia: Effects of Speaking Rate, p. 339.
[223] Cf. Harmes, S., Danilo, R., Homan, P., Lewis, J., Kramer, M., & Absher, R. (1984): Temporal and Articulatory Control of Fricative Articulation by Speakers with Broca's Aphasia, p. 384.

deficits in producing the fricative sounds, although there was some evidence that they demonstrated normal fricative durations.[224]

The purpose of this section of the current study is to study fricative sounds and try to address whether the Palestinian aphasics exhibit patterns that are consistent with other results found in other languages or whether they display particular patterns that could be language-conditioned. Thus, this section will address the following questions:

1- Are these patients able to implement voicing in fricative consonants by exhibiting patterns of glottal vibration similarly to the normal subjects?
2- Do these patients display variations in the duration of fricative noise indicating the ability to control the time of the glottal vibration and achieving normal durations of fricative noise as the normal subjects do?
3- If they do not exhibit normal patterns, what are the abnormal patterns that they demonstrate?

4.2.1. The acoustic features of the fricative [s] as produced by the normal speakers and the aphasic subjects

4.2.1.1. The acoustic features of the fricative [s] as produced by the normal speakers

It is known that sibilant fricatives are relatively robust in terms of their temporal and spectral features. The acoustic patterns of the normal speakers indicate that the fricative [s] is distinguished by the concentration of its greatest noise between approximately 4700Hz and 8000Hz, as shown in figure 73. Therefore, it is normally marked by a higher frequency range. With respect to the segment duration, it was 113 msec in initial position. Furthermore, the average intensity was 67.5dB. Additionally, the acoustical information about the energy distribution exhibited 27.29dB concentrated in the frequency range between 5000-6000Hz, as figure 74 illustrates.

[224] Cf. Harmes, S., Danilo, R., Homan, P., Lewis, J., Kramer, M., & Absher, R. (1984), p. 381.

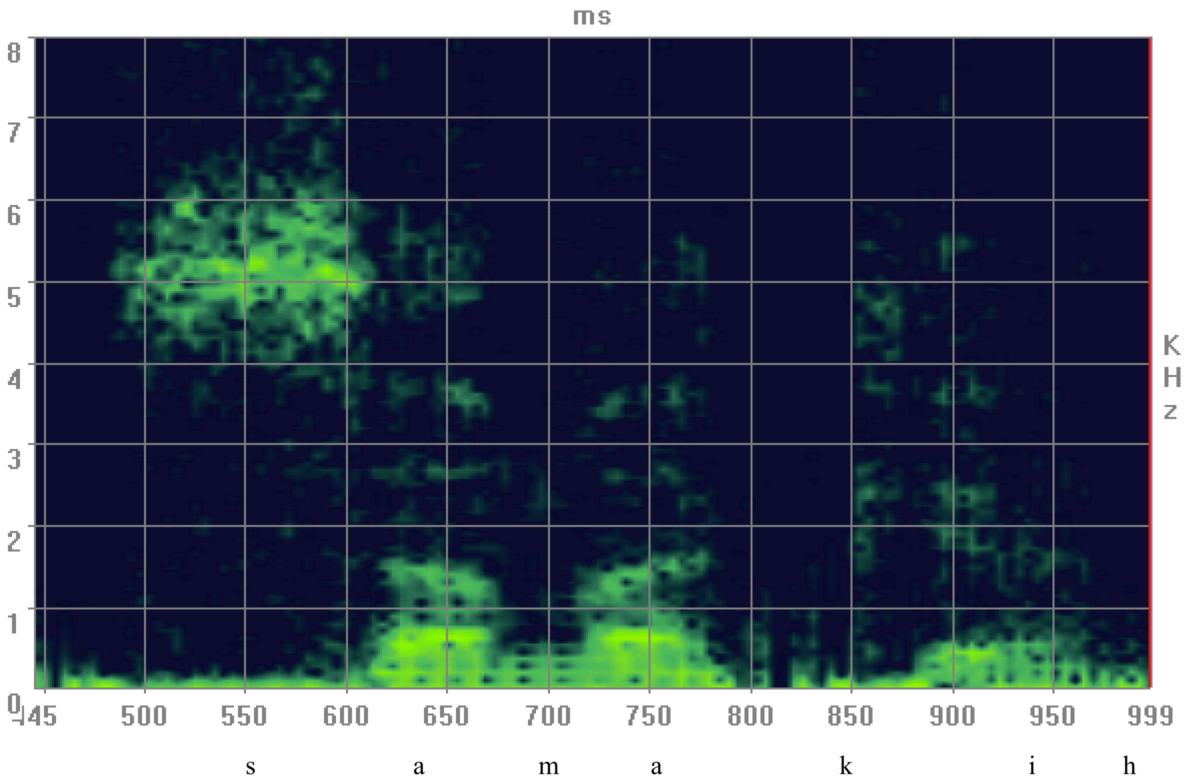


Figure 73: Spectrogram of the word [samakih] as produced by a normal speaker.

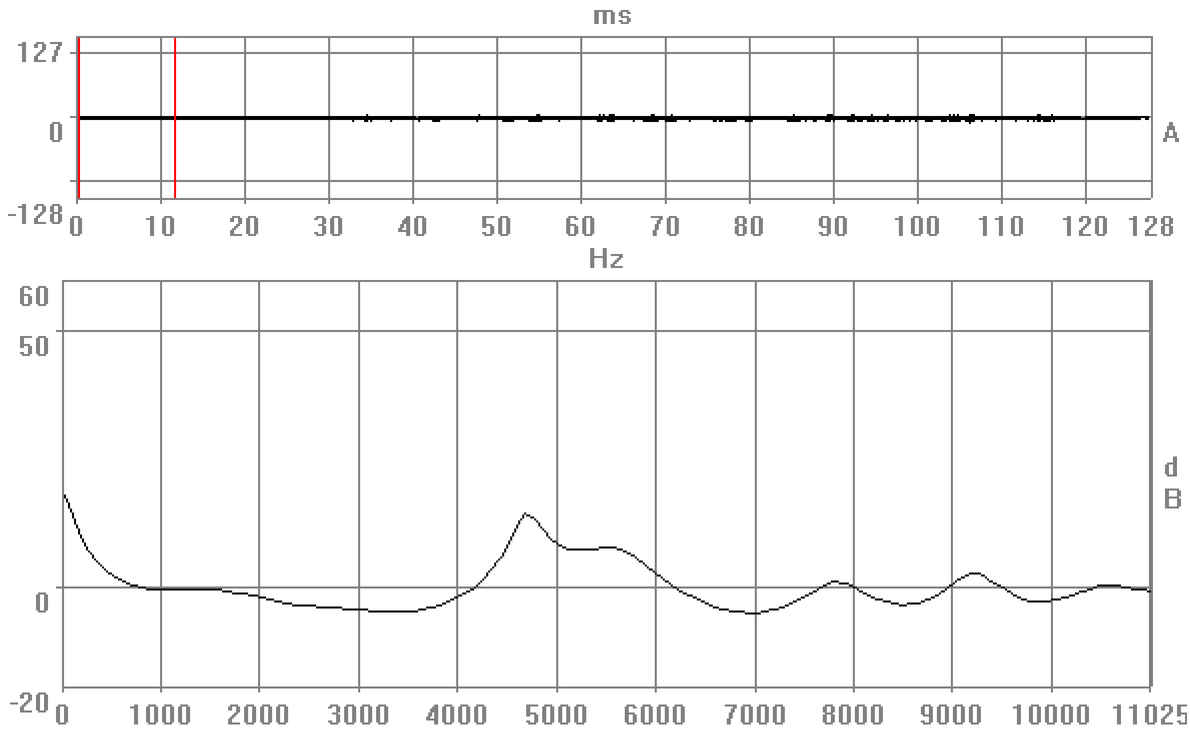


Figure 74: LPC of [s] in the word [samakih] as produced by a normal speaker.

In general, the following table summarizes the main acoustic features characterizing the fricative [s] as produced by the normal speakers.

Average energy distribution (dB)	Power bandwidth of energy concentration (Hz)	Mean frication duration (msec)	Intensity (dB)
27.29	5000-6000	113	67.5

Table 55: The acoustic features of [s] as produced by the normal speakers.

4.2.1.2. The acoustic features of the fricative [s] as produced by the aphasic subjects

Before we continue, we should briefly say, as noted earlier in different studies, that the aphasic subjects exhibited particular deficits in the fricative sounds. Therefore, based on the acoustic analysis, the acoustic features of their productions compared with that of the normal speakers and a discussion of the findings will be presented.

4.2.1.3. Results

Table 56 displays the main acoustical parameters of the aphasic productions. Thus, it is clearly seen that the aphasics exhibited relatively longer friction duration (117msec) than did the normal subjects (113msec). This is contrary to the results from Harmes et al.,[225] who indicated that their aphasic subjects exhibited shorter duration for [s] than the normal speakers particularly in disyllabic words.

Power bandwidth of energy concentration	Average energy distribution (dB) (Hz)	Mean frication duration (msec)	Intensity (dB)
1089-4861	23	117	54

Table 56: The acoustic features of [s] as produced by the aphasic subjects.

These results would suggest that the slow rate of speech produced by Broca's aphasics would be responsible for this slightly increased duration in continuous speech. As a group, the aphasics produced [s] with a noise friction spectrum that was characterized by a significant downward shifting for the higher spectral peaks in contrast to the normal subjects, as it can be seen in figure 75. Thus, it was between 1089-4861Hz for the aphasics, whereas for the normal speakers it was between 4861-5898Hz.

[225] Cf. Harmes, S., Danilo, R., Homan, P., Lewis, J., Kramer, M., & Absher, R. (1984), p. 374.

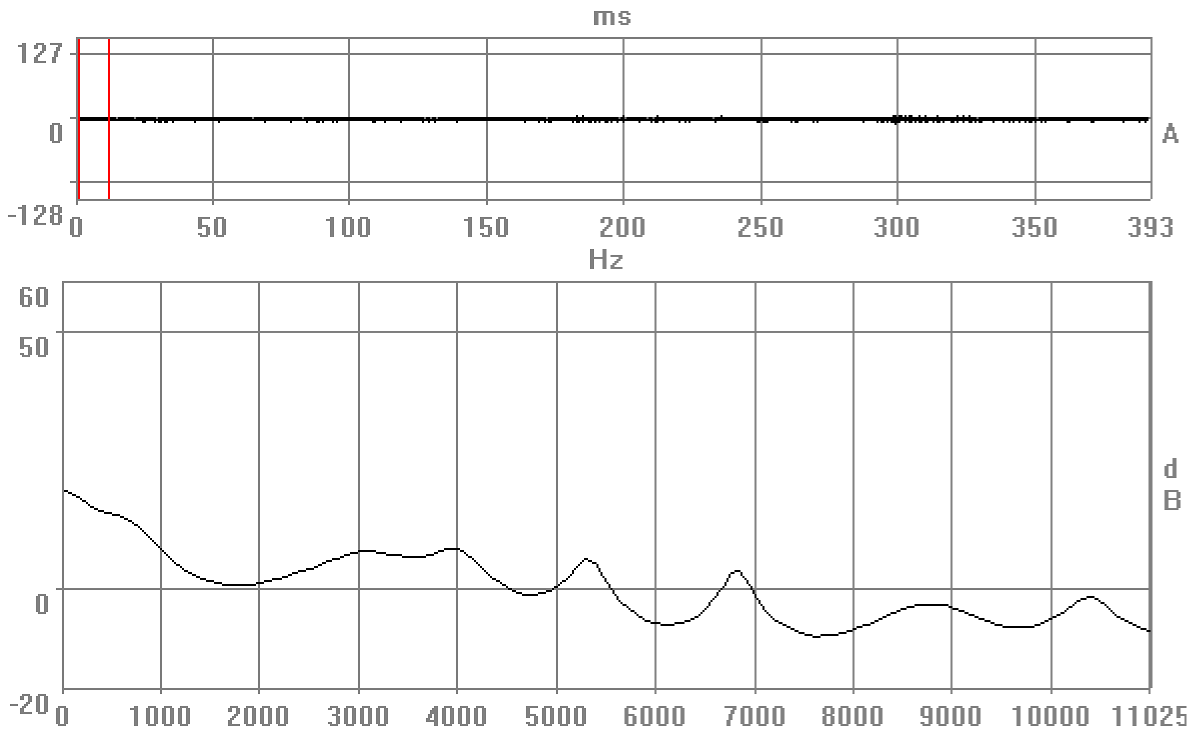


Figure 75: LPC of [s] from the word [samakih] 'fish' as produced by an aphasic subject.

With regard to the concentration of energy, the results of the current section indicate that the aphasic patients displayed a large bandwidth and the darker part of [s] noise is not off the top of the spectrogram in contrast to the normal speakers, as shown in figures 76 and 77. The absence of those dark zones probably reflects energy loss in the high frequency ranges in contrast to the normal speakers who displayed this until the frequency range 8000Hz. In addition, the distribution and the concentration of energy by the normal speakers achieved higher frequencies, as shown in figure 73. These acoustic patterns corresponded to the idea of the compact spectrum being described as a "result of its place of articulation in the front part of the vocal tract."[226]

[226] Jakobson, R., Fant, G., & Halle, M. (1952): Preliminaries to Speech Analysis: The Distinctive Features and Their Correlates, p. 27.

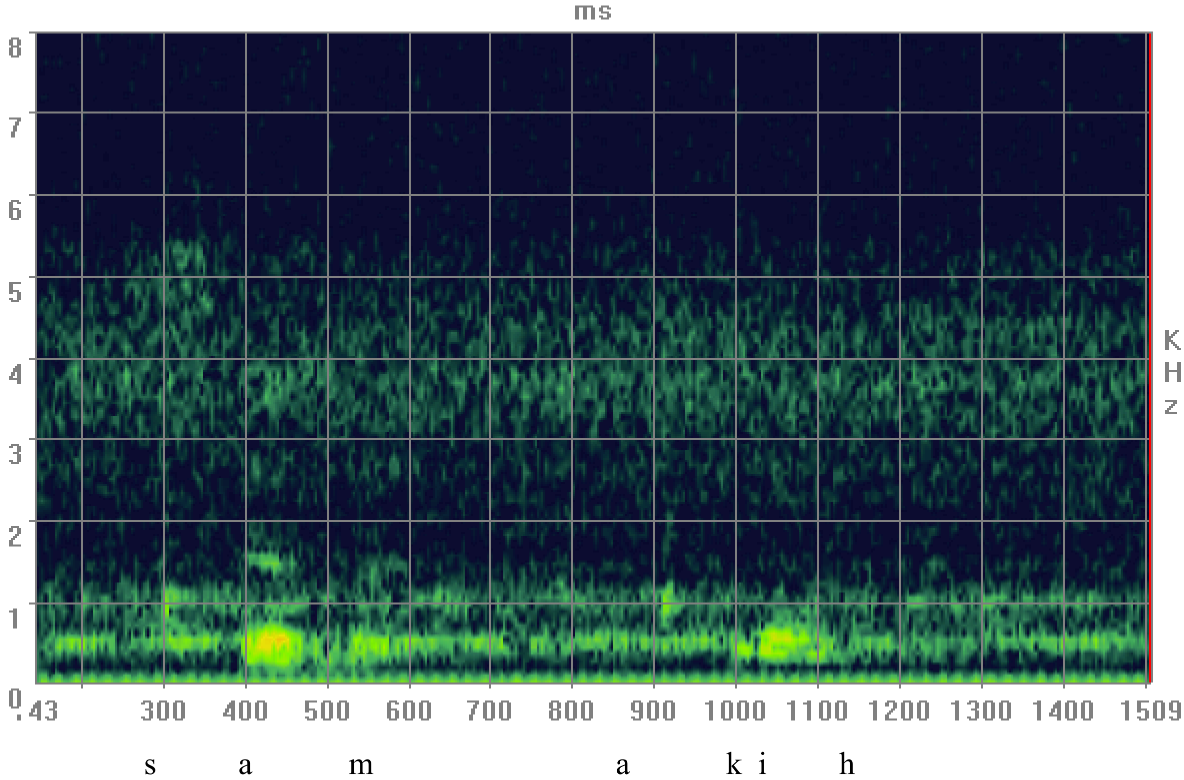


Figure 76: Spectrogram of the word [samakih] 'fish' as produced by an aphasic subject.

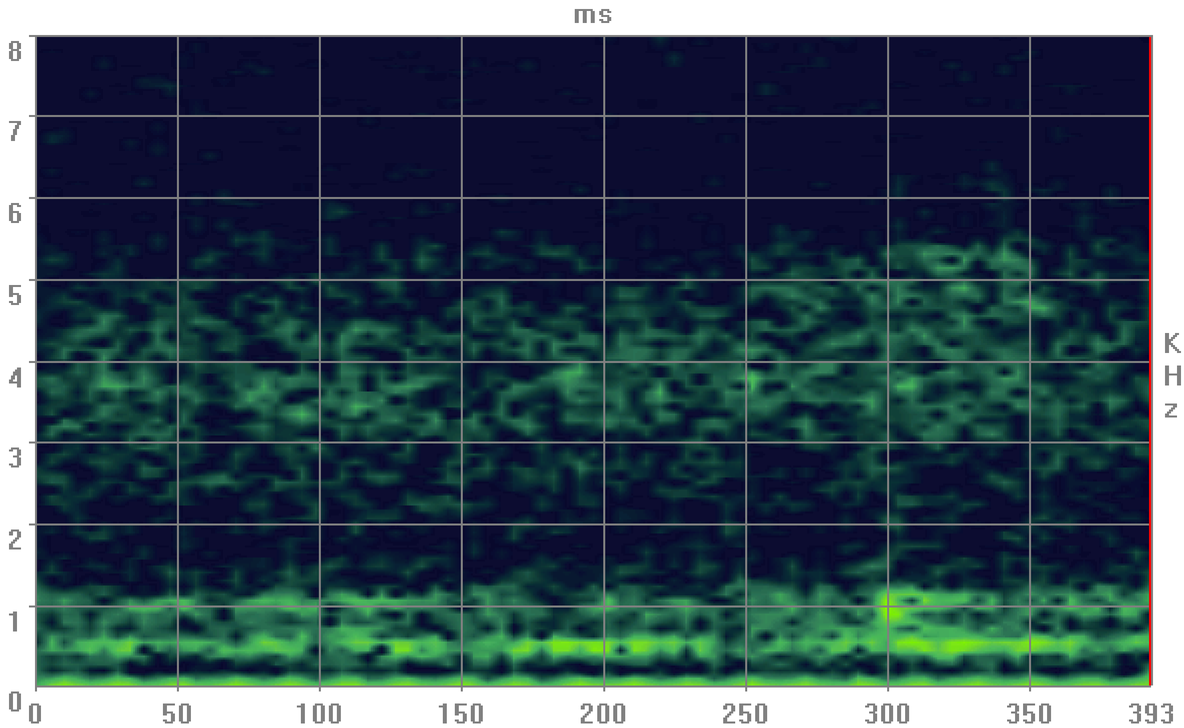


Figure 77: Spectrogram of [s] from the word [samakih] as produced by an aphasic subject.

4.2.2. The acoustic features of the fricative [ʃ] as produced by the normal speakers

Tables 57 and 58 shed light on different acoustic features of the fricative sound [ʃ] as produced by the normal speakers and the aphasic subjects. For example, the energy of [ʃ] produced by the aphasics was centred between 820-4900Hz, whereas for the normal speakers it was between 4800-5900Hz. Thus, by contrast, the energy is distributed over a wide range bandwidth by the aphasics compared to the normal speakers.

The tables below clearly demonstrate the intensity mean for [ʃ] by the aphasics and the normal speakers. Thus, it was 66.2dB for the normal speakers. In contrast, it was 57dB for the non-fluent patients displaying low pressure in the aphasic's productions. Consequently, the aphasics displayed low amplitude compared to the normal speakers, as can be seen from figures 78 and 79.

Power bandwidth of energy concentration (Hz)	Average energy distribution (dB)	Mean frication duration (msec)	Intensity (dB)
4800-5900	27.19	131	66.2

Table 57: The acoustic features of [ʃ] as produced by the normal speakers.

Power bandwidth of energy concentration (Hz)	Average energy distribution (dB)	Mean frication duration (msec)	Intensity (dB)
820-4900	25.2	208	57

Table 58: The acoustic features of [ʃ] as produced by the aphasic subjects.

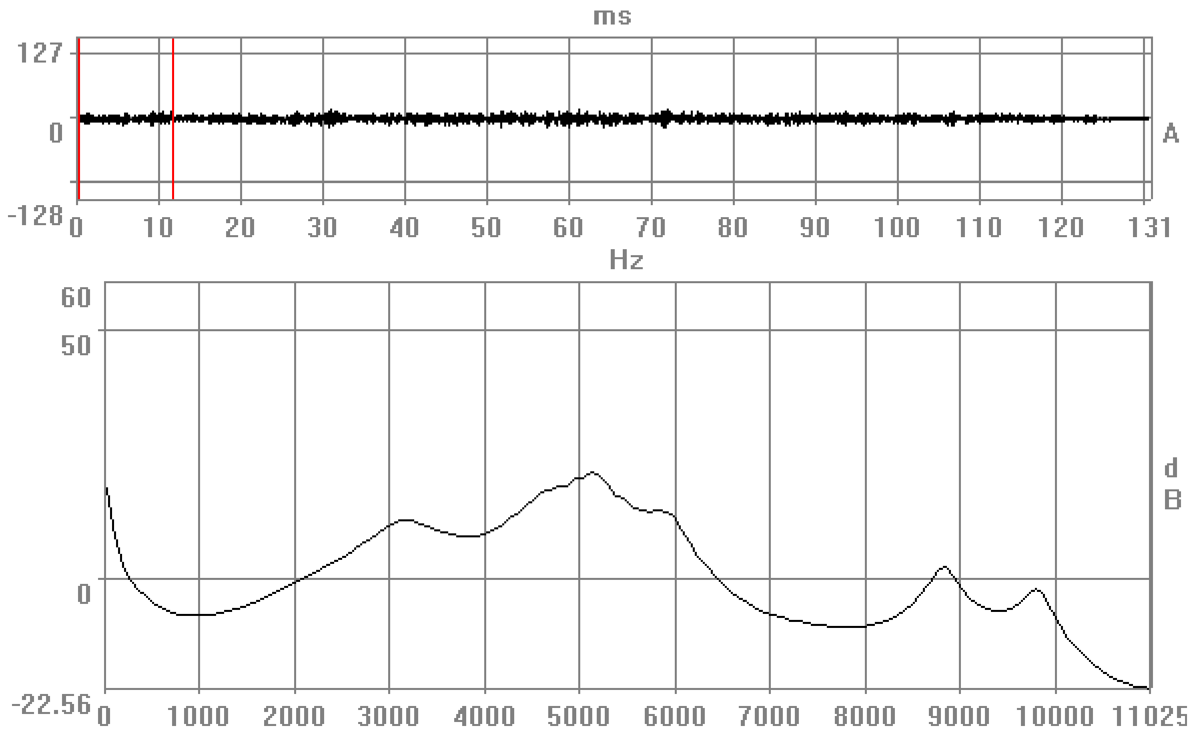


Figure 78: LPC of [ʃ] in the word [ʃaʕar] 'hair' as produced by a normal subject.

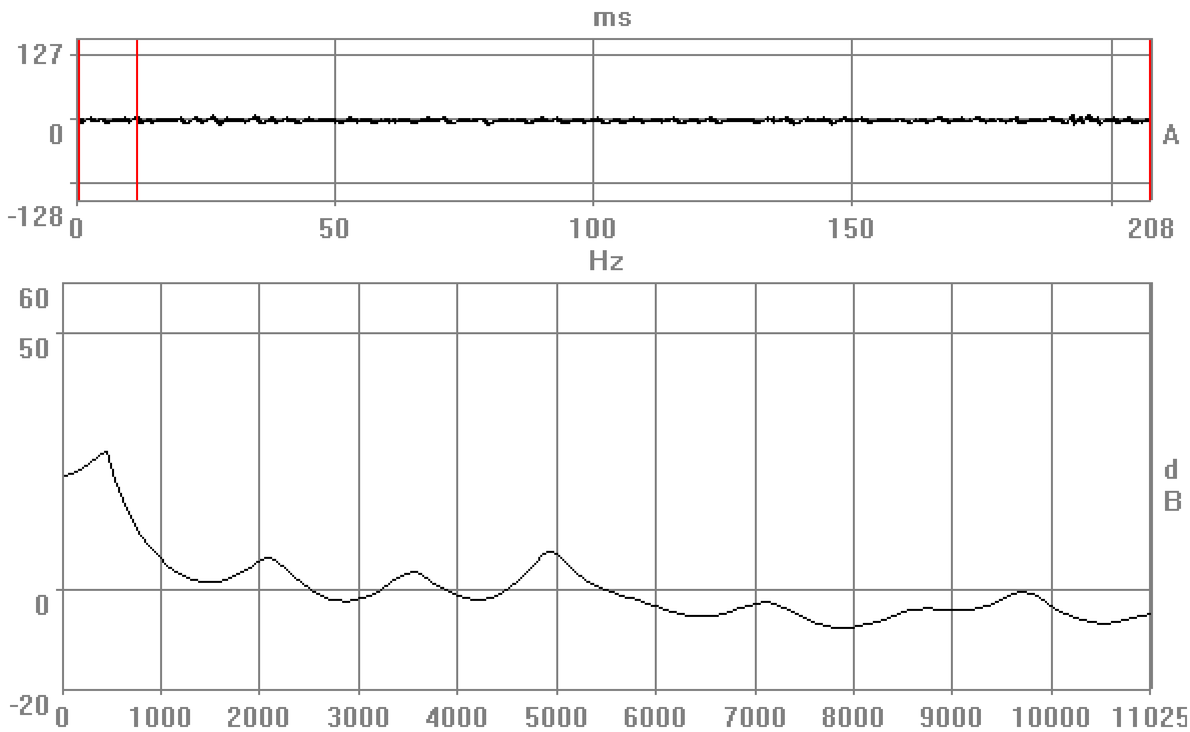


Figure 79: LPC of [ʃ] in the word [ʃaʕar] as produced by an aphasic subject.

In addition, the noise friction of this fricative sound by the normal speakers extended to the frequency range above 8000Hz, as shown in figure 80. In contrast, this acoustic parameter did not exceed to 5500Hz by the aphasics, as shown in figure 81.

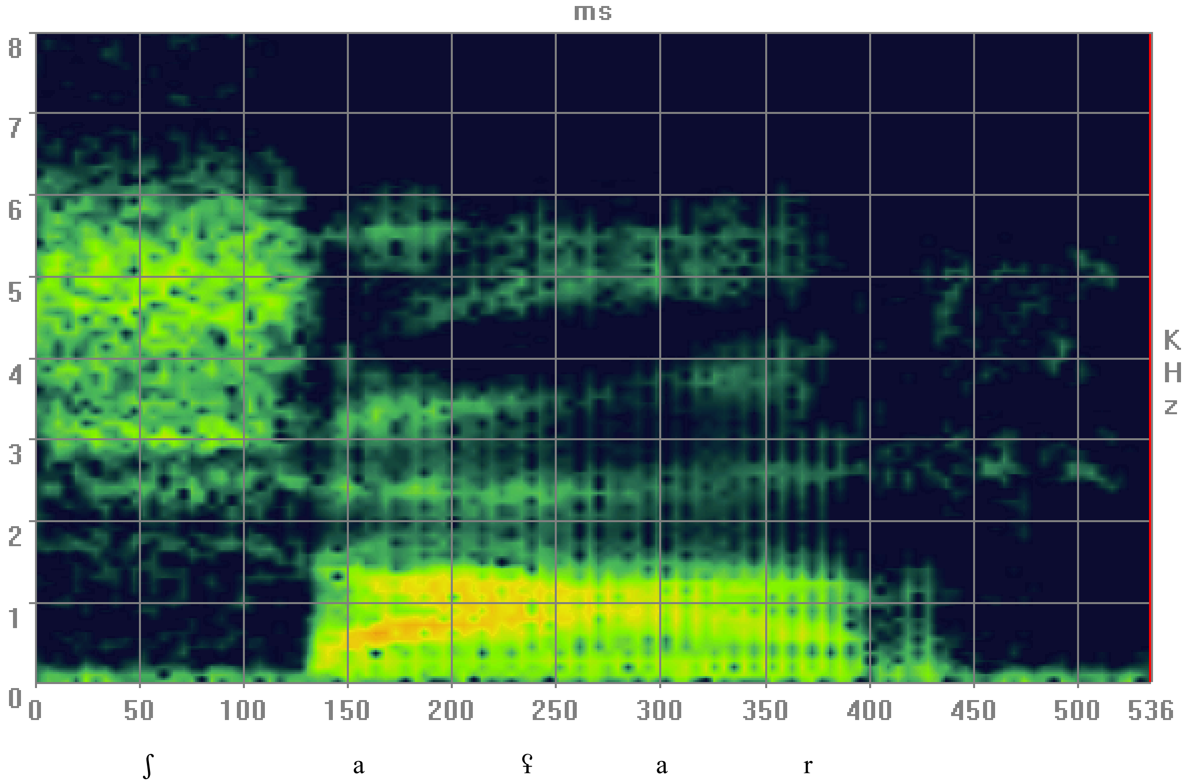


Figure 80: Spectrogram of the word [ʃaʕar] as produced by a normal speaker.

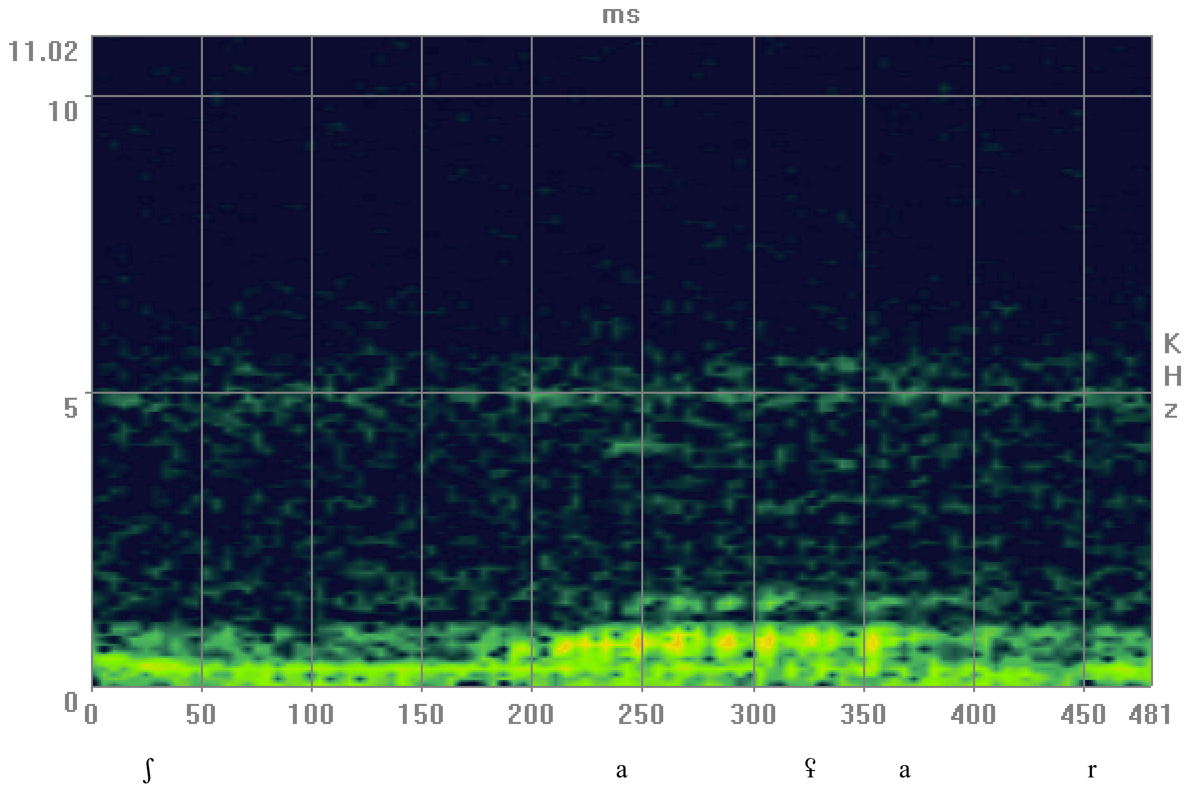


Figure 81: Spectrogram of the word [ʃaʕar] as produced by an aphasic subject.

Also, the results show that the aphasics displayed weak concentrations of energy in contrast to the normal speakers who exhibited dark areas even at high frequency ranges. Thus, as was predicted, the aphasics exhibited no patterns of concentrating the noise friction at high frequencies. The segment duration was 208msec in the aphasic group, whereas it was 131msec for the normal speakers.

4.2.3. A neurolinguistic discussion of the errors in the production of [s] and [ʃ]

After describing the acoustic features of the [s] and [ʃ] sounds produced by our aphasics, an analysis in terms of speech errors will be conducted in light of the classifications that were mentioned by Shuster and Wambaugh.[227] Their classifications of errors were as follows:

1- Substitutions: a sound replaced by another sound that is correctly articulated.
2- Voicing: the voiced sound either devoiced or the voiceless sound replaced by its voiced counterpart.
3- Distorted substitutions: a sound being replaced by another which is impaired either in manner or place like [ʃ] to backed [s].
4- Distortions: a sound being distorted in the manner or place of articulation.
5- Addition: a sound being added that resulted in a sequence that is permissible and there was no pause between the sounds, e.g. (take→stake).
6- Change: a sound was added that resulted in a sequence that is not permissible or there was a pause between the sounds, e.g. (take s-take).

When distributions of error types were considered, with the exception of voicing errors, the results indicated that the aphasic subjects exhibited all types of errors. Thus, interestingly, these patients did not substitute the voiceless [s] for its voiced counterpart [z]. In fact, this find is relatively striking because the aphasics normally exhibit voicing deficits as we have seen in their production of stop sounds. Table 59 summarizes the percentage of each type of error.

[227] Cf. Shuster, L., & Wambaugh, J. (2000): Perceptual and Acoustic Analyses of Speech Sound Errors in Apraxia of Speech Accompanied by Aphasia, p. 639.

Types of errors	[ʃ]	[s]
Substitution	50	40
Voicing	-	-
Distortion	36	30
Distorted substitution	7	17
Change	4	5
Addition	3	8

Table 59: The percentage of types of errors in [ʃ] and [s] as produced by the aphasic subjects.

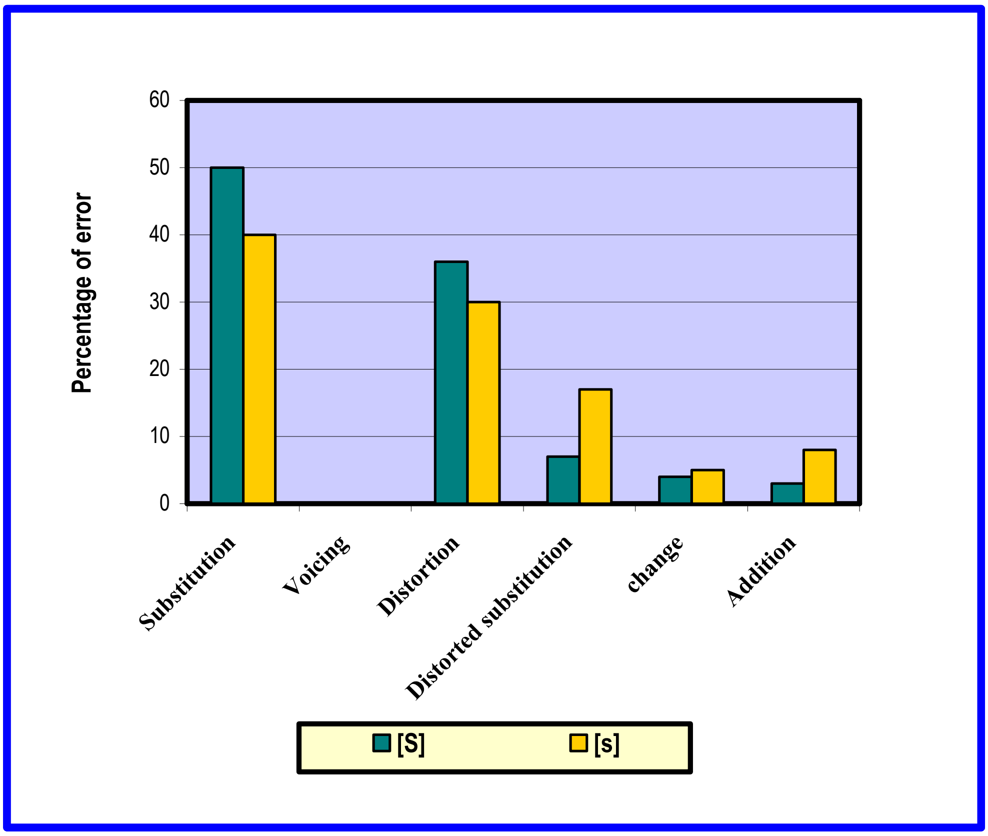


Figure 82: Percentage of types of errors in [ʃ] and [s] as produced by the aphasic subjects.

Furthermore, as shown in figure 82, it is clear that substitutions are the predominant type of errors, a feature normally associated predominantly with Wernicke's aphasia. However, the deficit lies at different levels in both types of aphasia. Another type of error was "change error" which is, as already mentioned, the addition of a sound leading to an unexpected sequence. For example, based on figures 83 and 84, it is clearly noticed that the aphasic subject (B4) had first produced [s] and then moved to [ʃ], whereas in the second word (figure 84) he first produced [s], then made a pause and again produced the target word.

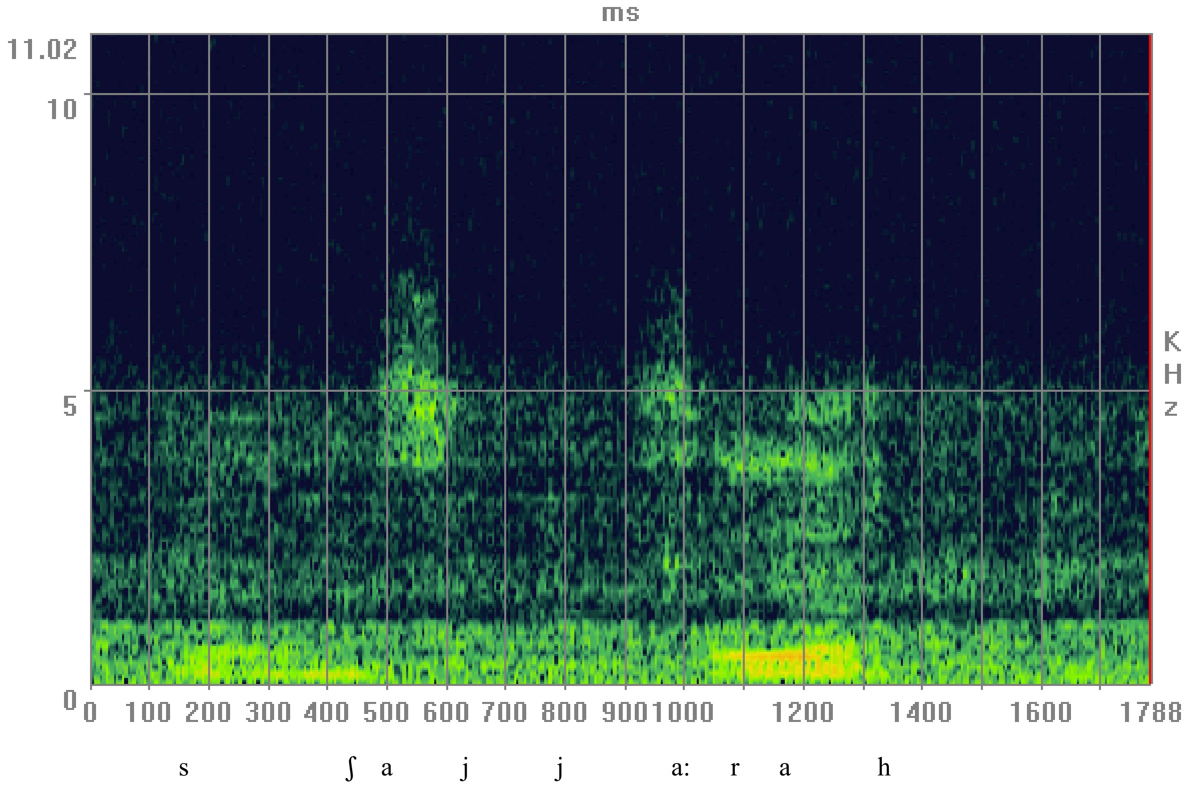


Figure 83: Spectrogram of the word [sʃajja: rah] indicating a change error.

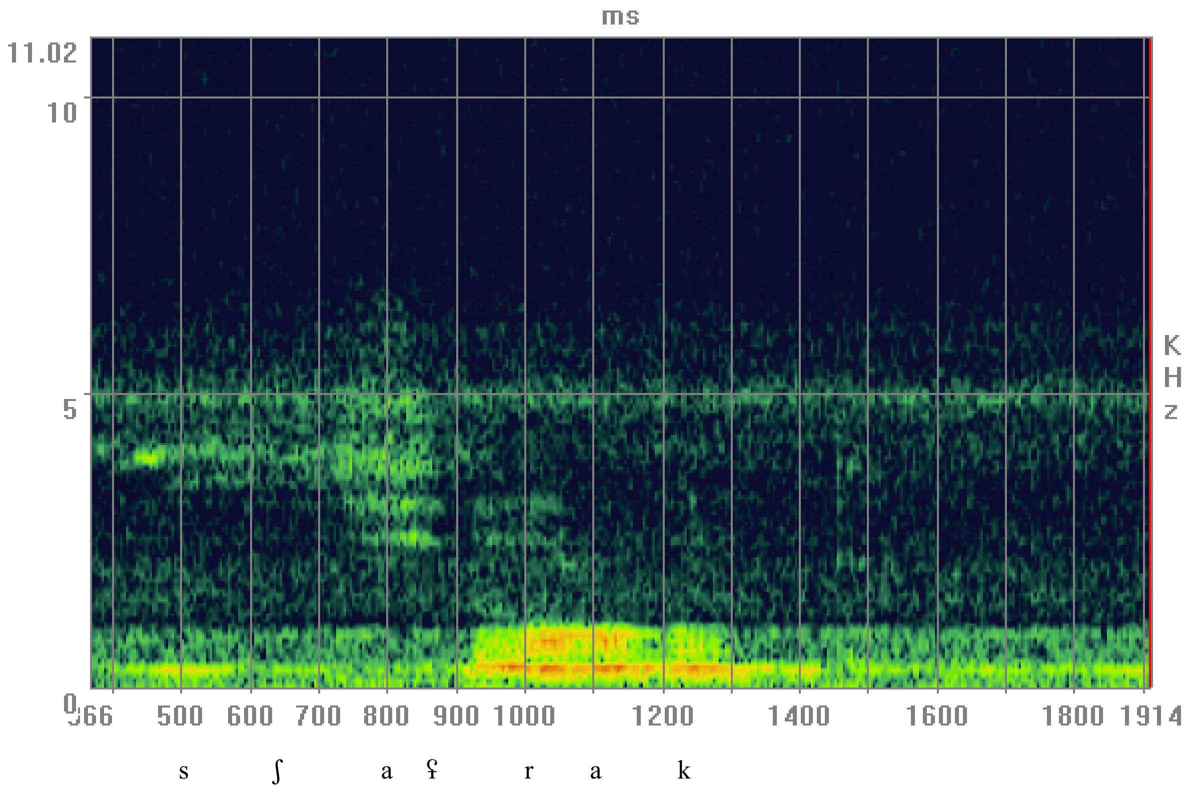


Figure 84: Spectrogram of the word [sʃaʕrak] indicating a change error.

Before we continue, we should consider some extreme "change error" productions noting that some of the non-fluent subjects exhibited extreme patterns by adding sounds that did not belong to the initial sound of the target sound. For instance, the aphasic subject (B5) added the stop consonant [d] in his attempts to produce the target word [ʔisri:r] 'bed,' as figure 85 clearly presents. This pattern contradicts the previous change of error whose additions were within the same consonant category.

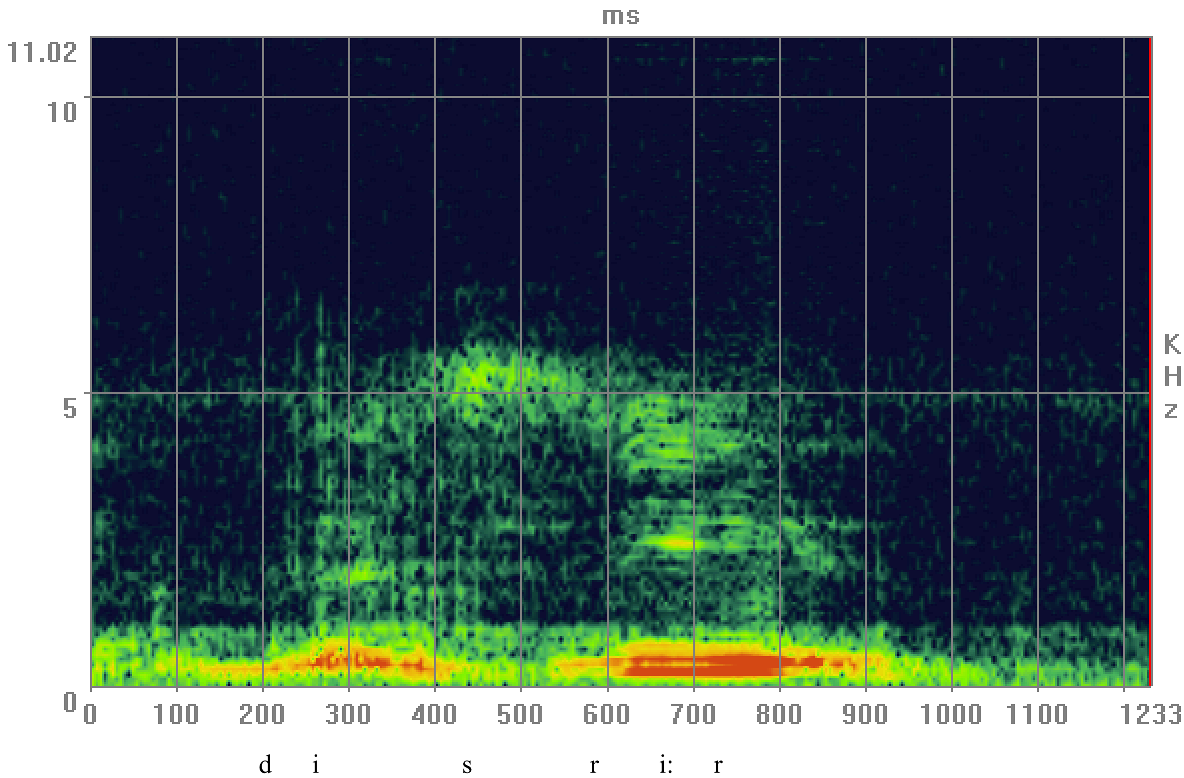


Figure 85: Spectrogram of the word [disri:r] indicating a change error.

As has been displayed many times, the aphasic subjects make more than one attempt to get the target in terms of continuous progression towards it. Importantly, even though this is considered as an articulatory deficit, this phonemic approximation would indicate a relative preservation of monitoring of speech production. Thus, consistent with previous results,[228] our aphasics attempted to get closer to the target in their sequence of errors. In general, these attempts would be associated with detecting errors by using a system that enabled the patients to compare the error sound with the target one. This was achieved by allowing only for the correct sound to be reused during the second attempt. Error detecting is completely different from one patient to another based on the severity or the site of lesion. In general, these errors

[228] Cf. McNeil, M., Liss, J., Tseng, C., & Kent, R. (1990): Effects of Speech Rate on the Absolute and Relative Timing of Apraxic and Conduction Aphasic Sentence Production, pp. 153-156.

shed light on the nature of the deficits by addressing the question whether this problem lies at the phonological level or at the phonetic and the implementation levels. Before trying to detect the answer, we have to measure the time latency between initiating the added phoneme and the real phonemes of the target word. As a result, it was 30msec for [sajja:rah] 'car' and only 18msec for [ʃaɣrak] 'your hair,' as exhibited in figures 83 and 84. Taking these figures into consideration, it would seem that this problem emerges at the planning level that requires precise modifications for the articulatory movements. When the previous observation is considered, the question might be whether this time latency (pause) could enable the speaker to reconsider his production in terms of reconstructing, re-realizing the wrong production and retrieving the correct segment. Furthermore, this issue would be associated with the aphasic's lexical activation ability. Therefore, it would seem reasonable that this deficit would reflect the fact that the lexical activation in Broca's aphasics is mainly reduced and would demonstrate longer reaction time. Furthermore, this latency would suggest that the processing time is increased.

Support for our observations comes from many studies that have demonstrated deficits in the lexical processing of mapping from sound to word meaning among Broca's aphasics.[229] Additionally, a possible interpretation for this latency is the activation of the sound supported from activation models of lexical access.[230] In particular, this approach is based on the idea that the activation of the lexical items depends on the extent of matching between the input segment and the target representation. Thus, an input that exactly matches its lexical representation will evoke the most activation.

However, the input that differs by a single phonetic feature will produce less activation. This would increase the differences in the number of features between the target and the output will lead to a decrease in the amount of activation. As a result, the magnitude of lexical activation will be greatest when the prime word phonologically matches its lexical entry and the opposite trend will be detected as the phonological distance of the prime word increases from that entry. In this regard, the results consistently exhibit that Broca's aphasics display deficits in the activation levels of lexical entries.[231] In addition, distortions were also

[229] Cf. Milberg, W., Blumstein, S., & Dworetzky, B. (1988a): Phonological Factors in Semantic Facilitation: Evidence from an Auditory Lexical Decision Task, p. 290.
[230] Cf. Elman, J. (1989): Connectionist Approaches to Acoustic/Phonetic Processing, pp. 240-255.
[231] Cf. Misiurski, C., Blumstein, S., Rissman, J., & Berman, D. (2005), p. 76.

respectively predominant after substitutions. Thus, by listening carefully to the productions of [s] and [ʃ] by the aphasics, it can be found that there is a kind of distortion in the place of articulations, as if it is in an intermediate place of articulation between the alveolar for [s] and palatal for [ʃ]. Therefore, to give evidence of this auditory perception an acoustic analysis has been conducted. As figure 86 shows, the energy is extended to 5500Hz for [ʃ]. The same figure displays, however, that the noise frication in this word started at a high frequency and is located respectively at two separate blocks. In fact, these acoustical values are respectively related to the sound [s] more than to [ʃ] as the acoustical values of each sound that were already mentioned in the previous discussions indicated.

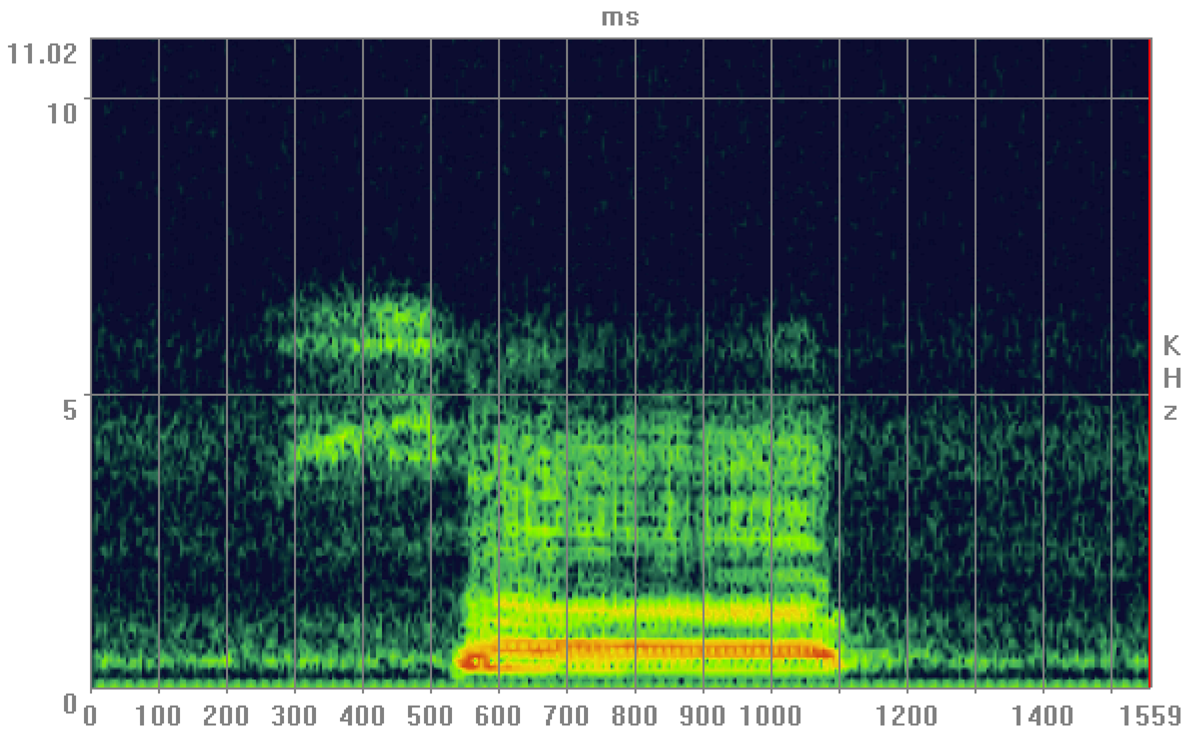


Figure 86: Spectrogram of production of [s] by an aphasic subject in the word [ʃa:b] 'boy' displaying perceived backed [s] articulation.

With regard to the production of fricative sounds, namely the fricative [ʃ], it is apparent that the aphasic subjects exhibited particular problems in producing [ʃ] as manifested in the number of errors and particularly the substitution ones. For instance, subject B2 exhibited a remarkable problem in producing the word [ʃimma:m] 'cantelope' by substituting [s] and [z] for [ʃ], as shown in the words:

[ʃimma:m] → [simma:m]

[ʃimma:m] → [zimma:m].

As figure 87 displays, he substituted [s] for [ʃ], as shown in the word [simma:m].

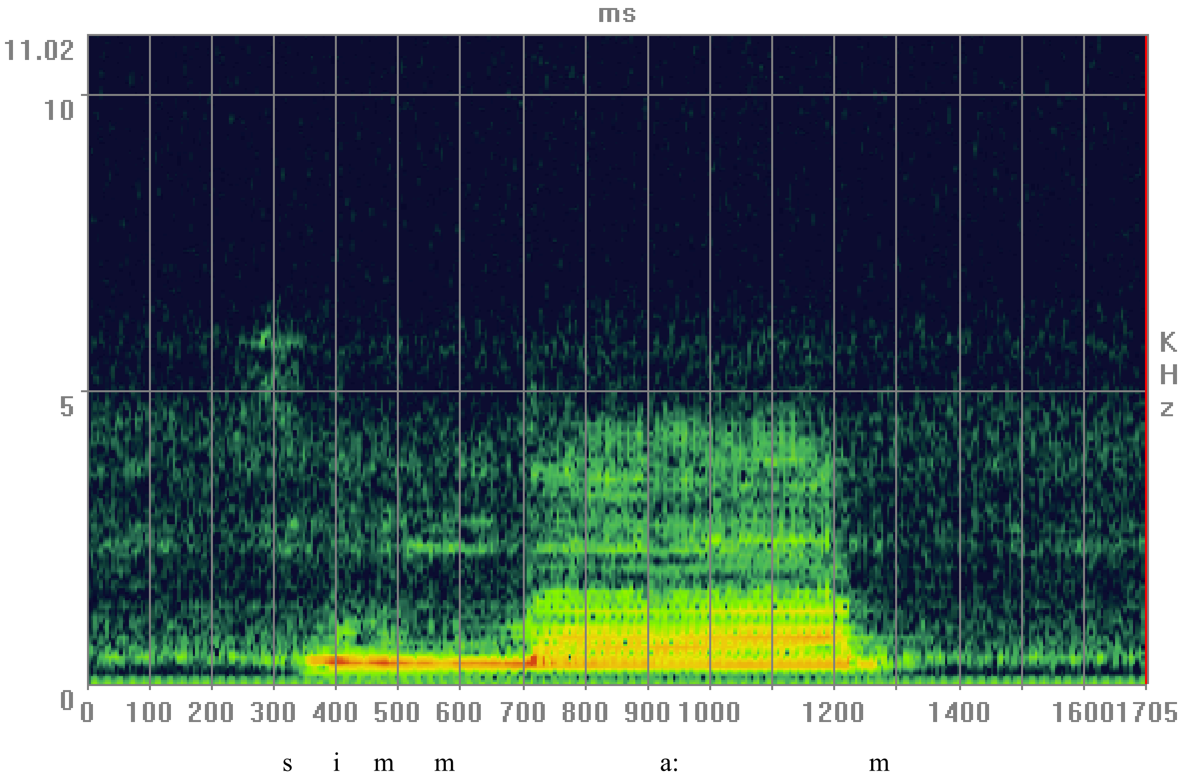


Figure 87: Spectrogram of a substitution error changing the word [ʃimma:m] 'cantelope' to [simma:m].

Thus, interestingly, the place of articulation was only involved in this substitution error because both sounds are voiceless and fricative. The subject also exhibits substitution involving two feature-change errors in voicing and the place of articulation. This is manifested in substituting [z] for [ʃ], as shown in figure 88. Importantly, it is clear that this error could not be considered a voicing error because the change extends to the place of articulation. In general, the data from Broca's aphasics gives some evidence to propose that the substitutions of the aphasic subjects were not in a systematic way. That means that some of the errors involved the place of articulation and others included voicing and place of articulation.

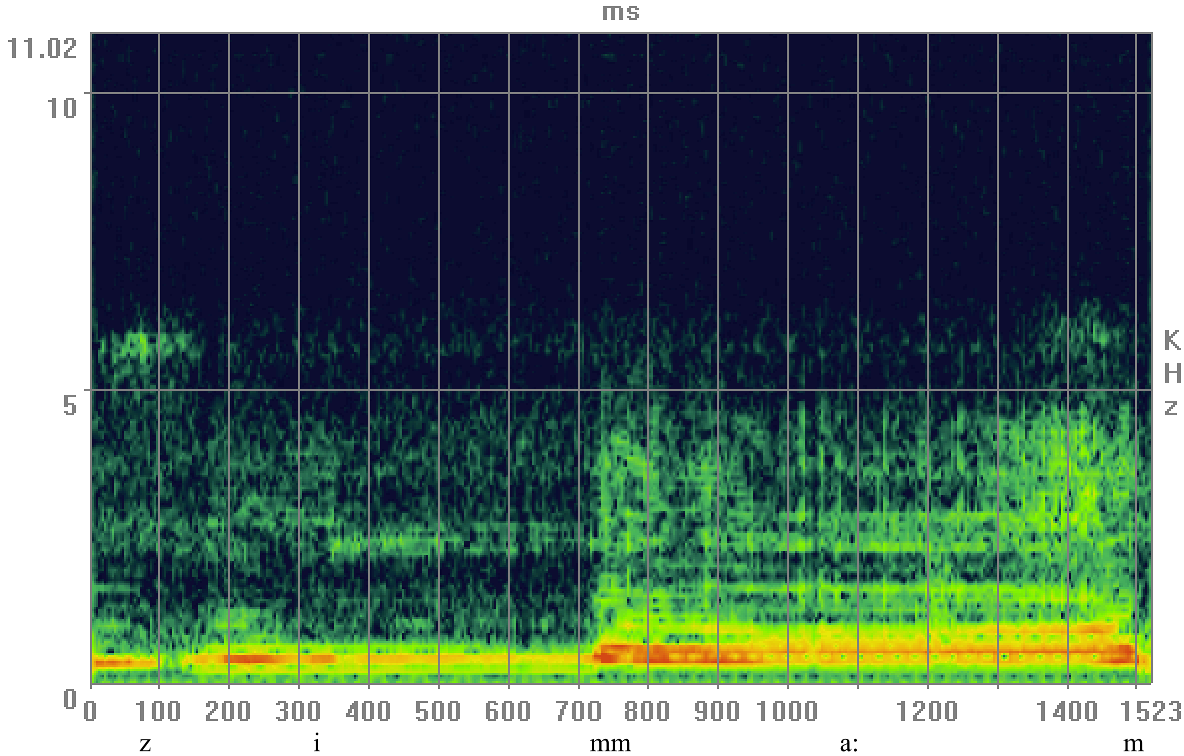
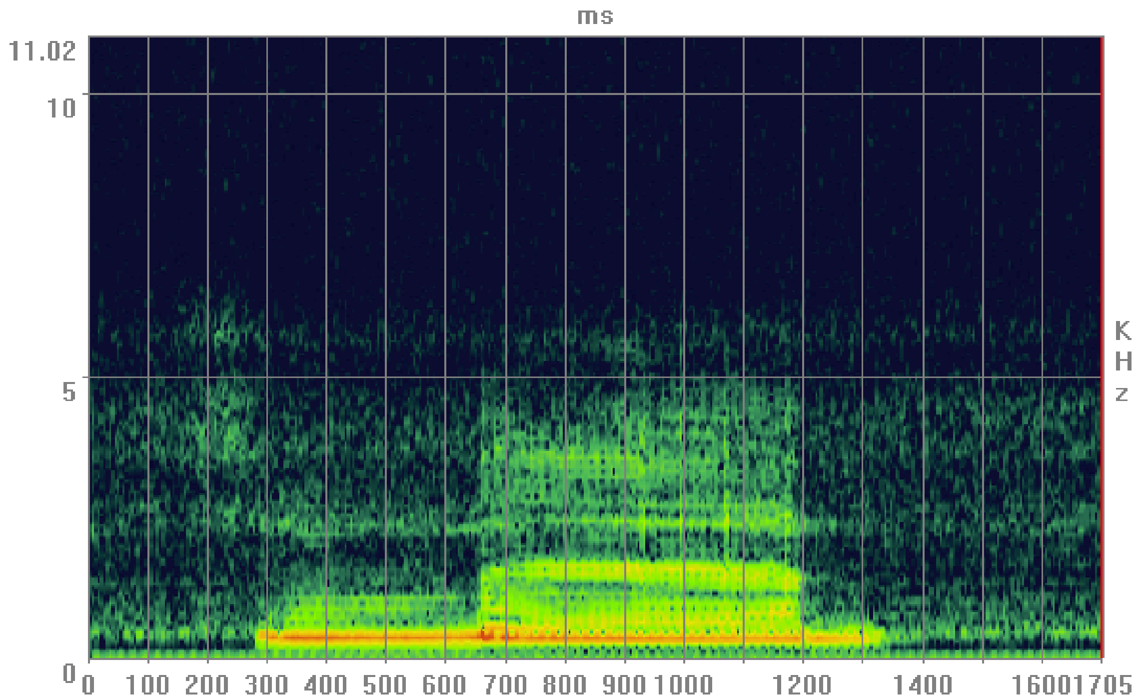


Figure 88: Spectrogram of a substitution error changing the word [ʃimma:m] to [zimma:m].

In addition to the other deficits appearing in the production of the fricative [ʃ], for instance, it was noticed that one of the aphasic subjects in producing the word [ʃimma:m] omitted the initial [ʃ] and lengthened the short vowel [i] into its long form [i:], as figure 89 clarifies. Furthermore, conformed well to this latter pattern, the duration of [i] was considerably lengthened in the word [ʃimma:m] by the aphasic B2 to 363msec, whereas it was 89msec by the normal speakers. It is also noticed that he tensed his segments in contrast to other aphasic subjects.



ʃ i mm a: m

Figure 89: Spectrogram of the word [ʃimma:m] illustrating extreme lengthening of the vowel [i].

Therefore, the non-fluent aphasic patients displayed problems in producing [ʃ] in contrast to other fricative consonants that were represented either as substitutions, distortions or even deletions. Some studies[232] have indicated that the word length, concreteness and the contextual factors could contribute to deficits in Broca's aphasics. In this case, word length and its syllabication form could contribute to this difficulty. For example, taking subject B2, who exhibited a particular problem in producing the word [ʃimma:m] as an example, it can be seen that this word is a disyllabic word having the form CVC/CVVC, but the two consonants are geminated. Thus, the syllabication structure of this word is not long. However, the aphasics in general exhibited particular sensitivity to the word's length. Furthermore, some investigations of Broca's aphasics have brought increasing support to the idea that these patients demonstrate deterioration in naming tasks as the number of syllables increases.[233] Additionally, the frequency of using a word in the language might have an impact on language processing in Broca's aphasics. In the case of the word addressed above, we tended to believe that this word is commonly used and did not give evidence for this difficulty. Support for this came from the subject himself who was able to produce it two times correctly, as figure 90 indicates, displaying inconsistency in his productions.

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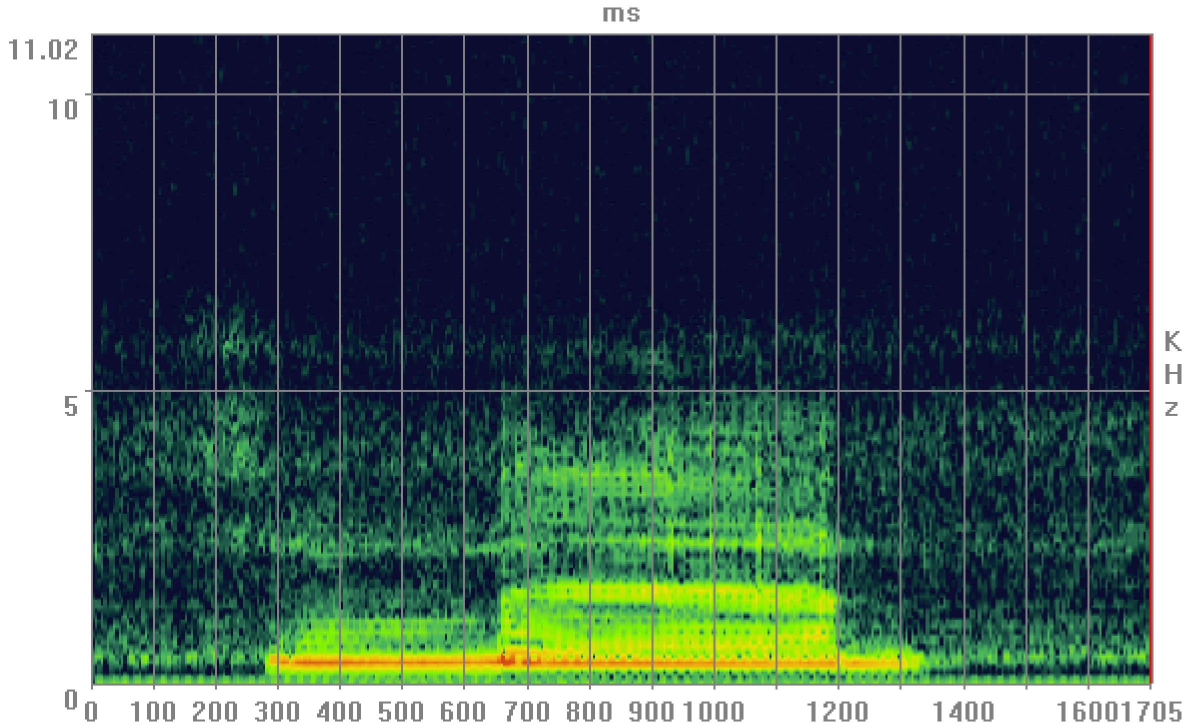
[232] Cf. Baum, S. &. Boyczuk, J. (1999): Speech Timing Subsequent to Brain Damage: Effects of Utterance Length and Complexity, pp. 31-34.

[233] Cf. Schirmer, A. (2004), p. 277.



ʃ i mm a: m

Figure 90: Spectrogram of the word [ʃimma:m] produced correctly by an aphasic subject.

The analysis, reveals that the aphasics demonstrated strong aspiration after the sibilant [ʃ], as figure 91 illustrates. This could be related to the way of terminating the air stream.

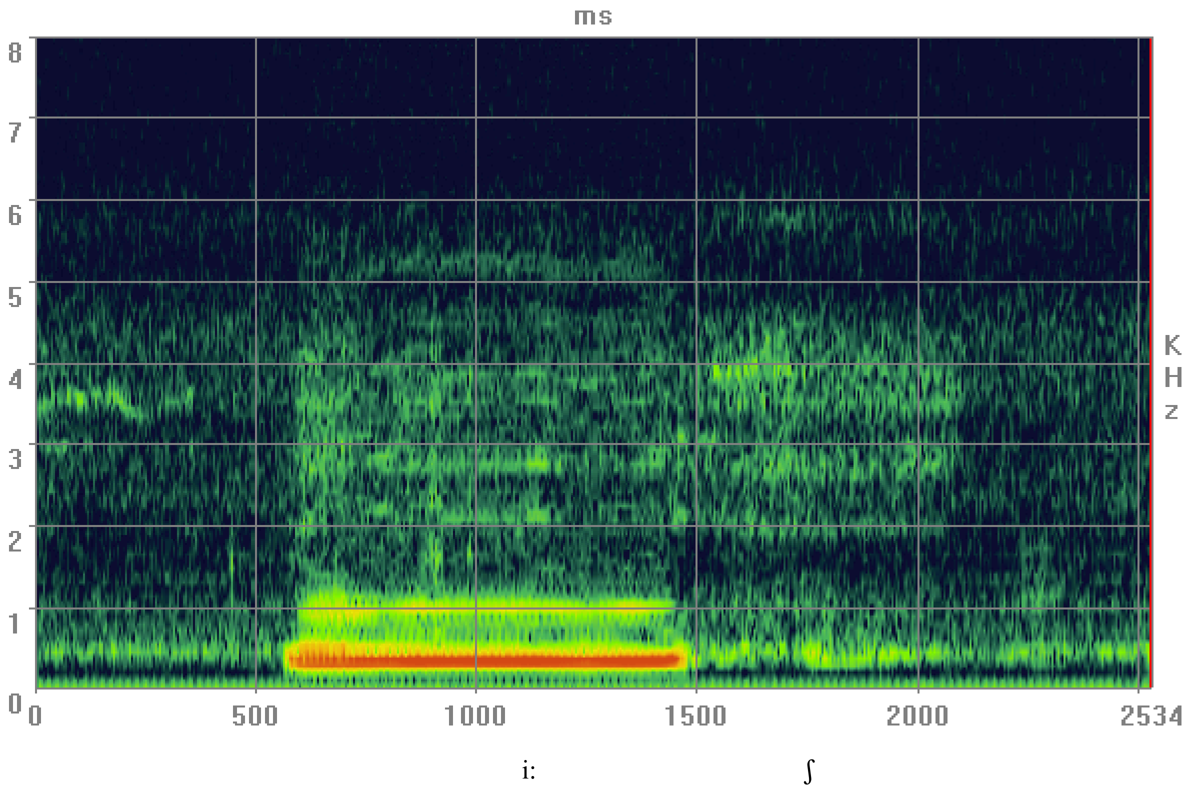


Figure 91: Spectrogram of the word [i:ʃ] illustrating heavy aspiration after the sibilant [ʃ] as produced by an aphasic subject.

In addition, complex errors were observed from productions of the non-fluent aphasic subjects indicating different phonological errors. For instance, by considering the word [ʃantih] 'bag,' which was produced by an aphasic subject as [ʃantʃih], as shown in figure 92, it can be noticed that it is addition error in nature but is triggered by a progressive assimilation in which the target phoneme assimilates to a previous phoneme in the word. However, at the same time, it would be reasonable to argue that the combination of [t] and [ʃ] sounds motivated a substitution in favour of the affricate sound [tʃ] that is used at the dialectal level. In the present case, in fact, this pattern of impairments indicates that many processes are involved in one word reflecting the severity and the effect of the phonological environment in triggering such errors.

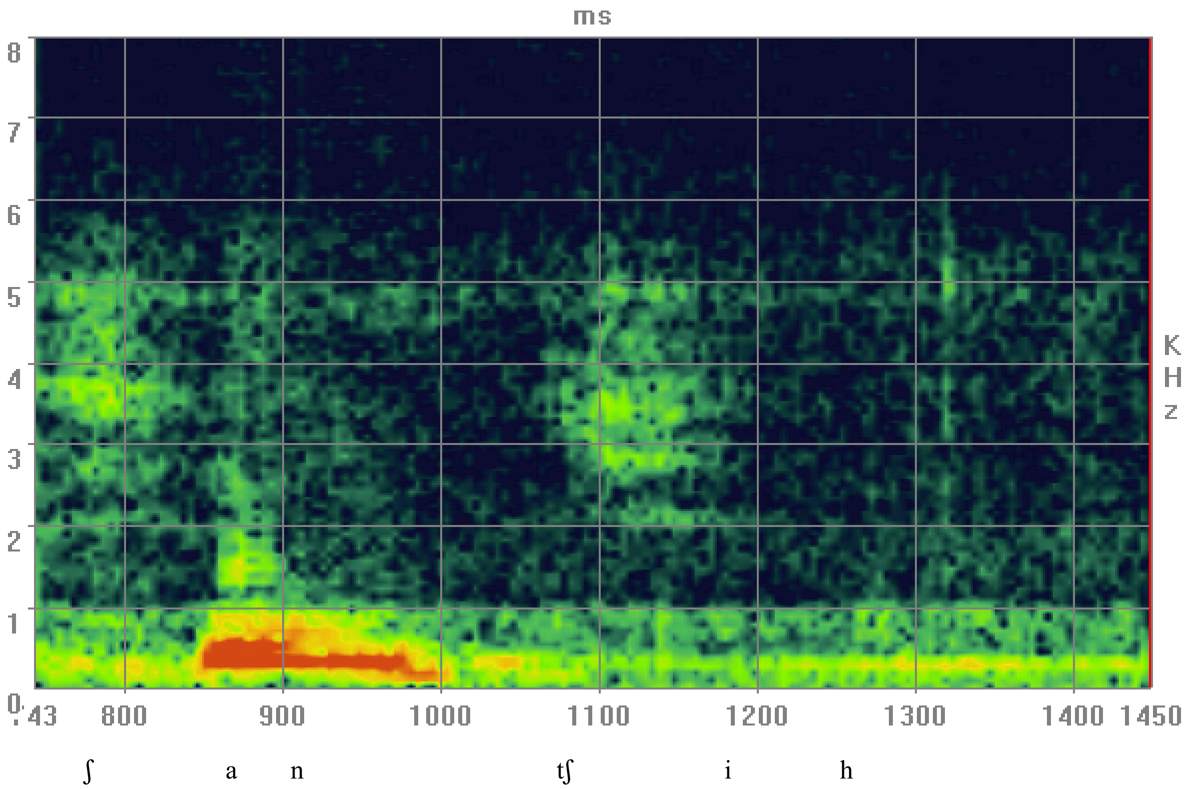


Figure 92: Spectrogram of the word [ʃantʃih] as produced by an aphasic subject illustrating multi-phonological processes.

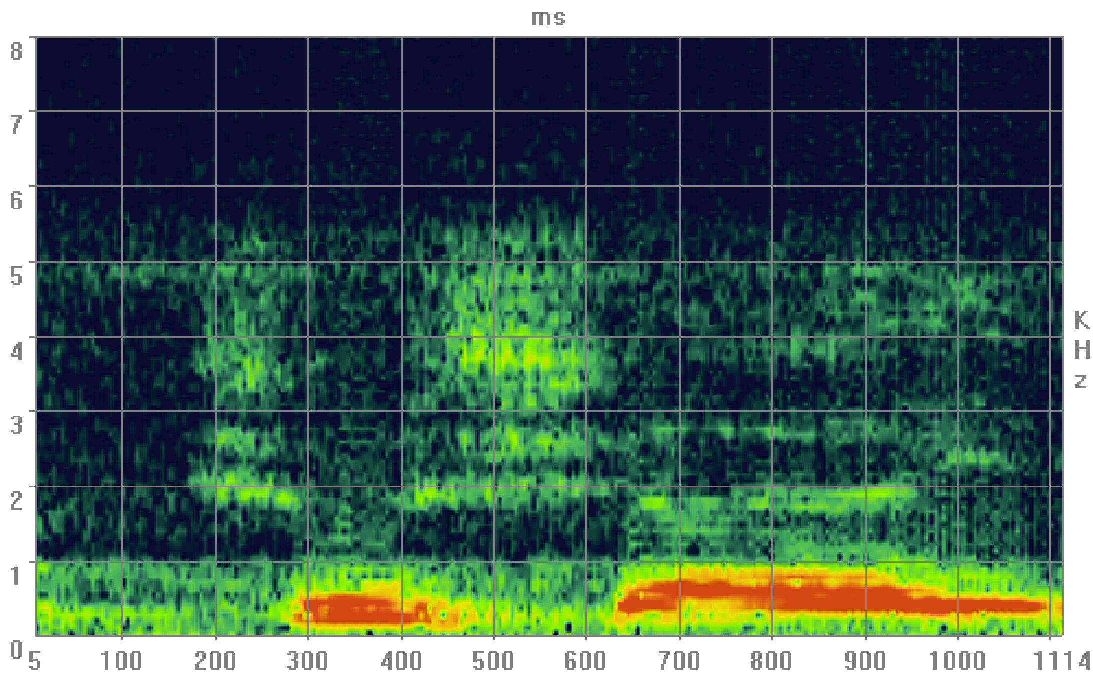
Concerning the production of the fricative [ʃ], in addition to the numerous errors that have already been revealed, Broca's aphasics exhibited a particular pattern of errors that has been called environment error "which can be accounted for by the influence of surrounding phonemes."[234]

In this sense, one of the environment errors that have been exhibited by our subjects is the intra-morphemic blend error, which has been defined by Blumstein as an "error triggered by a phoneme located in the same word."[235] For example, instead of saying [furʃa:jih] 'brush,' subject B4 said [ʃurʃa:jih], as the spectrogram in figure 93 indicates. So it is considered to be a regressive assimilation, which is distinguished by "anticipation of phoneme later in the sequence."[236] Metoui emphasized the motoric dimension of the regressive coarticulation "Es handelt sich um eine Bewegungsantizipation."[237] In the previous example, the consonant [ʃ] assimilated the target phoneme [f] to [ʃ]. Furthermore, it is clear that only one consonant [r]

[234] Blumstein, S. (1973): A Phonological Investigation of Aphasic Speech, p. 38.
[235] Ibid., p. 38.
[236] Ibid.
[237] Metoui, M. (2001), p. 43.

separated the assimilated phoneme from the triggered phoneme. Nonetheless, although Broca's aphasics displayed intra-morphemic blend errors, their patterns are inconsistent with observations reported in other studies[238] due to the fact that our aphasic subjects did not exhibit particular patterns where only one phoneme intervened between the assimilated and the contaminated phoneme as Blumstein indicated. Additionally, the results of the current section indicate no evidence of systematic preference for progressive or regressive assimilation among the aphasic subjects.

Taken together, the very fact that Broca's aphasics displayed intra-morphemic blends and change errors is further evidence that their deficits would emerge at planning a programme where specific and accurate articulatory modifications in the movements must be carried out before sequencing the utterance.



ʃ u r ʃ a: j i h

Figure 93: Spectrogram illustrating an intra-morphemic blend error of [ʃurʃa:jih] instead of [furʃa: jih] 'toothbrush.'

Moreover, we have to keep in mind that the physiological parameter in producing [ʃ] could be responsible for this massive difficulty. Thus, to produce the sibilant [ʃ], a precise neuromuscular coordination is required in activating and initiating many motoric gestures. In

[238] Cf. Blumstein, S. (1973), pp. 62-72.

this account, Metoui[239] in his comprehensive description of the Arabic sounds indicated that the production of [ʃ] requires different articulatory sequences. For example, in his discussion of the role of the lips, Metoui stated that "Für [ʃ] […] bewegt sich die Oberlippe vorwärts und abwärts, die Unterlippe vorwärts und aufwärts und verringert damit stark die Lippenöffnung."[240] As we have seen, the lips are active in producing this sound working with other articulators. Considering the role of the lower jaw, it is noticed that a great degree of coordination is needed to produce it. In this account, Metoui indicated that "[…] die Kieferöffnung verringert sich in einer Bewegung nach vorn und nach oben. Danach folgt in beiden Fällen eine Schleife nach hinten und nach unten."[241]

The direction and the degree of the tongue's movement are considered to be deciding factors in the process of production.

> "[…] bei der Vorderzunge führt diese Bewegung zum Beginn der Konstruktion hin nach vorn und nach unten, einhergehend mit einer Verringerung der Distanz zum Palatum. Über die nächsten 80 ms führt die Bewegung nach oben und nach unten, wobei sich die Distanz zum Palatum weiter verkleinert, danach folgt nach unten und nach hinten. Die Distanz zum Palatum vergrößert sich. Der Abstand zwischen Zungenrücken und Palatum verringert sich. Der Zungenrücken vollzieht hierbei zunächst eine bogenförmige Bewegung nach oben und nach hinten, um sich anschließend nach hinten und nach unten zu bewegen. Die Distanz zum Palatum vergrößert sich. Der Bereich der Verengung zwischen Hinterzunge und Velum verlagert sich bis zum ende der Konstriktion, mit einer eingebetteten Schleife, nach vorn und nach oben. Die Distanz zum Velum verengert sich […] die Zungenwurzel […] zeigt zum Beginn der Konstriktion hin zunächst eine Bewegung nach hinten und nach unten [...] die Distanz zur Pharynxwand steigt zunächst an und kehrt am Ende der Realisierung wieder zur Ausgangsposition zurück. Der rhinopharyngeal Kanal schließt sich während der ersten 40 ms der Realisierung[...] die Glottis zeigt eine Bewegung in mehreren Schleifen nach vorn und nach unten."[242]

In light of this detailed description of [ʃ] production, it can be seen that its sagital groove is wide and the tongue is found to be flatter than for [s] causing non-sharp friction noise. In addition, the production of [ʃ] requires lip-rounding rather than the lip spreading for [s]. Thus,

239 Cf. Metoui, M. (2001), pp. 207-210.
240 Ibid., p. 207.
241 Ibid., p. 208.
242 Ibid., pp. 208-210.

a great amount of fine motor control is required for large movements of the lips such as in the production of labials. Consequently, it seems likely that the aphasics were unable to perform those complex gestures because of the constraints in their motoric system.

To conclude, from an acoustical point of view, the findings revealed that the aphasic subjects do not make a clear distinction between the fricative sounds [s] and [ʃ]. Furthermore, the noise frequency for both sounds is clearly lower indicating overlapping between the two consonants, e.g. the noise frequency of [s] overlapped relatively with the higher end of the fricative [ʃ]. Nevertheless, it is noteworthy that the gesture complexity and the highly required coordination for the articulators that have to be executed timely and precisely contribute to this difficulty. The findings of misarticulating the sibilant fricatives are generally consistent with what has been reported from other languages. In this regard, several studies have indicated that the aphasic subjects demonstrated imprecise articulatory positioning.[243] Furthermore, like previous research, the performance of our aphasic patients would suggest that those errors could be related to phonetic-motoric problems. As a whole, by processing an utterance by Broca's aphasics, who generally exhibited phonetic-motoric deficiency, misarticulations have emerged either as distortions or substitutions. In addition, abnormalities in the vocal tract's configuration and slowness in the movement of the articulators resulting in imprecise articulations or substituting one sound for another contribute to this difficulty.

4.2.4. The acoustic features of the fricative [χ] as produced by the normal speakers and the aphasic subjects

According to the tables 60 and 61, different results of the acoustical parameters of the aphasic productions and the normal speakers can be noticed. In this account, with regard to the mean frication duration, it has appeared that the aphasics produced the sound [χ] longer than the normal speakers. It was 298msec for the aphasics and 98msec for the normal speakers. Furthermore, the normal subjects produced their [χ] with a high degree of aperiodicity indicating a high point of constriction and high velocity of the air (turbulence) passing through the constrictions. The results show that the aphasics display tensed dark points on the spectrogram in the frequency range 895-3763Hz, whereas the concentration of energy by the

[243] Cf. Gelfand, J., & Bookheimer, S. (2003): Dissociating Neural Mechanisms of Temporal Sequencing and Processing Phonemes, p. 837.

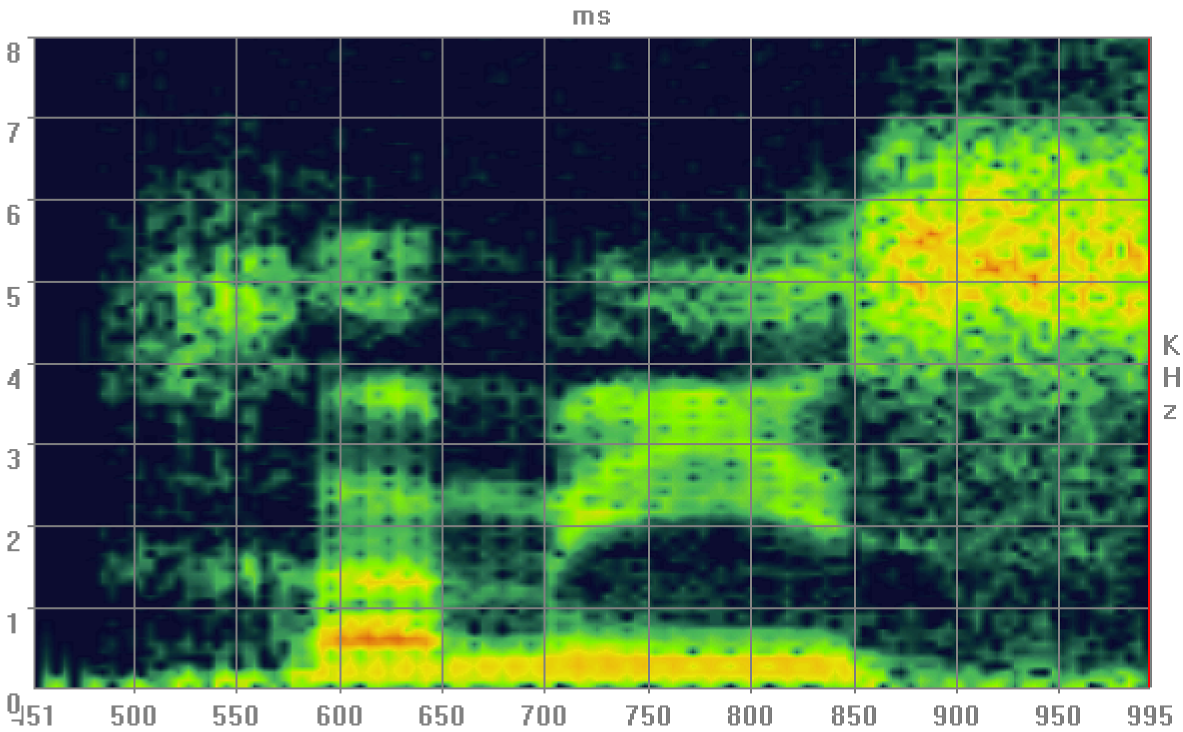
normal speakers can be noticed at higher frequency values between 1550-4590Hz, as shown in figures 94 and 95.

Power bandwidth of energy concentration (Hz)	Mean frication duration (r	Intensity (dB)
1550-4590	98	60

Table 60: The acoustic features of [χ] as produced by the normal speakers.

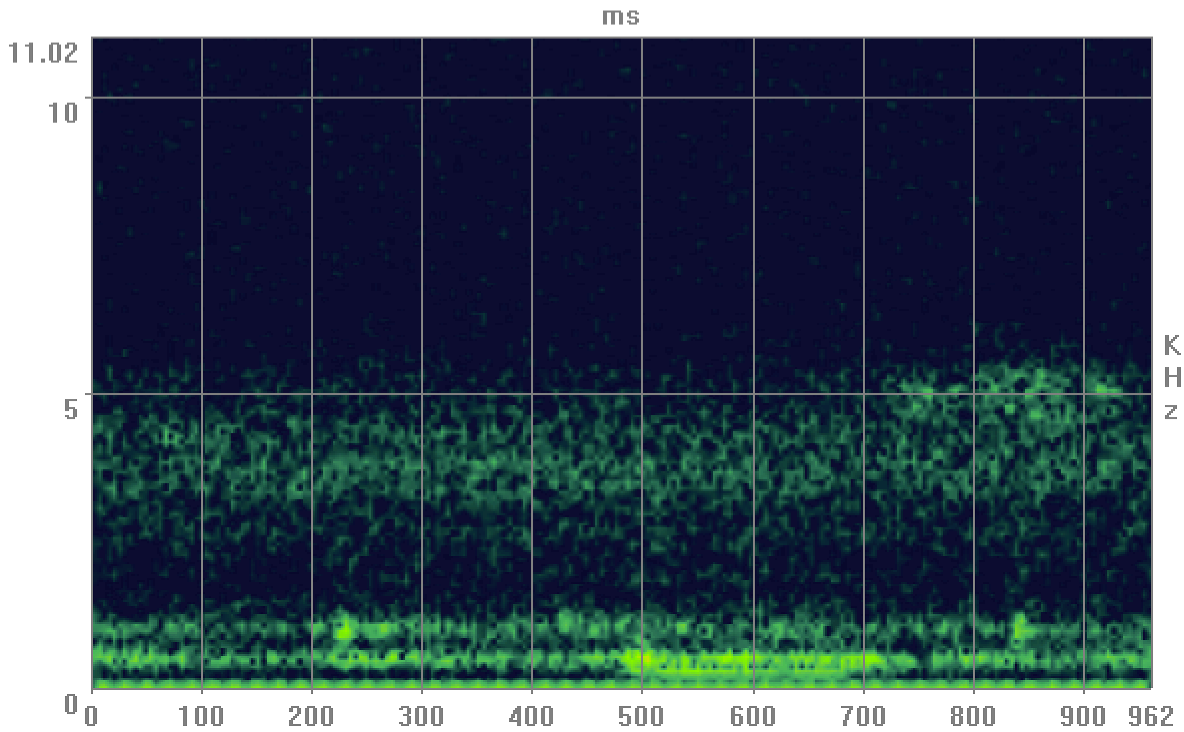
Power bandwidth of energy concentration (Hz)	Mean frication duration (r	Intensity (dB)
895-3763	298	52

Table 61: The acoustic features of [χ] as produced by the aphasic subjects.



χ a m i: s

Figure 94: Spectrogram of the word [χami: s] 'Thursday' as produced by a normal speaker.



χ a m i: s

Figure 95: Spectrogram of the word [χami: s] as produced by an aphasic subject.

In addition, as shown in figure 94, the noise frication of the sound produced by the normal speakers could reach frequencies over 7000Hz, whereas it does not exceed 5200Hz among the aphasics, as exhibited in figure 96.

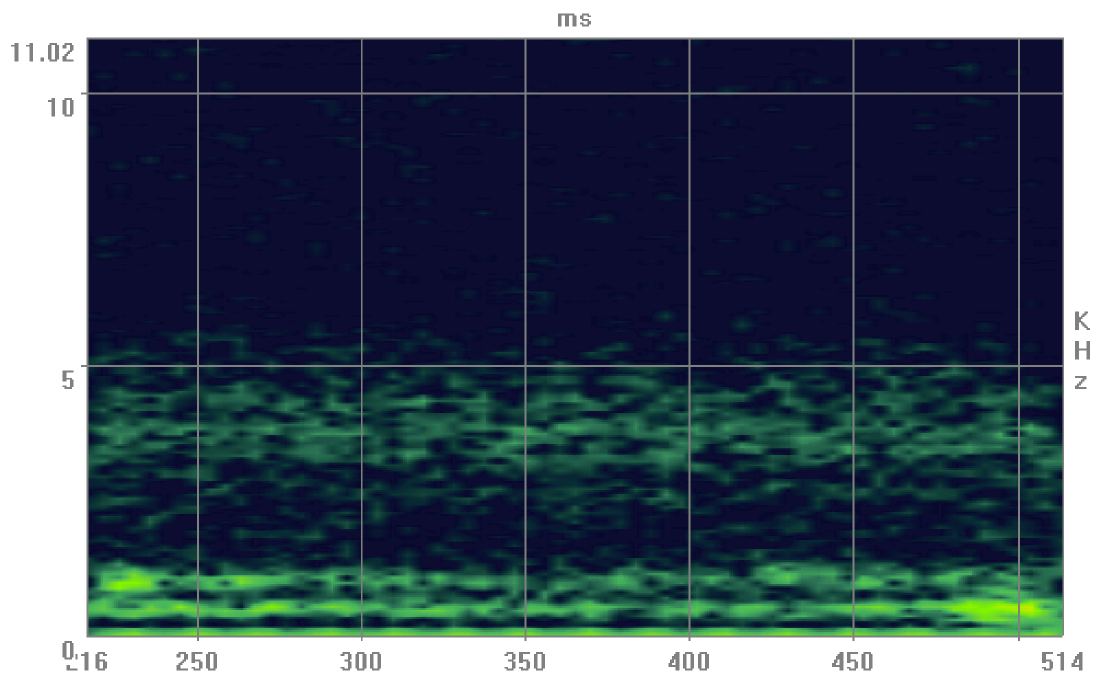


Figure 96: Spectrogram of [χ] in the word [χami: s] as produced by an aphasic subject.

In fact, it is also noteworthy that the aphasics produced their energy concentration at low frequencies in contrast to the normal speakers. Furthermore, there is a greater low mean intensity of their segments to 52dB. On the other hand, the normal subjects increased the intensity to 60dB. Clearly, the aphasic subjects exhibit low amplitude compared to the normal speakers, as shown in figure 97.

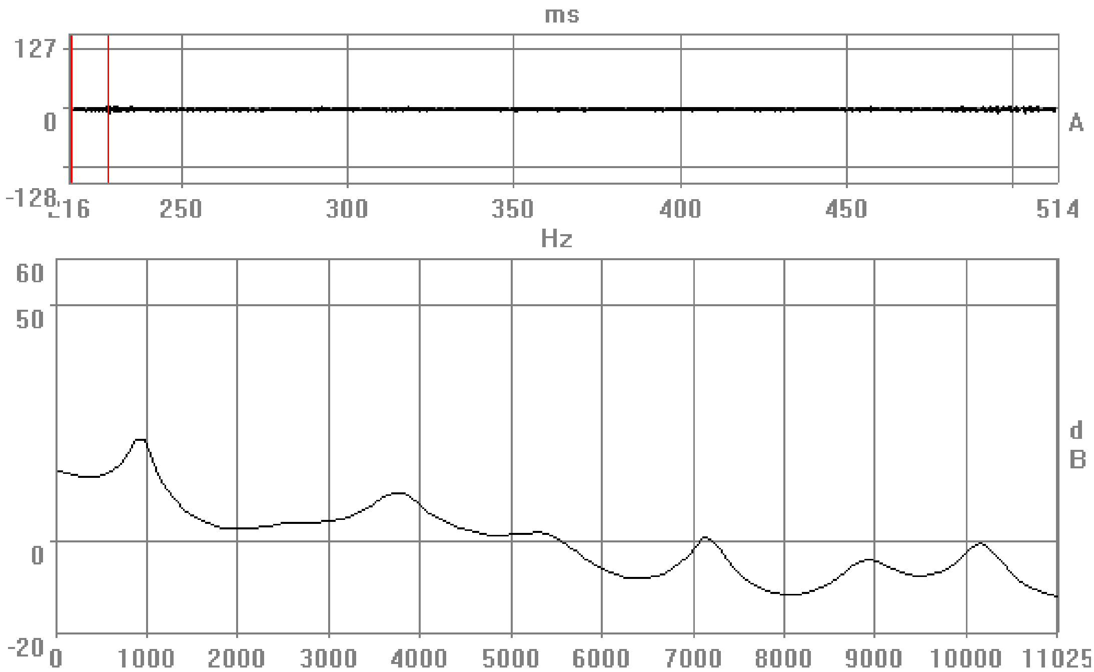
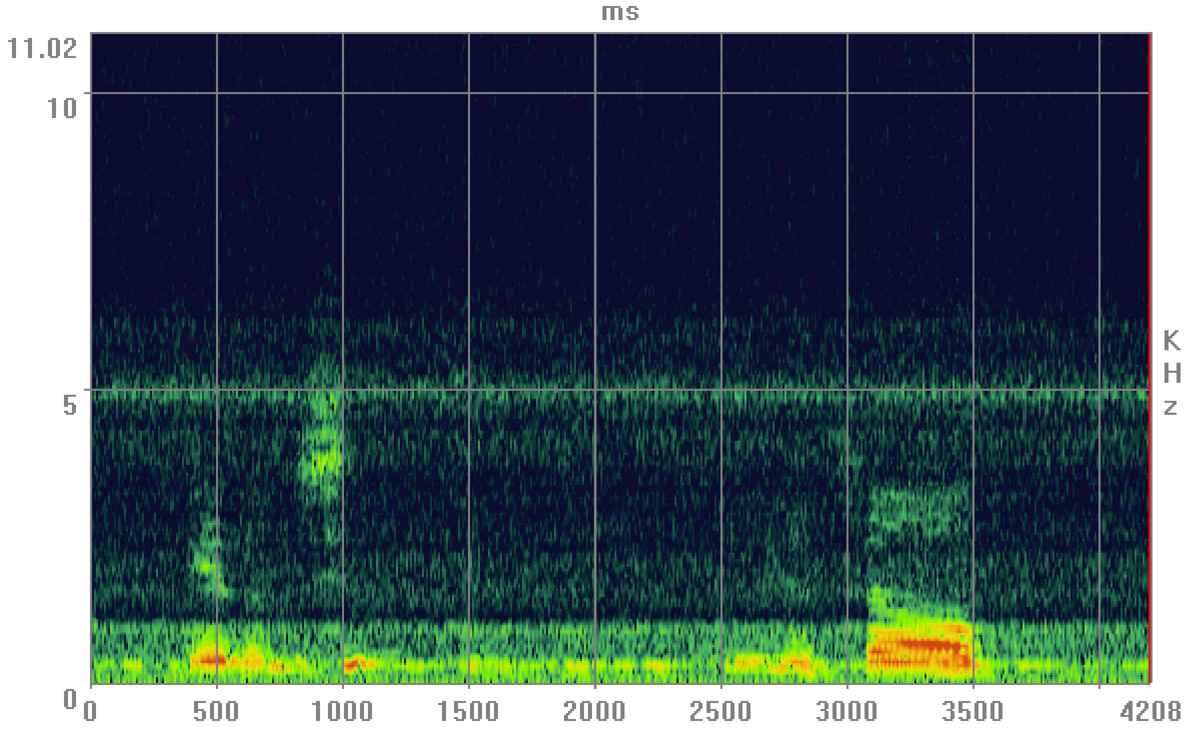


Figure 97: LPC of [χ] in the word [χami: s] as produced by an aphasic subject.

Not surprisingly, besides the acoustic deviations of our Broca's aphasics, they exhibited articulatory deficits as well. For example, subject B1 replaced [χ] in the word [χɛ:ʃ] with the erroneous [ʃ] producing the word [ʃɛ:ʃ]. This kind of substitution calls for attention because the subjects displayed big problems in producing the consonant [ʃ] as it has been discussed before. Therefore, an interesting question in light of this finding could emerge as to why these patients substitute [ʃ] for [χ] and could not produce it in the place where it should be correctly produced. Here, the morphological structure of the word [χɛ:ʃ] could lead to a kind of anticipatory coarticulation effects.

Furthermore, once again, the aphasic subjects exhibited the same impairment called "change error" that has been seen in the production of [s] and [ʃ].

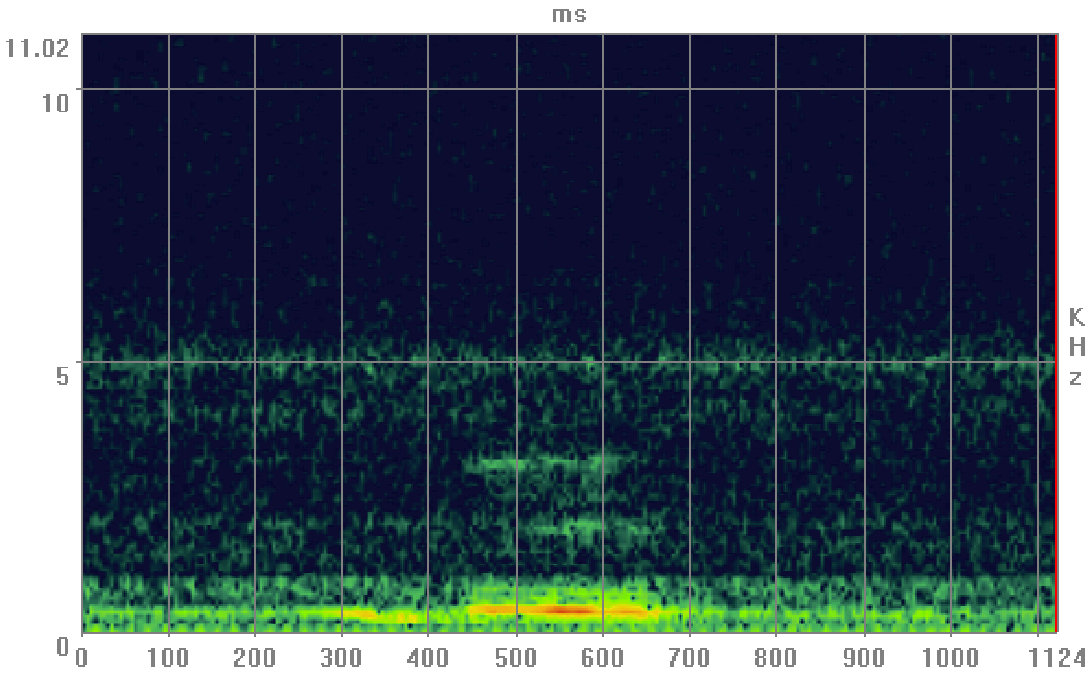
For instance, one of the subjects in his attempts to produce the word [ʔiχja:r] 'cucumber' replaced the target sound with other sounds by shifting rapidly to another with a long pause. In this respect, he produced the sound [ð], then moved to [ʃ] and then to [χ]. What is interesting that before producing the word [ʔiχja:r] he produced the short vowel [i], then lengthened it to [i:] to reach the target consonant, as shown in figure 98. This could be considered one of the extremist types of errors noticed.



i i: χ j a: r

Figure 98: Spectrogram of the word [iχja:r] 'cucumber' displaying a change error by an aphasic subject.

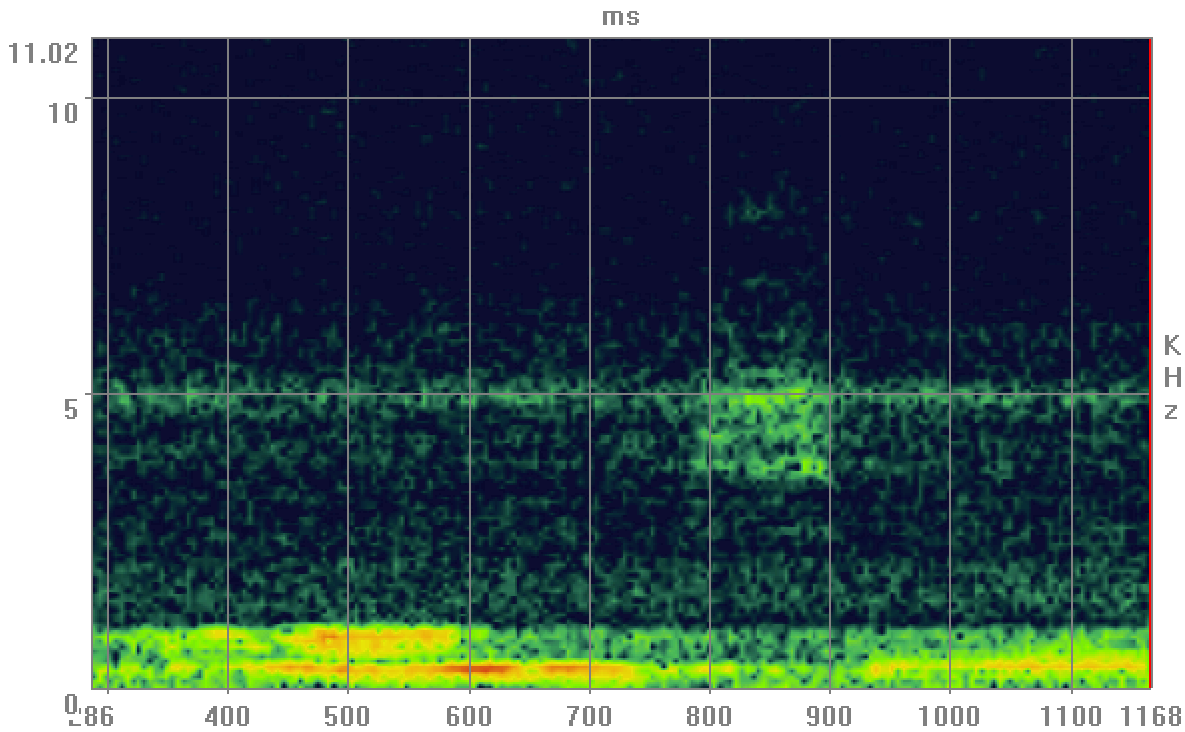
Furthermore, the aphasics tended to delete the sound [χ] from initial positions. For example, as can be seen from figure 99, they said [li:l], instead of [χali:l] 'Hebron,' by deleting one syllable CV [χa].



l i: l

Figure 99: Spectrogram of the word [li:l] instead of [χali:l] displaying deletion of [χa] from the initial position.

Significantly, it is of further of importance to indicate that the results contradict with what one might expect namely that the largest problem could lie in the voicing feature. However, the findings in some cases indicate that the direction of shifting was from voiceless to voiced fricatives and the substituted sounds differ only in one feature from the target sound, displaying that the problem affects the voiceless fricatives rather than the voiced ones. For example, subject B3, as figure 100 shows, substituted [ʕ] for [χ], sharing with each other only the manner of articulation.



ʕ a m s i: n

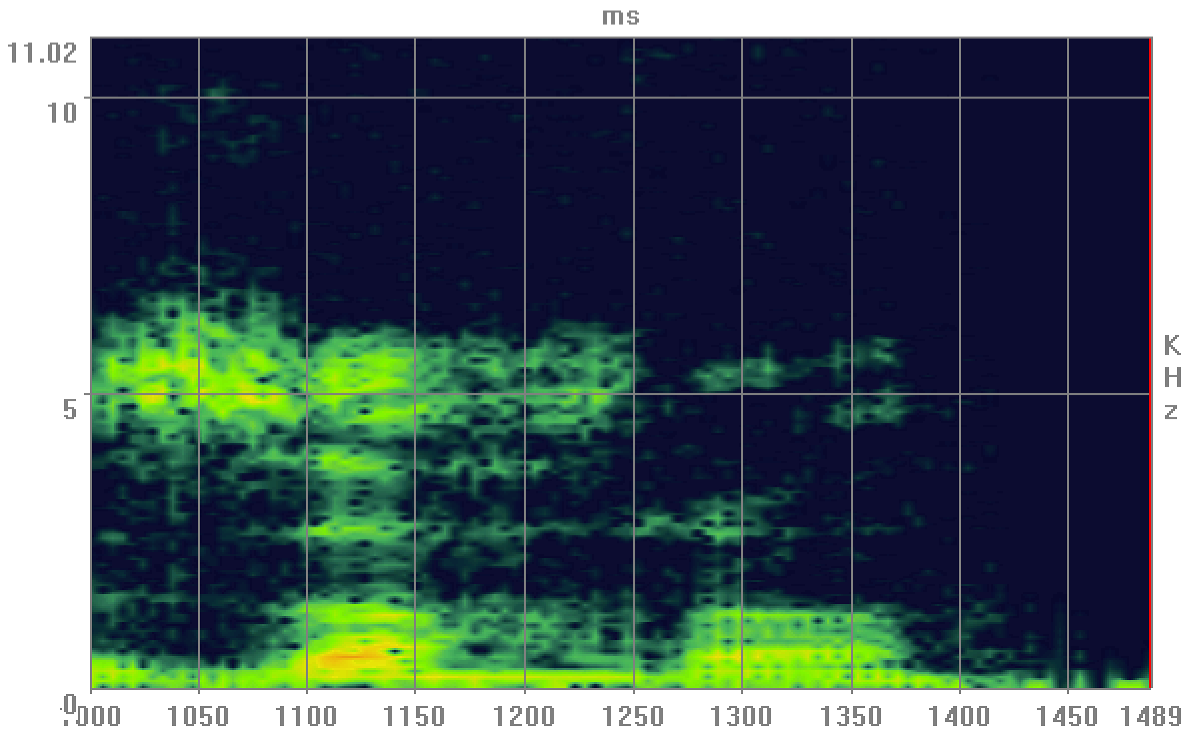
Figure 100: Spectrogram illustrating a substitution of [ʕamsi:n] for [χamsi:n] 'fifty.'

To sum the findings up, the problem of the aphasic subjects was clear in producing [χ] based on acoustical and physiological indications.

4.2.5. The fricative [z]

4.2.5.1. The acoustic features of [z] as produced by the normal speakers and the aphasic subjects

As it can be seen in figure 101, it is clear that the normal speakers displayed prominent peaks at a high frequency level, demonstrating maximum amplitude at frequency average between 4580-5480Hz with the absence of such peaks mainly at lower frequency ranges.



z a h r a h

Figure 101: Spectrogram of the word [zahrah] 'cauliflower' as produced by a normal speaker.

Basically, it appears that the geometry and the configuration of the vocal tract downstream of the constriction have a clear effect on the noise source of spectrum and its amplitude. This means that the distribution and density of energy at the high frequency averages are associated with the place of articulation formed at the front part of the vocal tract. This suggestion leads to characterizing such a spectrum as a "compact spectrum."[244] However, the patterns exhibited weakness of the acoustic energy formed back at the place of constriction, which is acoustically known as "acoustic coupling."[245] Figures 102 and 103 in addition to the table below summarize the main acoustic feature of the fricative [z] as produced by the normal speakers.

Power bandwidth of energy concentration (Hz)	Average energy distribution(dB)	Mean frication duration (msec)	Intensity (dB)
4580-5480	27.5	68	64

Table 62: The acoustic features of [z] as produced by the normal speakers.

[244] Jakobson, R., Fant, G., & Halle, M. (1952), p. 27.
[245] Johnson, K. (2002), p. 116.

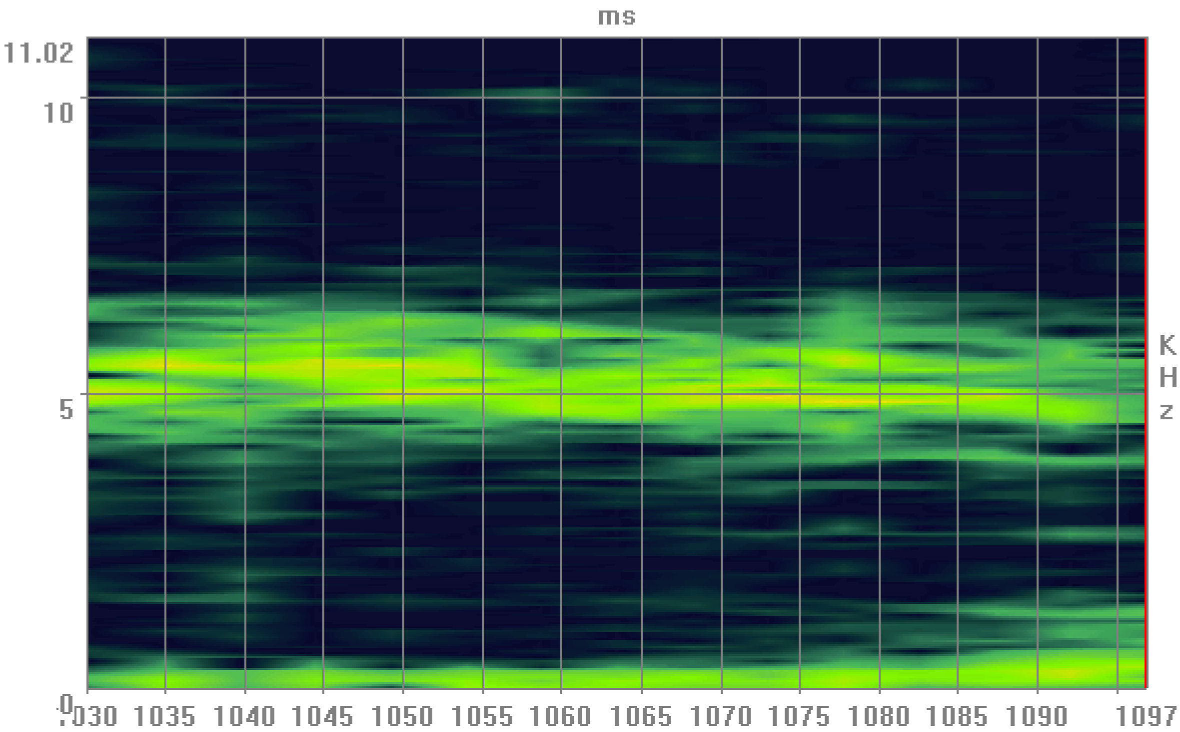


Figure 102: Spectrogram of [z] from the word [zahrah] as produced by a normal speaker.

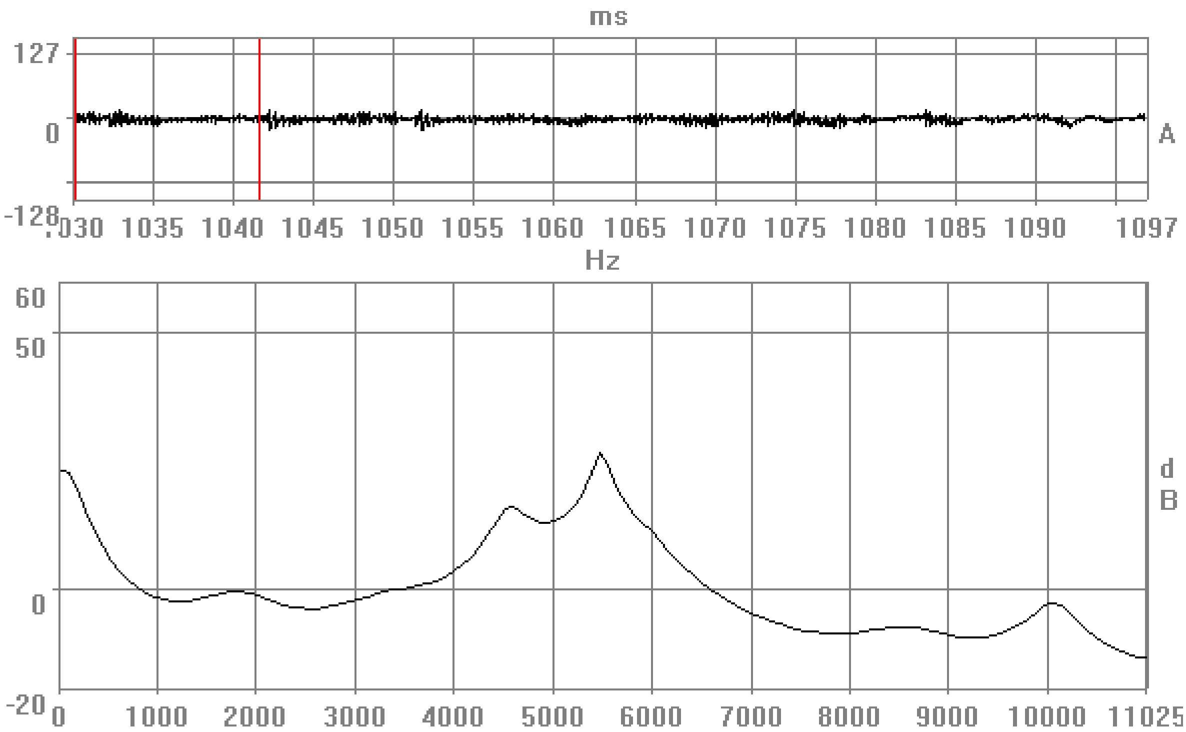
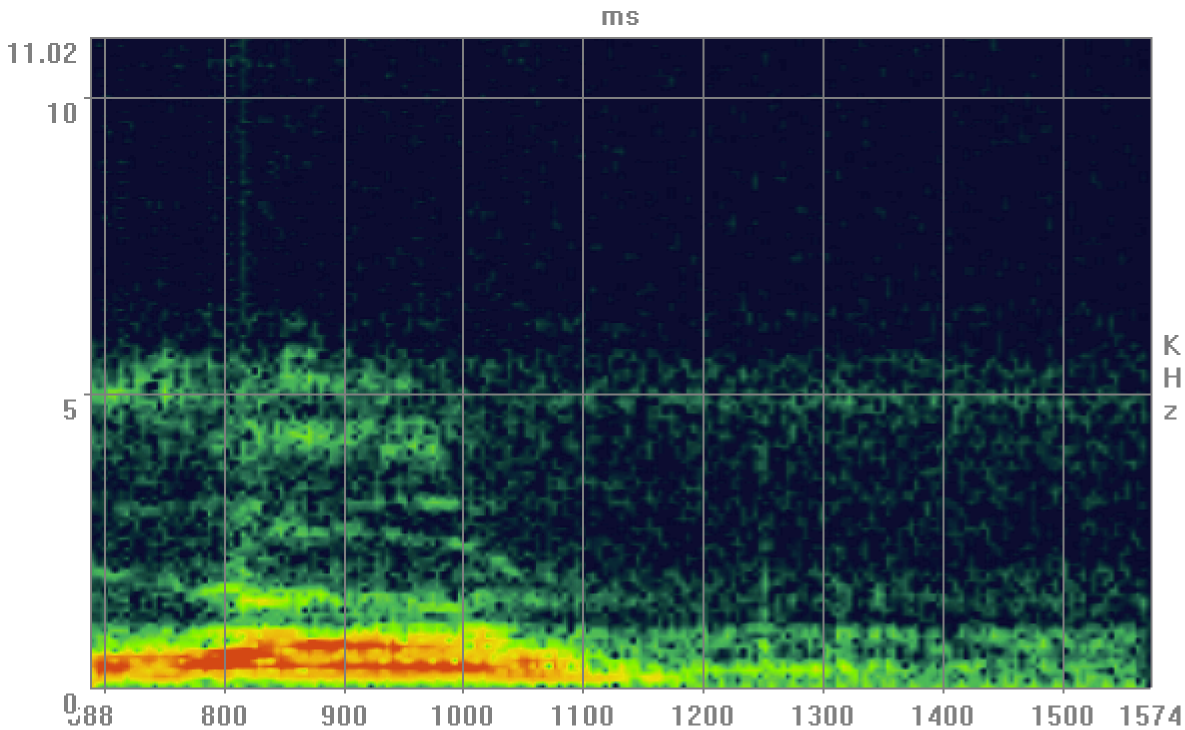


Figure 103: LPC of [z] from the word [zahrah] as produced by a normal speaker.

Contrary to the patterns shown by the normal group, the aphasics displayed maximum amplitude between the frequencies ranging between 320Hz-5055Hz, as figures 104 and 105 illustrate.



z a h r a h

Figure 104: Spectrogram of the word [zahrah] as produced by an aphasic subject.

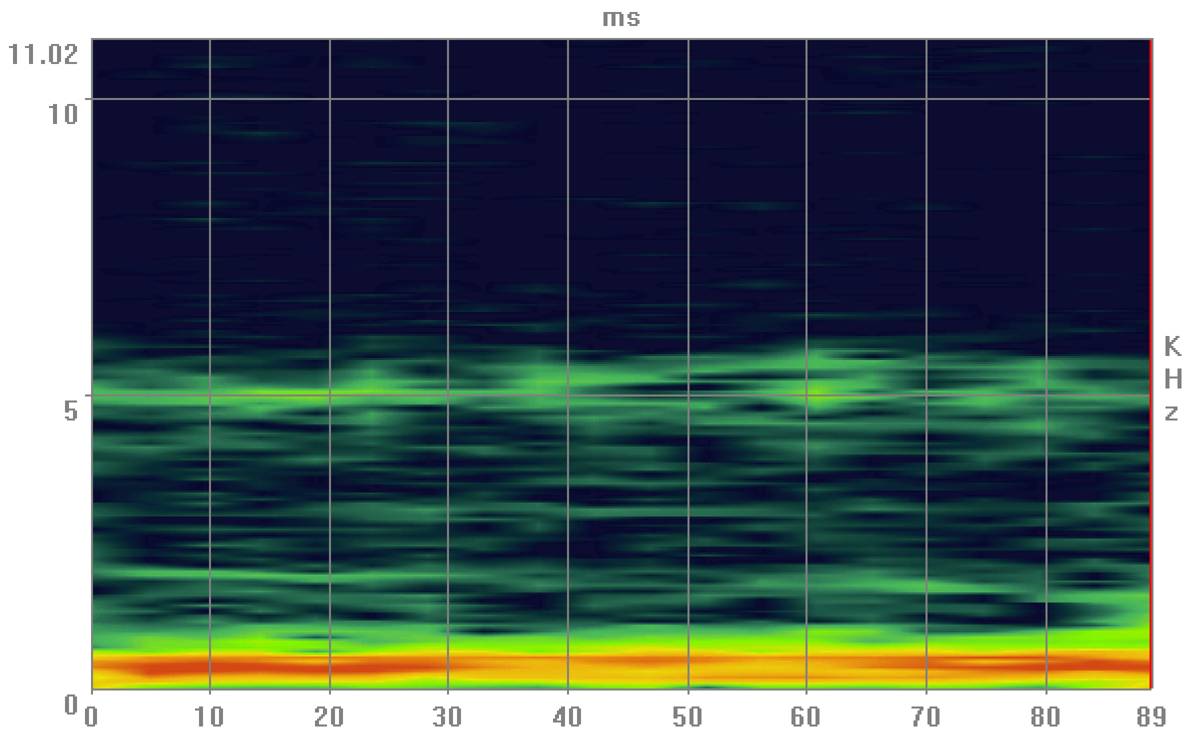


Figure 105: Spectrogram of [z] in the word [zahrah] as produced by an aphasic subject.

The mean intensity of the [z] was 59dB for the aphasic patients, whereas it was 64dB for the normal subjects. Furthermore, there was a gradual increase in the frication noise duration in the aphasics with 75msec on average relative to the normal speakers with 68msec.

Power bandwidth of energy concentration (Hz)	Average energy distribution(dB)	Mean frication duration (msec)	Intensity (dB)
320-5055	24	75	59

Table 63: The acoustic features of [z] as exhibited by the aphasic subjects.

In addition, there is a general pattern emerging from the aphasic productions indicated that Broca's aphasics displayed the first three formants notably far from each other, as shown in figure 106.

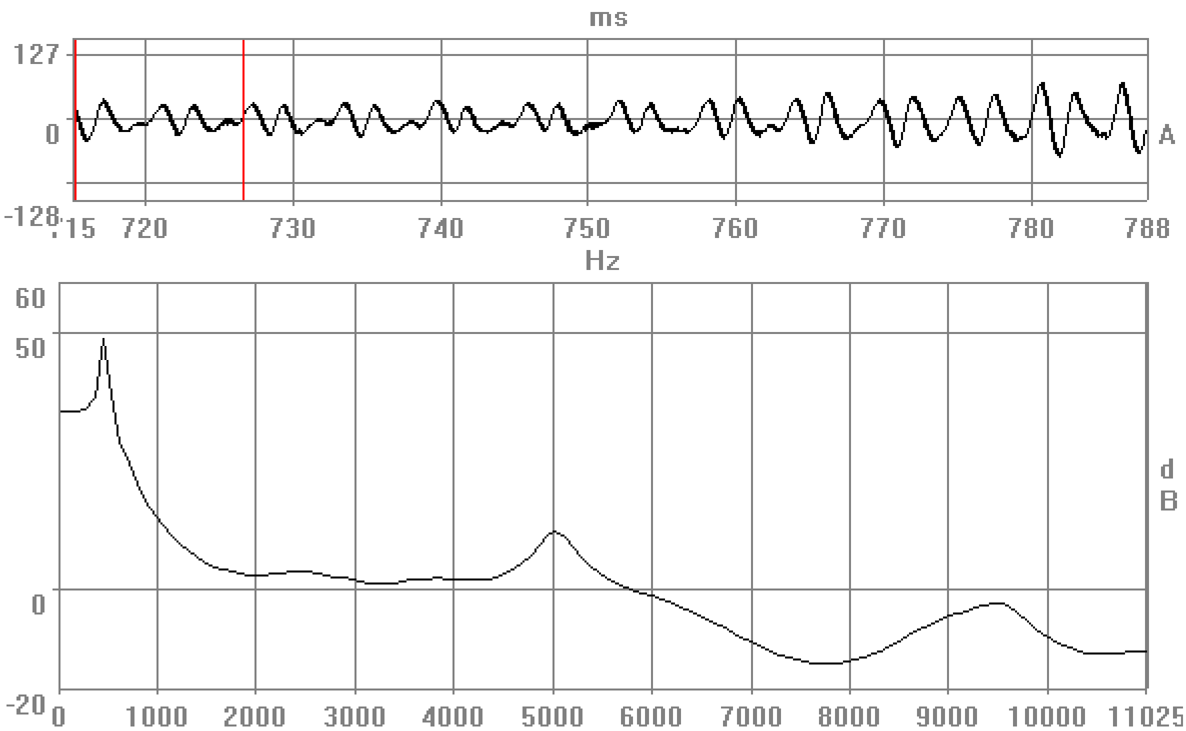


Figure 106: LPC of [z] from the word [zahrah] as produced by an aphasic subject.

4.2.5.2. The speech errors in the consonant [z]

With regard to the nature of deficits in producing the fricative [z], the results of the current section indicate that the aphasic subjects displayed tremendous deficits in initiating [z]. To avoid such difficulty, on the one hand, they relied on vowel initiation, as shown in figure 107.

On the other hand, they tended to lengthen the short vowel [a] to [a:], which is not phonologically required.

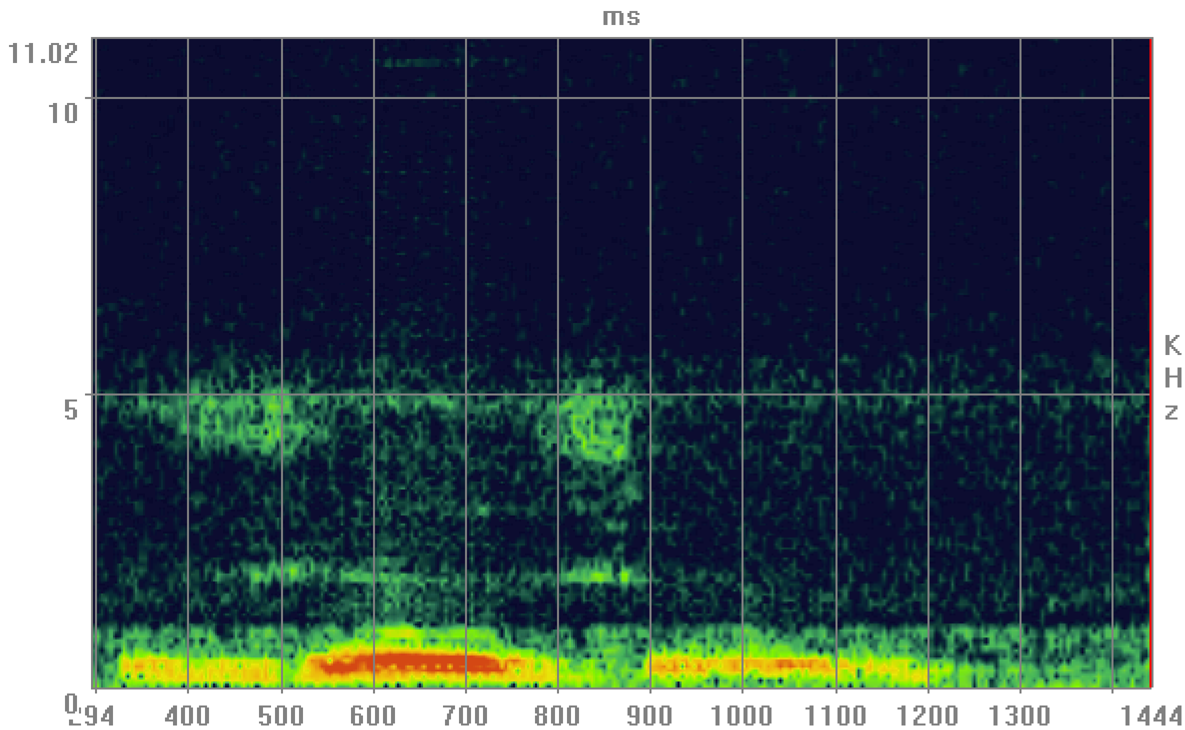


Figure 107: Spectrogram of the word [iza:su:n] illustrating lengthening of vowels and relying on the vowel to initiate the utterance as produced by an aphasic subject.

4.2.6. The emphatic fricative [sˤ]

4.2.6.1. The acoustic features of the emphatic fricative [sˤ] as exhibited by the normal speakers and the aphasic subjects

In general, emphasis is found to be in most of the Arabic dialects. This phenomenon has contributed to launching a great bulk of research in order to understand its nature and mechanism in terms of phonological, physiological and acoustical aspects. Importantly, emphasis in Arabic has a phonemic function. This means that the difference between the emphatic sound and its non-emphatic counterpart causes a difference in the meaning like [tˤɑ:b] 'recovered' and [ta:b] 'expressed penitence for.' Furthermore, according to Davis, emphasis is distinguished by "a primary articulation at the dental/alveolar region and with a secondary articulation."[246] Watson[247] points out that conducting emphasis involves association between two levels: pharyngealization and labialization. In general, it thus appears

[246] Cf. Davis, S. (1995): Emphasis in Grounded Phonology, p. 465.
[247] Cf. Watson, J. (1999): Remarks and Replies: The Directionality of Emphasis in Arabic, pp. 290-297.

that emphasis requires accessing a set of components involving the pharynx in a mechanism that is relatively similar to the way in the production of pharyngeal sounds. Before we continue, emphasis will be addressed in more detail in chapter five. In fact, from an acoustical point of view, emphasis is mainly distinguished by a lowering of the second formant F2 of the vowel following the emphatic consonant as it will be discussed in the next few pages.

Table 64 presents the acoustic features for the fricative [sˤ] as produced by the normal speakers. In this study, it has been noticed that the normal speaker's noise friction extended to the high frequency ranges, starting relatively from 4500Hz to above the frequency range 8000Hz, as figure 108 illustrates.

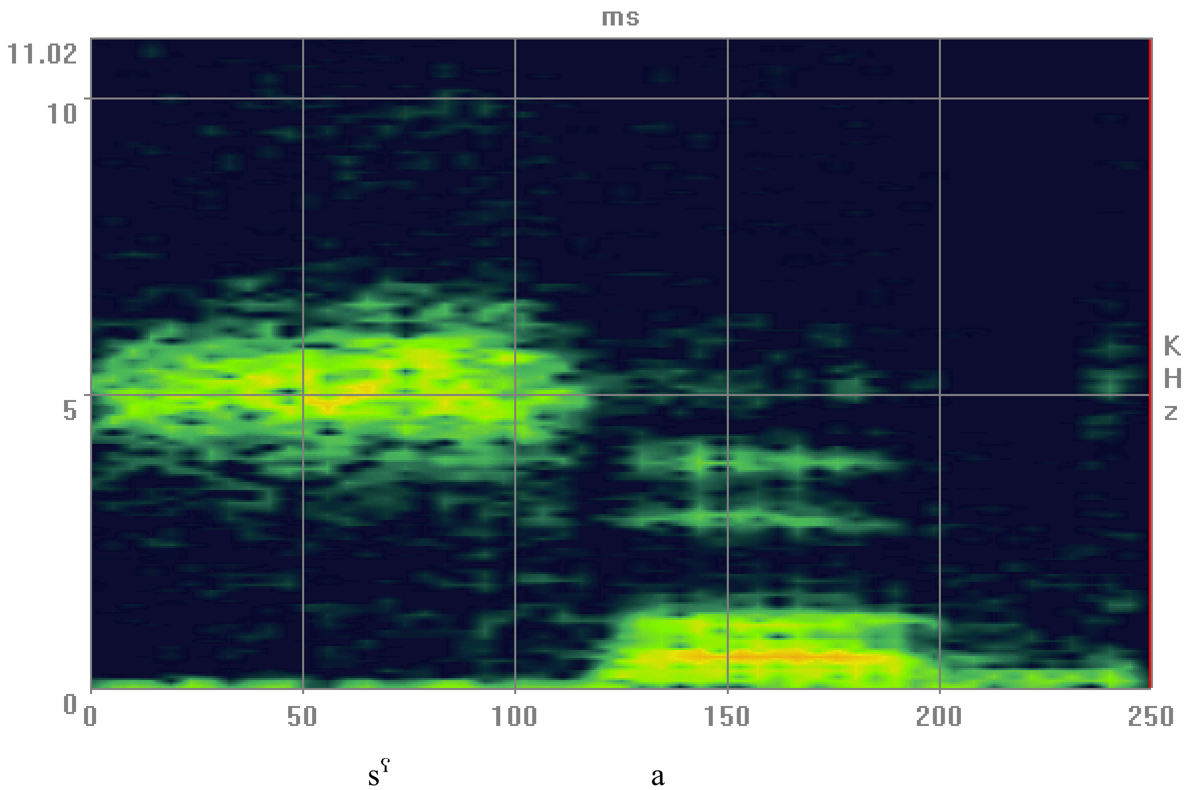


Figure 108: Spectrogram of the syllable [sˤɑ] from the word [sˤɑdi:qi:] as produced by a normal speaker.

Furthermore, the energy concentration was between 4599-5436Hz, based on figure 109.

Power bandwidth of energy concentration (Hz)	Average energy distribution(dB)	Mean frication duration (msec)	Intensity (dB)
4599-5436	28.1	127	65.2

Table 64: The acoustic features of [sˤ] as produced by the normal subjects.

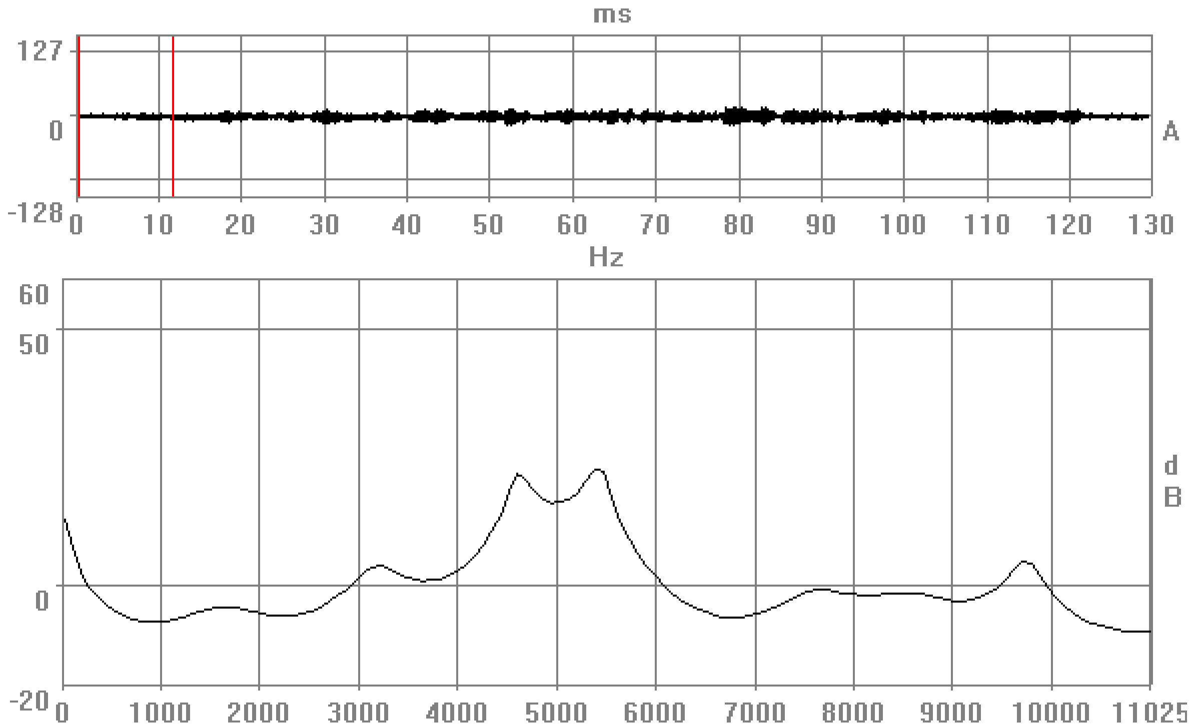
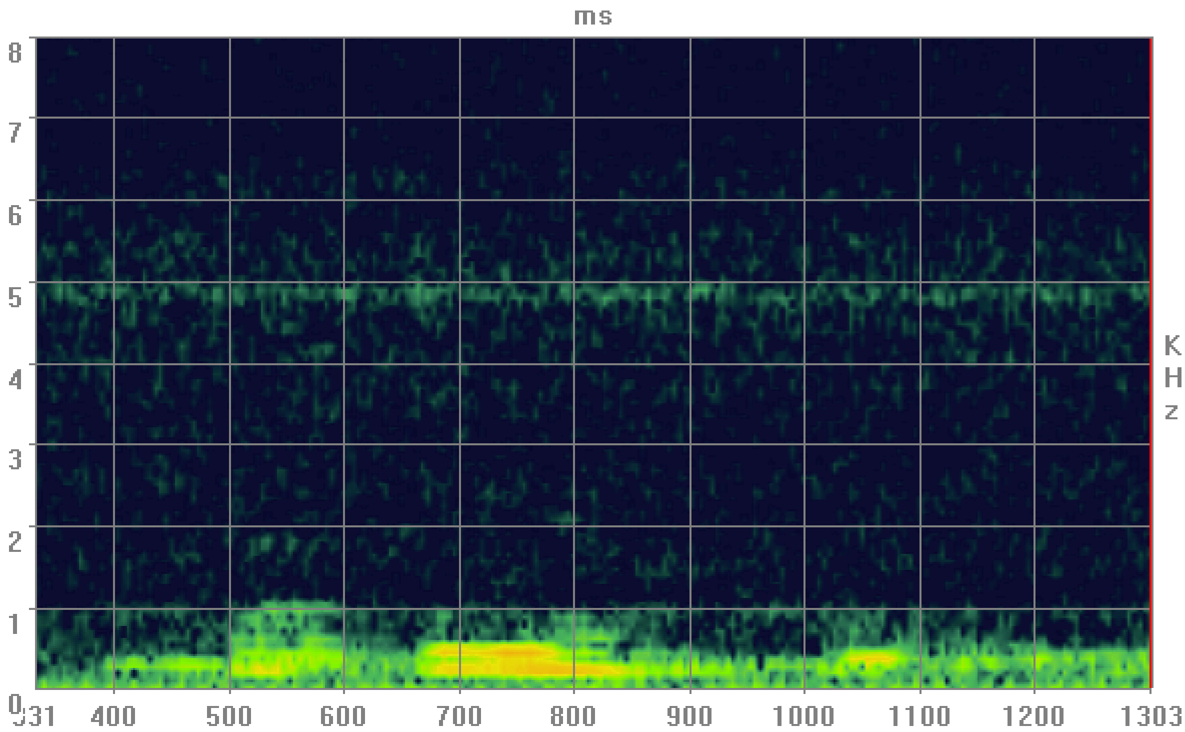


Figure 109: LPC of [sˤ] from the word [sˤɑdi:qi:] 'my friend' as produced by a normal speaker.

On the contrary, the aphasic subjects display energy concentration between 2380-4900Hz, as shown in figures 110 and 111. In general, the shortness of the front cavity formed during its articulation and the increased size of the constriction cavity helped in increasing the ranges of frequency.[248]

[248] Cf. Munhall, K. (2001): Functional Imaging during Speech Production, pp. 100-103.



sˤ a d i: q i

Figure 110: Spectrogram of the word [sˤɑdi:qi] as produced by an aphasic subject.

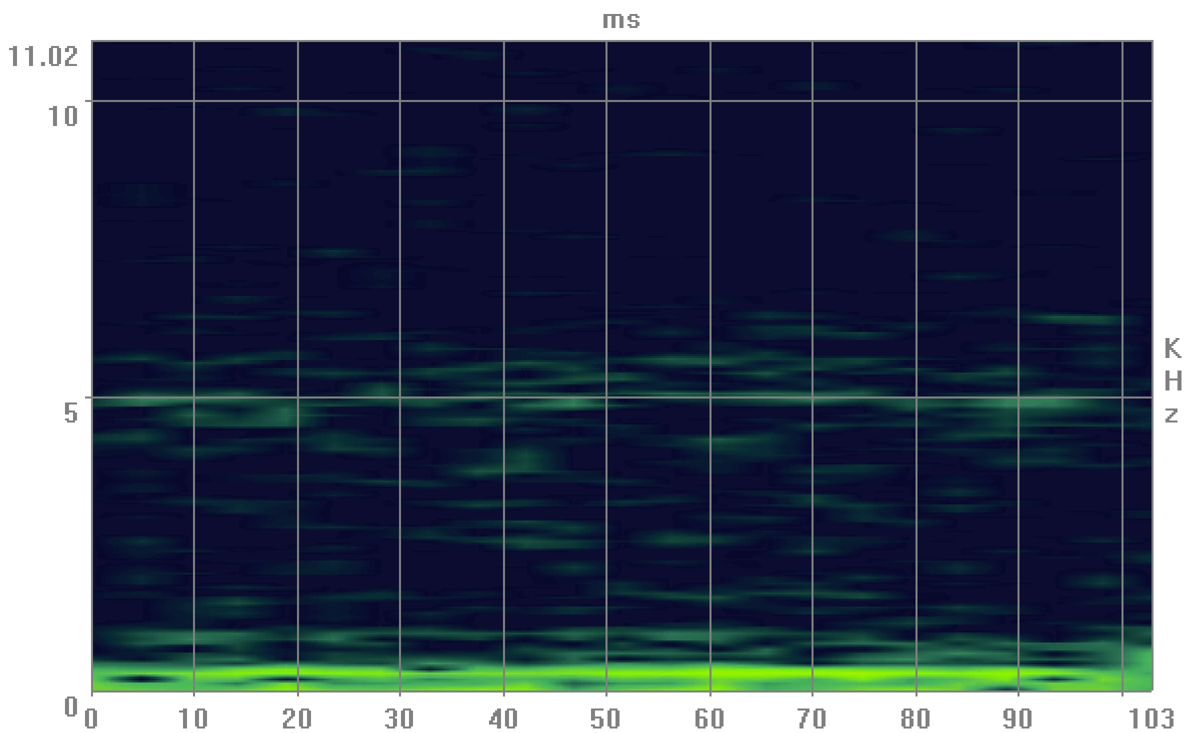


Figure 111: Spectrogram of [sˤ] in the word [sˤɑdi:qi] as produced by an aphasic subject.

Furthermore, the highest peak in which the energy was maximally concentrated was on average 5434Hz by the normal subjects, whereas the aphasics displayed this in average at 4900Hz, which is clearly seen in figure 112.

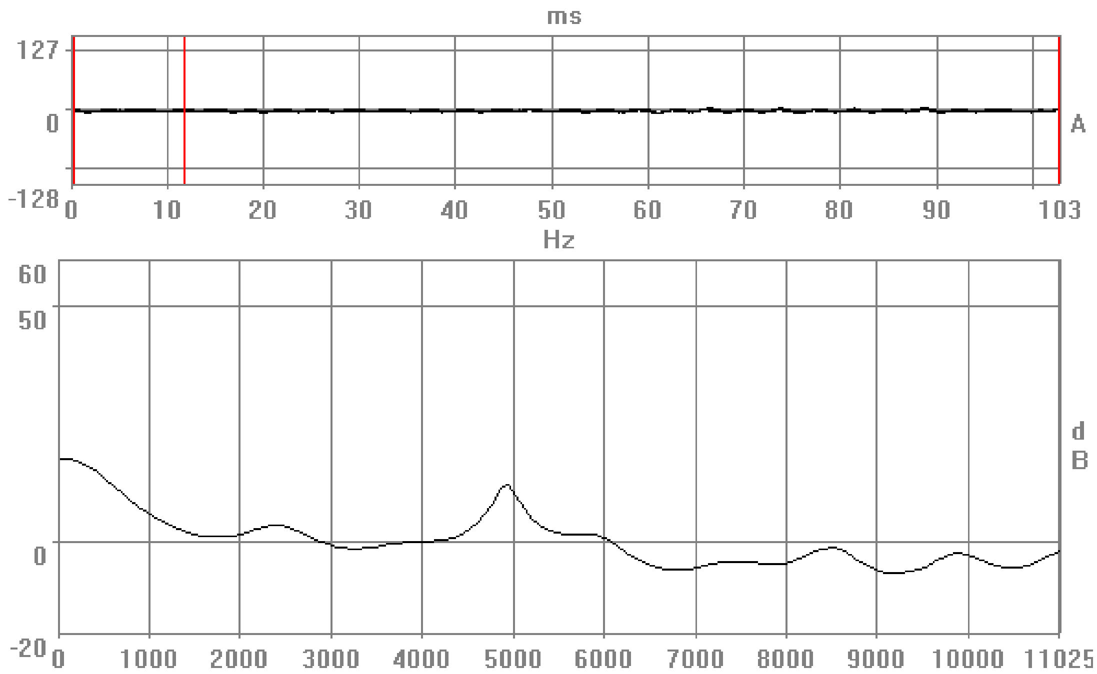


Figure 112: LPC of [sˤ] from the word [sˤɑdi:qi] as produced by an aphasic subject.

Power bandwidth of energy concentration (Hz)	Average energy distribution(dB)	Mean frication duration (msec)	Intensity (dB)
2380-4900	23.1	100	55

Table 65: The acoustic features of [sˤ] as produced by the aphasic subjects.

On the other hand, this emphatic sound, as produced by the normal speakers, exhibits relatively smaller frequency averages at which the energy is maximally intense in contrast to the sibilant non-emphatic [s]. Many factors come into play here:

1- The emphatic feature that makes a wide oral configuration backed to the place of constriction.
2- The lowering degree of constriction through the vocal tract.
3- The relative backness of its place of articulation.

Importantly, it was noted that the non-fluent aphasics in the present acoustic analysis produced the emphatic fricative [sˁ] shorter than the normal speakers did by registering 100msec on average compared to the normal speakers, who exhibited 127msec. In fact, this pattern runs contrary to the general patterns observed for the non-fluent aphasic patients when they produced longer segment duration. Furthermore, the normal speakers produced this emphatic sound longer than its non-emphatic counterpart. In this regard, it was 127msec for the fricative [sˁ] and 113msec for the non-emphatic [s], while the aphasic patients produced the sound [s] with 117msec. This finding would be related to the fact that the emphatic sound produced a large cavity backed to the area of constriction. As a result, hydrodynamic variations should be taken into consideration. This means that the particle should firstly spread in the vicinity and then pass through the constriction requiring more time for its evacuation. In addition, the backed place of articulation leads to an increase in the length of the vocal tract in front of the place of constriction. Thus, in addition to the other acoustic facts, this would be reflected in the intensity average percentage, which was found to be relatively smaller for the fricative [s] than for the fricative emphatic [sˁ].

Concerning the formant F2, many studies found that there is a remarkable lowering of F2 of the vowel following the emphatic consonant compared to the counterpart segment in non-emphatic environment.[249] In contrast, the aphasic subjects exhibit values that completely contradict with what has been displayed by the normal speakers. In general, the normal speakers on average manifested a lowering in F2 of about 337Hz for the vowel [a] in the emphatic environment compared to the same vowel in the non-emphatic environment. On the contrary, the F2 value in emphatic environments for the vowel [a] by the aphasic subjects was significantly higher with an average of 830Hz. There was a 300Hz increase in F2 in the emphatic environment compared to the same vowel in the non-emphatic environment produced by the aphasics. Furthermore, the normal speakers displayed an overall spectrum for an emphatic syllable more compact than its plain counterpart. This result would be related to the occurrence of the secondary back articulation that contributes to bringing the first two formants closer together by significantly lowering the second formant. The frequency values for the first two formants were successively 541Hz and 1943Hz for the aphasics and 530Hz and 1115Hz for the normal subjects, as figure 113 illustrates. Therefore, the aphasics

[249] Cf. El-Halees, Y. (1985): The Role of F1 in the Place of Articulation Distinction in Arabic, p. 298.

displayed a less compact spectrum distinguished by an increase in the frequency value of F2 of the following vowel.

As a whole, the vowel in the syllable with the emphatic target consonant clearly has a more compact spectrum for the normal speakers as opposed to the aphasics. The way of producing this sound, which requires main and secondary articulation, could contribute to the aphasics' inability to produce the emphatic fricative [sˤ]. On that basis, the way of producing this sound places the speech production system under great demands, requiring strong constriction at the alveolar area and pharynx, which might be challenging for the articulators. In this sense, Metoui found "eine starke Verengung im Pharynx, die bis zum epiglottalen Bereich gehen kann."[250]

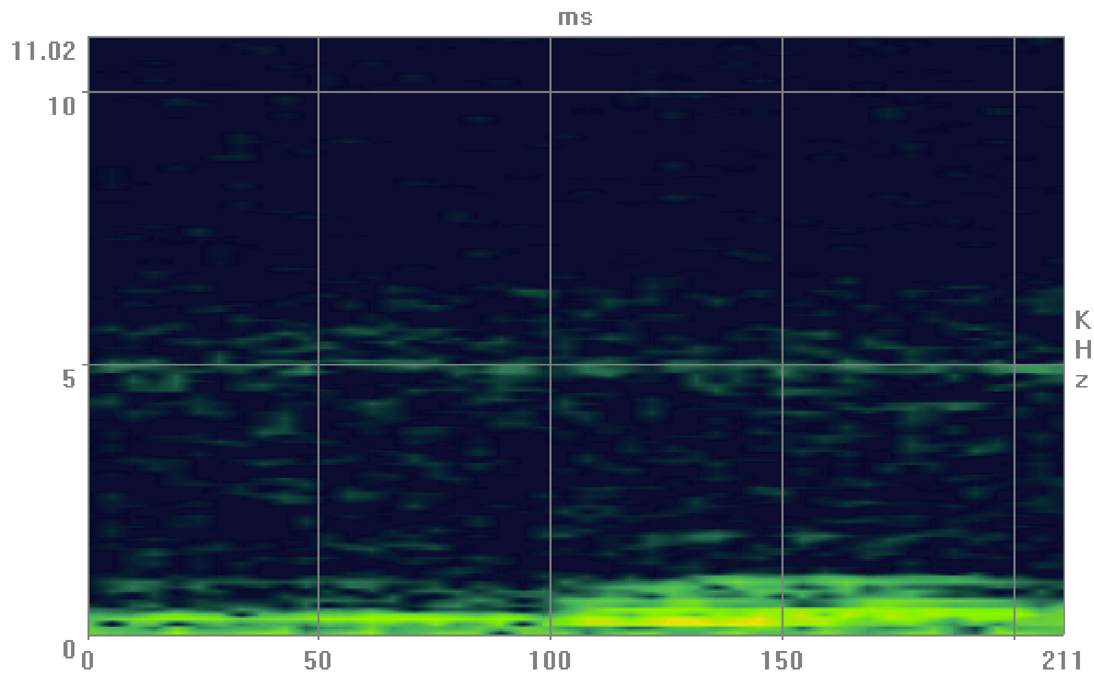


Figure 113: Spectrogram of the syllable [sˤɑ] in the word [sˤɑdi: qi:] as produced by an aphasic subject.

To sum up, the present findings indicate that a lowering of F2 in the vowel following the emphatic consonant is a valid and reliable acoustic correlate of emphasis. However, the aphasics displayed a lowering of F2 for the vowel in adjacent syllables in contrast to its non-emphatic counterpart, but less than that for the vowel produced by the normal speakers. This

[250] Metoui, M. (2001), p. 96.

suggests that the aphasics were unable to maintain this acoustic rule reflecting deficits in the production of emphatic fricative sounds.

4.2.6.2. The articulation errors in the emphatic fricative [sˤ]

In fact, as already noticed in the previous discussions of the aphasic patterns, neither the non-emphatic fricative sounds under study were produced accurately, nor the emphatic ones, as in the case of [sˤ]. In this sense, the subjects tended to substitute [sˤ] for its non-emphatic counterpart [s]. For example, one of the aphasic subjects, in his attempts to produce the emphatic sound [sˤ] in the word [asˤfar] 'yellow,' failed to articulate [sˤ] and changed it to the non-emphatic counterpart [s] by producing the word [asfar] 'resulted,' as shown in figure 114.

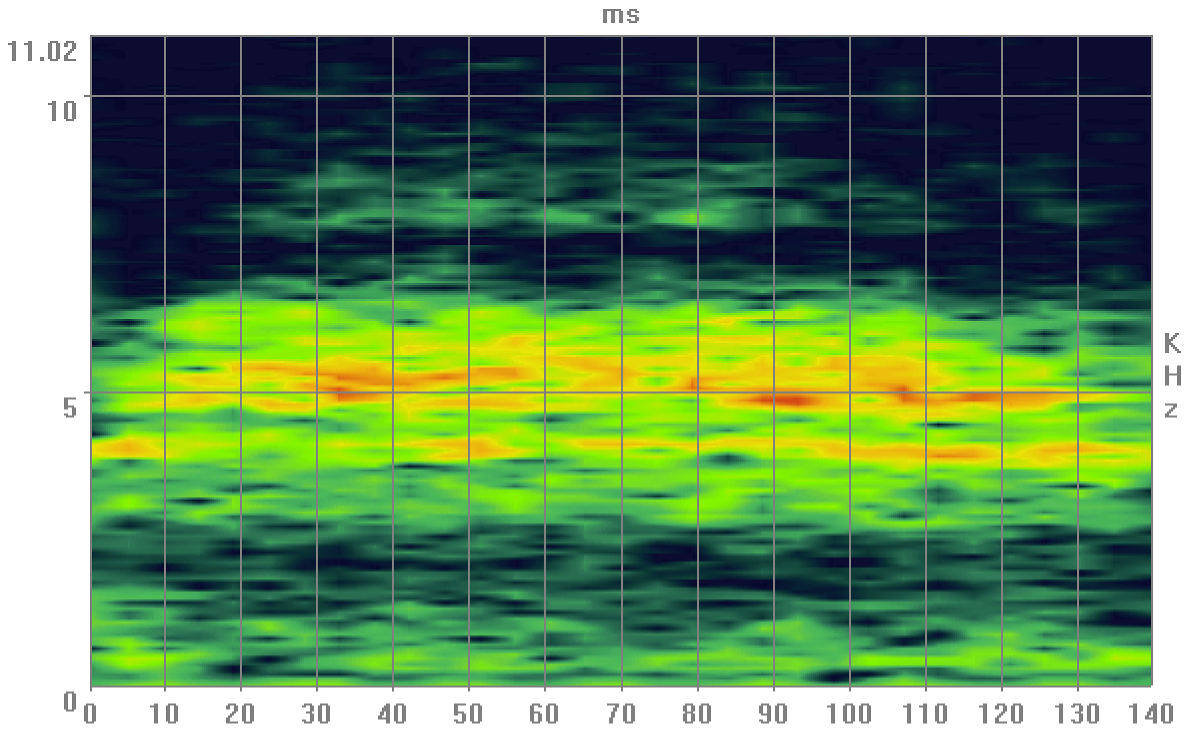


Figure 114: Spectrogram of the substituted [s] in the word [asfar] as produced by an aphasic subject.

From an acoustical point of view, when interpreting the previous observation, there are really two opposing patterns: on the one hand, the substituted non-emphatic [s] shows a different pattern than that exhibited by the same subject during his correct productions of [s] in that the substituted [s] was so intense, achieving 74dB, on the other hand, his [s] in correct productions was 57dB on average. Moreover, the frequency values of the first three formants was remarkably increased for the substituted [s] in contrast to the original [s] whose formant values were greatly smaller than those for the substituted [s], as shown in figure 115.

In addition to that, as opposed to the fricative [s], in the subject's productions the noise friction extended over most of the frequency ranges. It is of importance, however, to indicate that the two words [asfar] 'resulted' and [asˤfar] 'yellow colour' are minimal pairs.

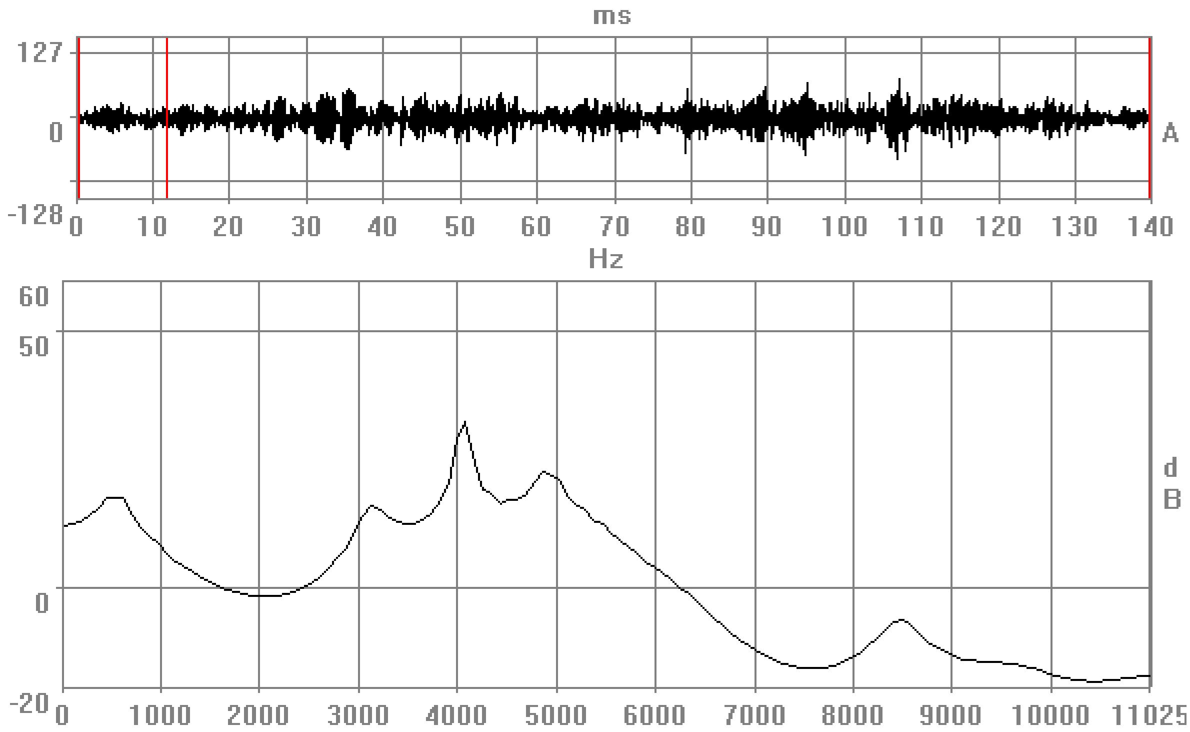
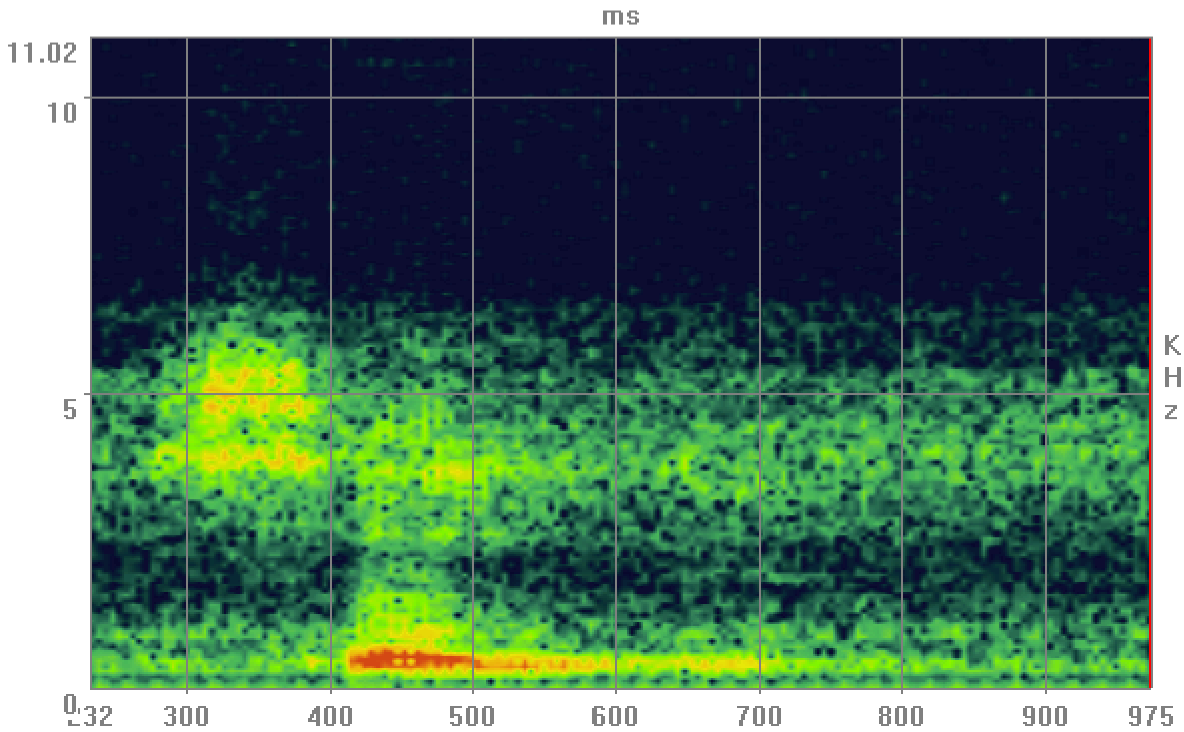


Figure 115: LPC of the substituted [s] in the word [asfar] as produced by an aphasic subject.

It was sometimes difficult to judge whether this sound is [sˤ] or its non-emphatic counterpart [s]. Therefore, based on the spectrogram and the LPC analysis in figures 116 and 119, some deficits were defined as the emphatic sound and others as the non fricative [s]. These deficits are considered to be distorted substitutions rather than pure substitutions, as shown in figures 116 and 117.



bi s^ʕ a l i

Figure 116: Spectrogram of the word [bis^{ʕ}ɑli] 'praying' as produced by an aphasic subject.

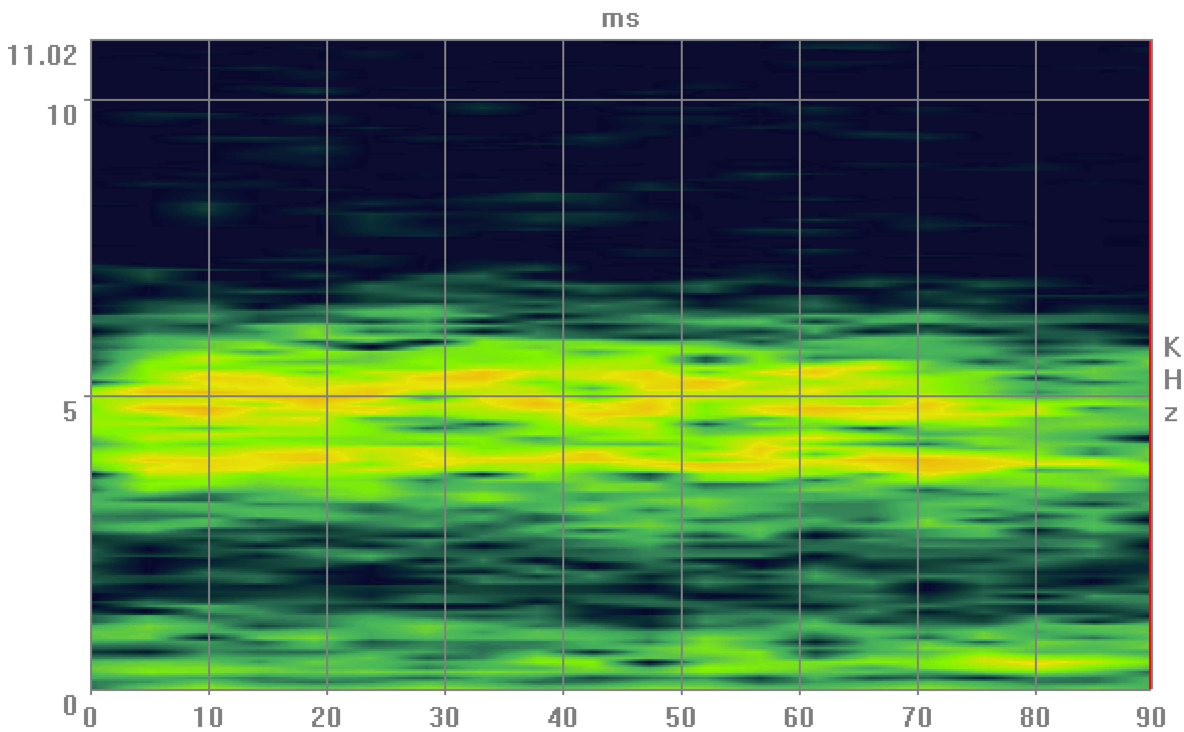


Figure 117: Spectrogram of emphatic [s^ʕ] from the word [bis^{ʕ}ɑli] as produced by an aphasic subject.

More generally, it can be noted that the general form of the wave expressed by the LPC, as shown in figure 118, respectively resembles what has been exhibited by a normal subject, as shown in figure 109. Also, the peak ranges where the energy was most intense lie within the range represented by the normal speakers. This example, therefore, would emphasize the importance of the acoustic analysis in the diagnosis of articulation disorders because it could be possible to perceive a sound as an error, but the acoustic analysis categorized it within normal ranges or distortions.

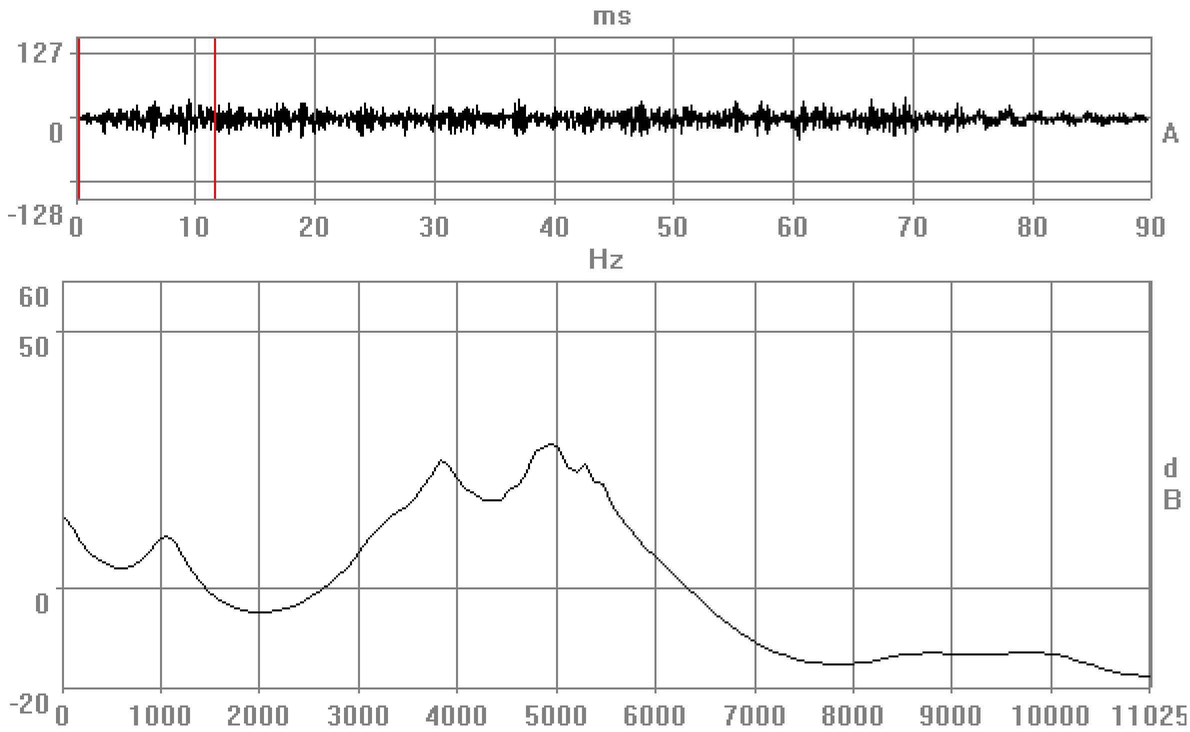


Figure 118: LPC of [sˤ] in the word [bisˤɑli] 'praying' as produced by an aphasic subject.

To conclude, based on the results reported above, it can be said that the aphasic subjects exhibited acoustic features that differ from those of the normal speakers. The acoustic data reveals that this is the only emphatic fricative sound that shows a problem by those patients. For example, the aphasics demonstrated no deficits in producing the fricative dental-alveolaremphatic, suggesting that sounds with less motor complexity are better articulated.

4.2.7. Neurolinguistic and phonetic discussions

With respect to the mean frication duration, different results can be seen between the aphasic patients and the normal speakers, as shown in figure 119. These can be summarized as follows:

1- It is true for the aphasic group as well as for the normal speakers that the average duration of the voiceless fricatives was longer than the voiced fricative sounds.
2- The sound [ʃ] achieved the longest duration among the normal speakers, whereas the sound [χ] was the longest by the aphasics indicating a deviation from the patterns of the normal speakers.
3- The normal speakers and aphasic subjects produced [z] as their shortest sound.
4- The normal speakers produced the emphatic sound longer than its non-emphatic counterpart, while the aphasics opposed this pattern.

Consonant	Aphasic subjects	Normal speakers
s	117	113
ʃ	208	131
χ	298	98
z	75	68
sˤ	100	127

Table 66: Summary of the segment duration (msec) for the consonants understudy as produced by the normal speakers and the aphasic subjects.

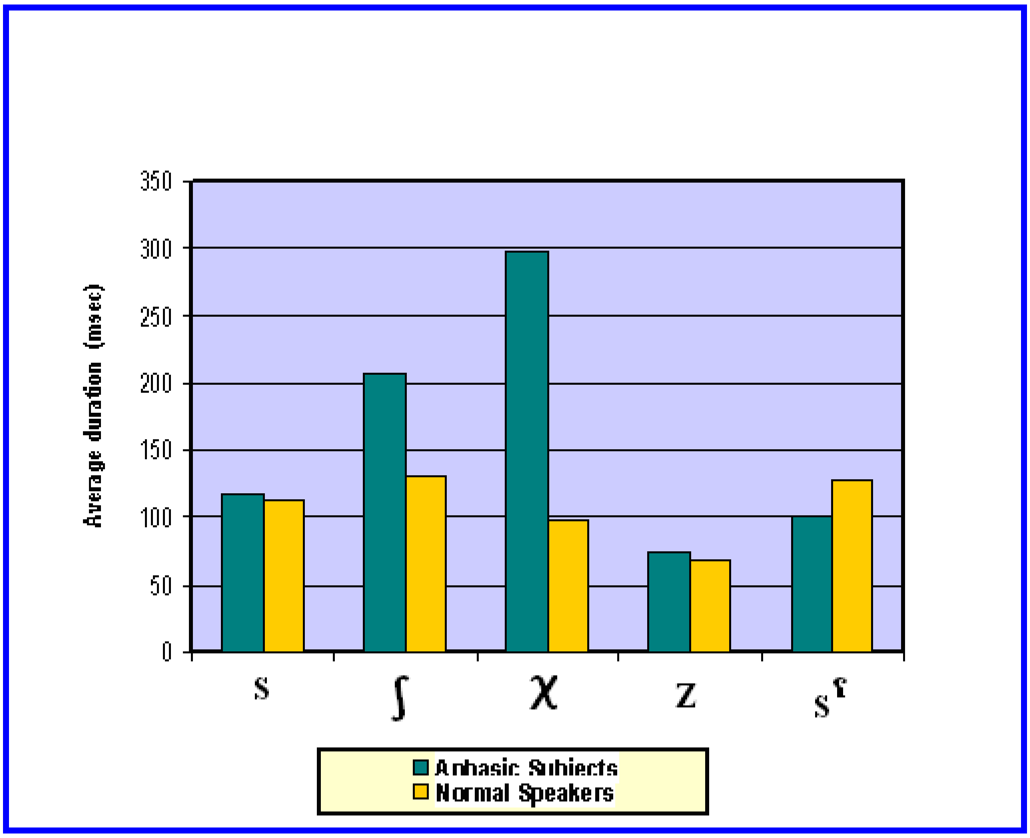


Figure 119: Summary of the segment duration (msec) for the sounds understudy as produced by the normal speakers and the aphasic subjects.

Furthermore, the following average intensities and power bandwidths for the aphasic and the normal subjects were noticed:

1- The sound [s] has achieved the highest frequency by the normal speakers. However, the aphasics did not follow this trend by producing the highest frequency for [z].
2- Taken together, the normal speakers exhibited higher frequency and intensity for the voiceless fricatives than for their voiced counterparts as in the case of [s] and [z]. In contrast, the aphasics were not compliant with this rule by displaying specific deficit and overlapping between the two sounds.
3- While the normal speakers demonstrated a lower average for intensity and frequency of each emphatic sound for its non-emphatic counterpart, the aphasics contradicted with such patterns as it is clear with [sˤ] and [s].

4- With regard to the effect of place of articulation, the frequency average is lowered as the place of articulation is moved back. This was noticed for the normal subjects as well as the aphasic patients.

5- Concerning the effect of tightness constriction and air turbulence on the intensity, the following ranking was demonstrated by the normal speakers. It runs from the highest to the lowest average:

[s], [ʃ], [sˤ], [z] and [χ].

The aphasic subjects did not completely adhere to this ranking by revealing the following order:

[z], [ʃ], [sˤ], [s] and [χ]

6- The energy of the spectrograms was generally flat in the case of the aphasic subjects, displayed a reduction of energy at the higher frequencies compared to the normal speakers. Therefore, a remarkable reduction in the peaks of the spectrum was noticed demonstrating weaker amplitude values of the fricatives compared to those exhibited by the normal control subjects. The lower amplitude values of the aphasics suggest an inappropriate adducting of the vocal folds or abnormal expanding of the volume of the vocal tract.

In general, these results suggest that the locus of the speech production deficit of the Broca's aphasics did not lie at the higher stages of speech production involving phoneme selection but rather at the implementation level. However, those findings were not consistent with the deficits in the production of voicing in stop consonants, which is considered the result of a timing disorder as indicated in different studies.[251]

To sum up, Broca's aphasic subjects in the current study were able to maintain the phonetic distinction between voiced and voiceless fricatives. This would give evidence to the source of the errors that would be related to lower level impairments. Concerning the voiced fricatives, the results demonstrated that the speech impairments were not necessarily always related to deficits in the timing of articulatory gestures. Rather, these patients displayed a great problem with laryngeal control resulting in difficulties in initiating and sustaining normal amplitudes of glottal excitation. Furthermore, it may be important to indicate that, as noted earlier, the aphasic subjects demonstrated remarkable problems in producing fricative sounds and the

[251] Cf. Blumstein, S., Cooper, W., Goodglass, H., Hstatlender, S., & Gottlieb, J. (1980), p. 168.

voiceless ones in particular. Substitutions and distortions were the predominant types of errors involving particularly the place of articulation feature.

In keeping with the results reported from several studies,[252] our findings indicate that the target phoneme and the substituted one rarely differed by more than one distinctive feature and the place of articulation is the most involved. This is in accordance with other non-Arabic investigations. The articulation errors were distributed over many types of errors including fricative deletion and substitution as well as fricative stopping and distortion. Nonetheless, although the aphasic patients exhibited voicing disorders in the stop consonants, it was noticed that they did not demonstrate such a deficit in the fricative sounds. This finding is consistent with what was reported by other scholars, e.g. Blumstein[253] and Haley et al.[254] Those error patterns may give some evidence to suggest that this problem did not indicate a disability in selecting the distinctive features for speech, but a sloppiness of motor execution.[255]

The aphasics in their production displayed a kind of dis-coordination between different levels involving particularly the respiratory drive, laryngeal and articulatory posturing. In fact, they were inable to maintain a fine, organized, timed, precise and coordinated control of the motor commands in producing the sounds. However, apart from these facts, it is natural to expect that the articulatory inaccuracy increased as the utterance complexity grew because this requires proper and complex sequences demands that are essential for the production process. The sibilant fricatives, in particular the fricative [ʃ], were found especially difficult to be produced precisely. For example, the fricative [ʃ] was erroneously substituted by the following phonemes:

[s]
[z]
[tʃ]

These difficulties would emphasize a disability in their articulatory positioning as well as a reduction in the distinction between the places of articulation in the form of overlapping,

[252] Cf. Blumstein, S. (1973), p. 48.
[253] Cf. ibid., pp. 46-53.
[254] Cf. Haley, K., Bays, M., & Ohde, R. (2001), pp. 1132-1140.
[255] Cf. Harmes, S., Danilo, R., Homan, P., Lewis, J., Kramer, M., & Absher, R. (1984), p. 384.

suggesting a deficiency in the phonetic-motor control involving neuromuscular impairments. Contrary to expectations, the aphasics exhibited only minimal problems with the voiced fricative that affected only the sound [z] contradicting with Code and Ball,[256] who examined the control of voicing during production by Broca's aphasics. They reported from relatively complete devoicing of the voiced fricatives, a feature that has not been evidenced in the current study. Moreover, some of the aphasics tended to make pauses between the syllables that form the word causing unusual tempo and slowing the rate of speech. For example, one of the aphasics made in producing the word [ʔawla:d] (boys) (CVC/CVVC), as figure 120 indicates, a pause between the two syllables lasting for more than 170msec.

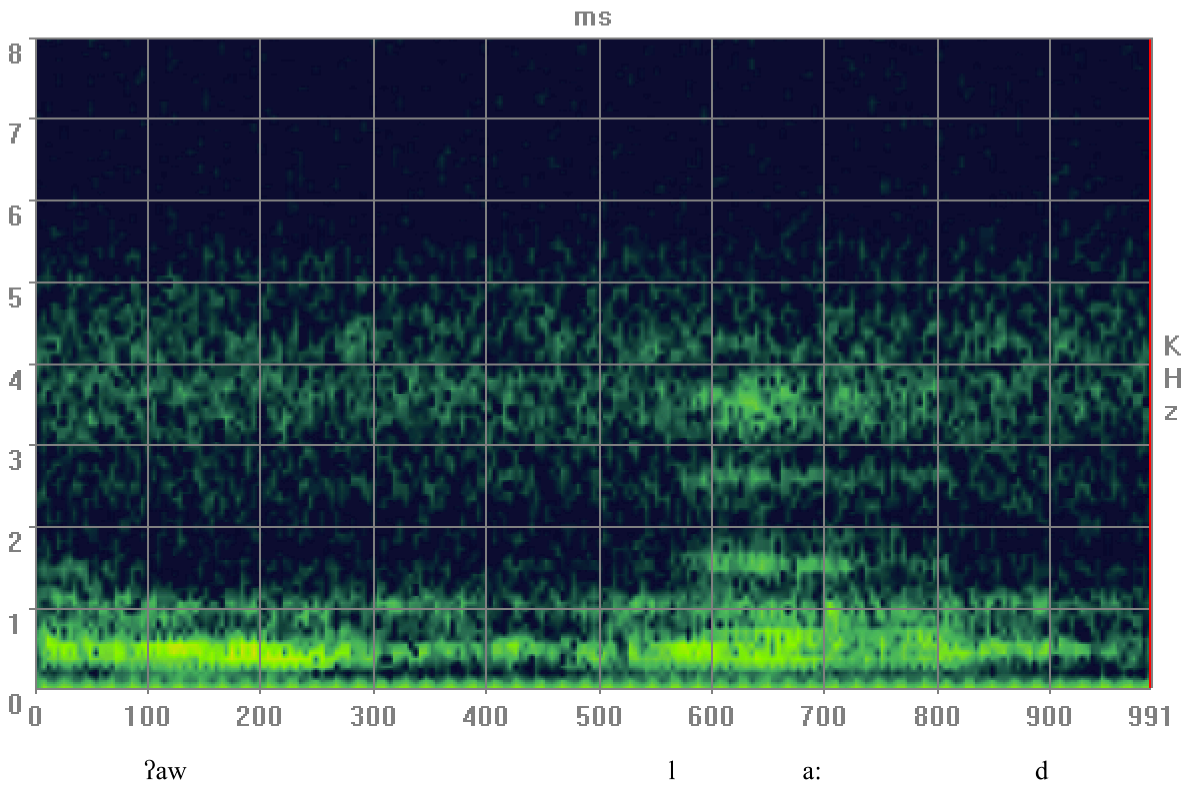


Figure 120: Spectrogram of [ʔawla:d] 'boys' illustrating unusual pause between the syllables.

On the other hand, another aphasic subject substituted [χ] for [ʔ] in producing the same word [ʔawla:d] [boys], as shown in figure 121, demonstrating a lack of motor control in the speech production process.

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[256] Cf. Code, C., & Ball, M. (1982): Fricative Production in Broca's Aphasia: A Spectrographic Analysis, p. 325.

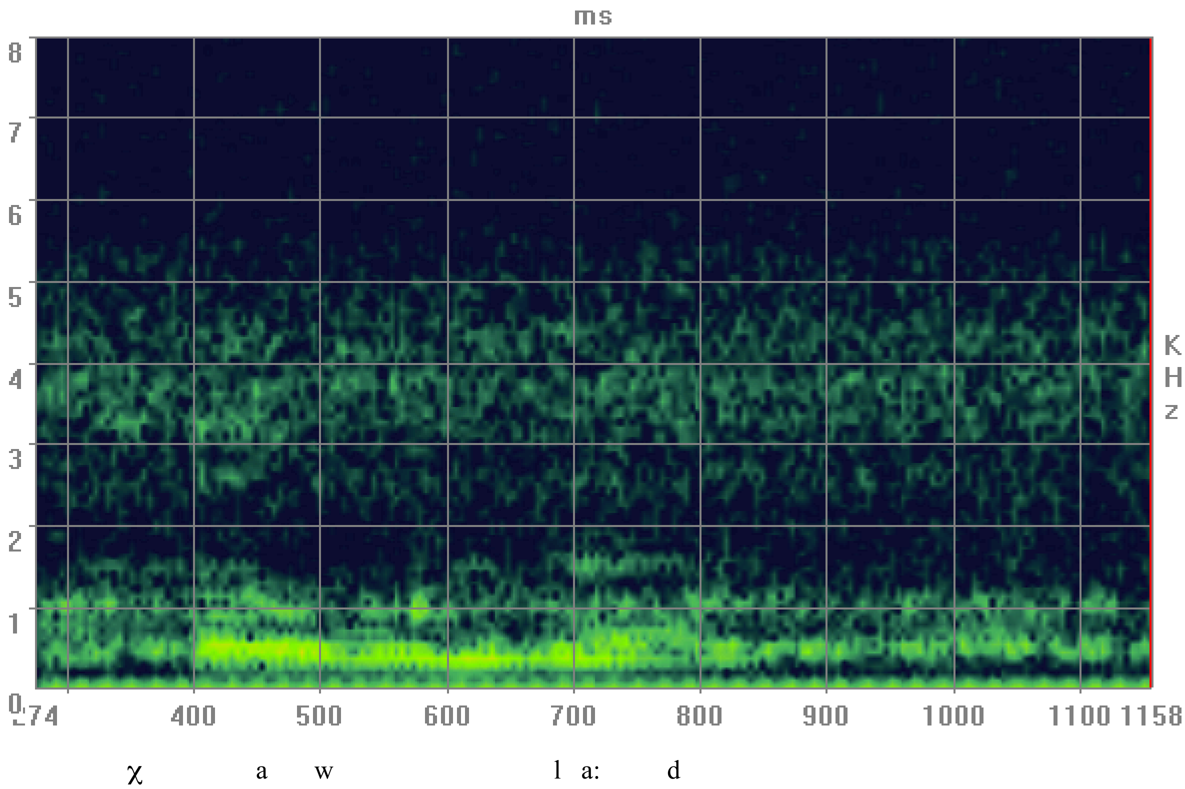

Figure 121: Spectrogram of [χawla:d] demonstrating a substituted [χ] for [ʔ].

4.2.8. Conclusion

Broca's aphasics in the current study were able to maintain the phonetic distinction between voiced and voiceless fricatives. With respect to the nature of the error, the results obtained from the aphasic patterns would suggest that those errors might also arise when phonological representations can not activate their corresponding articulatory programs. Given the fact that Broca's aphasics exhibited phonetic errors more than phonological ones, an impairment of articulatory planning is then more difficult to identify and the presence of phonetic errors has been considered a crucial criterion. In light of these controversial views, we will argue that a planning deficit may also result in phonological errors, but with indications that are related to the complexity of the movements to be programmed. The articulation process demands a great precision of articulatory movement. In fact, articulation requires different parameters that are found to be difficult to achieve by Broca's aphasics such as strength, range, accuracy and speed.

Furthermore, with regard to the type of errors, the results of the current section indicate that substitutions were made more than any other kind of errors. Alveolar sounds were mostly affected reflecting articulatory implementation errors. Figure 123 provides a summary of the direction of the error in terms of place distance analysis. Thus, based on the six main places of articulation- labial, dental, alveolar, palatal, velar, glottal- a substitution of palatal for alveolar was considered an error of one place, whereas substitution of velar for labial was considered a three-place error.

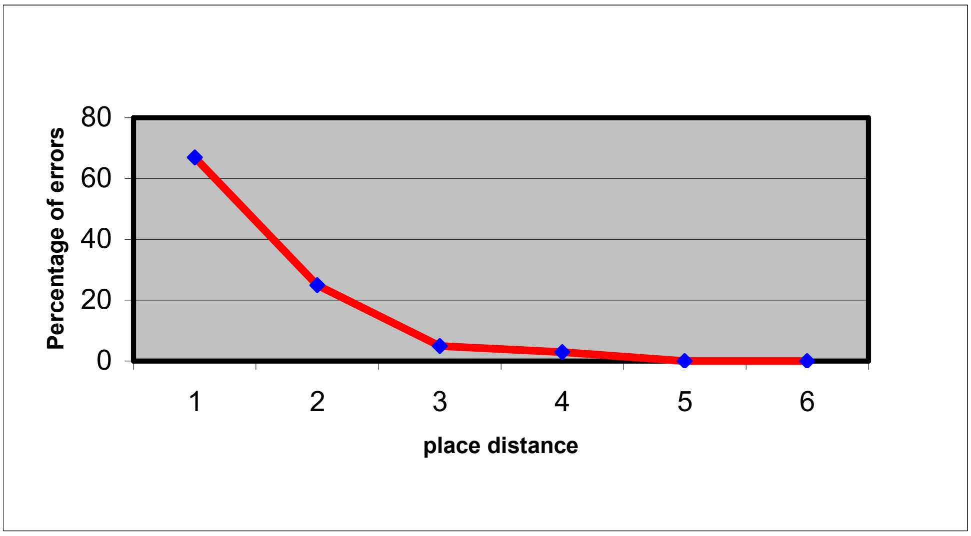

Figure 122: Distribution of errors by place distance.

As figure 122 indicates, most of the errors were categorized as one place-distance errors. The target phoneme in most of the cases was substituted by resulting phonemes having the same place of articulation. However, there are substitutions in which more than one number of features is involved. In addition, fricatives that have back place of articulation were mostly affected by substitution. In contrast, consonant deletions were found to affect mainly complex clusters. In particular, although errors were overall distributed, they were on consonants mainly in word-initial positions. A predominance of consonant errors in our study would emphasize the fact that those error patterns could arise from deficits at various levels. In this account, they might occur as result of a deficit of phonological encoding as indicated by Caramazza et al.[257] However, our findings would suggest that those errors emerged from a deficit of articulatory planning associated with a deficit of articulatory implementation due to the complexity of the consonant segments. Support for this belief came from Keller,[258] who characterized those errors as gesture simplifications which were particularly produced more often by Broca's aphasics than other types of aphasia. Moreover, some of Broca's aphasics

[257] Cf. Caramazza, A., Chialant, D., Capasso R., & Miceli, G. (2000): Separate Processing of Consonants and Vowels, pp. 428-430.
[258] Cf. Keller, E. (1984): Simplification and Gesture Reduction in Phonological Disorders of Apraxia and Aphasia, pp. 222-230.

displayed unusually long vowel durations. On the other hand, they showed a capability to maintain duration differences between voiced and voiceless fricatives by maintaining shorter duration for voiced fricatives than for voiceless fricatives. De-emphasis for the emphatic [sˤ] was remarkable indicating the loss of the secondary articulation.

4.3. Affricate sounds

The current subsection investigates the amount of deficits and the types of errors in producing the affricate sounds. We hypothesized that the problem will be greater in this category than it was with the fricatives based on the motoric complexity that is demanded in the production process. In this sense, there is some evidence to predict that this motoric complexity will be a challenge for the aphasics, who exhibited constraint in implementing complex motor sets involving planning and execution of successive gestures.

Standard Arabic has only one affricate sound [dʒ]. This sound is voiced and alveo-palatal, produced with the blade of the tongue lifted against the region just behind the alveolar ridge. Basically, its production starts as a plosive and ends as a fricative sound. This means its articulation begins like that of a plosive, which is in our case [d], by completely blocking the outgoing airstream and then continues with a gradual release of the air as for a fricative [ʒ]. This sound has a voiceless counterpart that is spoken at the dialectal level [tʃ]. As a result, a complete closure is first formed between organ and place of articulation, whereas simultaneously a velar closure is built up. An air pressure builds up behind this blockage at the closure phase. The compressed air is slowly released resulting in an audible friction noise. Despite the previous description of the production of the affricates, it is also important to note that those sounds are not a stop followed by an affricative sound. Bauman-Waengler[259] indicates two factors that come into play in the differentiation of the isolated consonants from the affricate sounds:

1- The initial position of the stop portion.
2- The nature of the movement from the stop to the fricative portion of the affricates.

Accordingly, [t] in [tʃ] is found to be posteriorly produced in contrast to its position in an isolated form. At the same time, "the front of the tongue [is] dropped relatively slowly

[259] Bauman-Waengler, J. (2004): Articulatory and Phonological Impairment: A clinical Focus, p. 260.

creating momentarily a constriction that is typical for the [ʃ] sound."[260] Taken together, the results showed that substitutions were the predominant type of error. For instance, the subjects tended to substitute [g] to [dʒ]. For example, instead of saying [dʒamal] 'camel,' they said [gamal], as figure 123 displays.

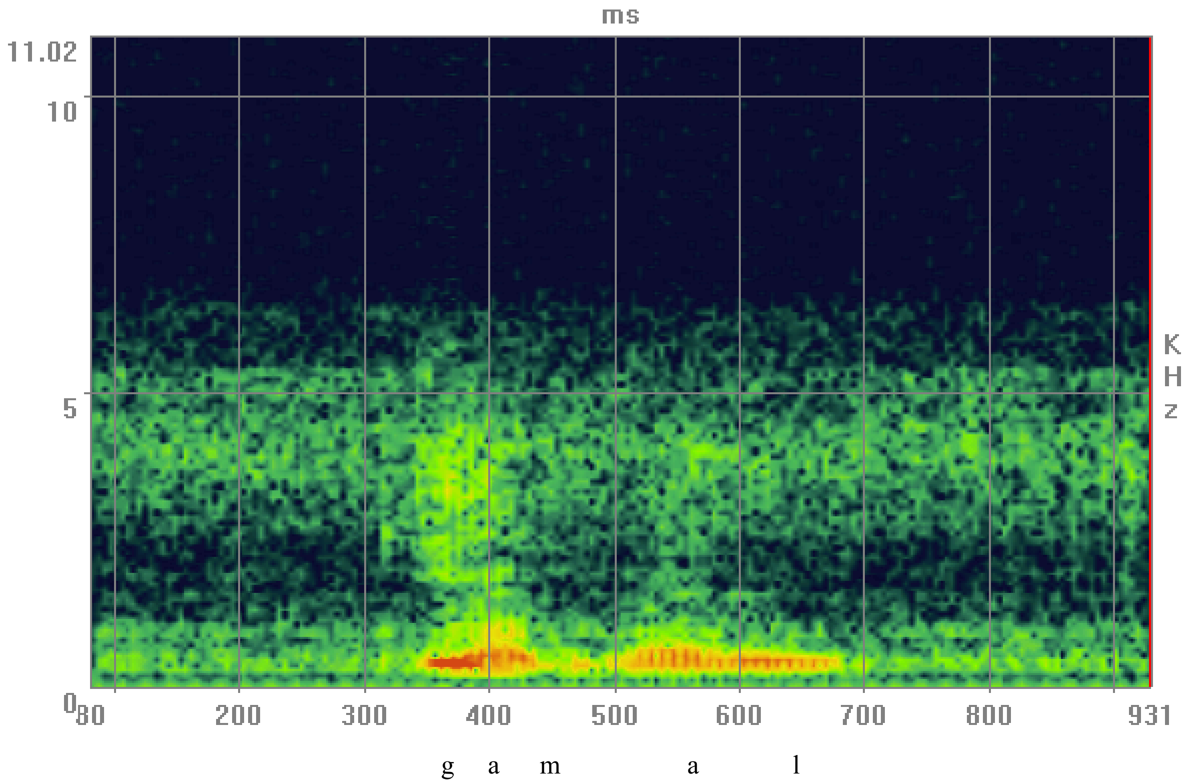

Figure 123: Spectrogram of [gamal] instead of [dʒamal] as produced by an aphasic subject.

Substituting [g] for [dʒ] is considered to be an unusual error type. One expects that the change will be from [dʒ] to [d] or [ʒ] and not to [g] because this sound does not exist in the Palestinian phonemic inventory neither in the standards form nor at the dialectal level. However, the sound [g] is used as a voiced counterpart for the sound [q] in some Palestinian dialects, e.g.

[qamar] → [gamar] 'moon'

On the other hand, [g] is the spoken form of [dʒ] in Egypt. In addition, because of the complexity of the affricate sounds the sound [dʒ] has been used in many forms in the Arabic dialects. For example, in Palestine, Syria and Lebanon the speakers usually omit the plosive

[260] Cf. Bauman-Waengler, J. (2004), p. 260.

part and keep the fricative part [ʒ], seeking simplicity in the production, e.g. [dʒamiʕah] 'university' → [ʒamiʕa]. On the other hand, in some parts of south Egypt, the speakers opposed the process by omitting the fricative part and keeping the plosive one, e.g. [dʒɛ:ʃ] 'army' → [dɛ:ʃ]. Consequently, in light of these variations of this sound, one question which might be raised is whether the substitution of [g] for [dʒ] could be considered as a normal change. Based on the Palestinian phonemic inventory, this should be categorized under substitution because [g] is not used as an allophone for [dʒ] in daily speech. Other support also comes from the subjects themselves, who added the sound [g] before uttering the sound [dʒ]. For instance, as figure 124 shows, one of the aphasic subjects, in his attempts to produce the word [dʒundi] 'solder,' produces the sound [g], followed by a pause lasting for 663msec before moving to the affricate sound [dʒ], displaying a deficit in implementation of the articulatory gestures.

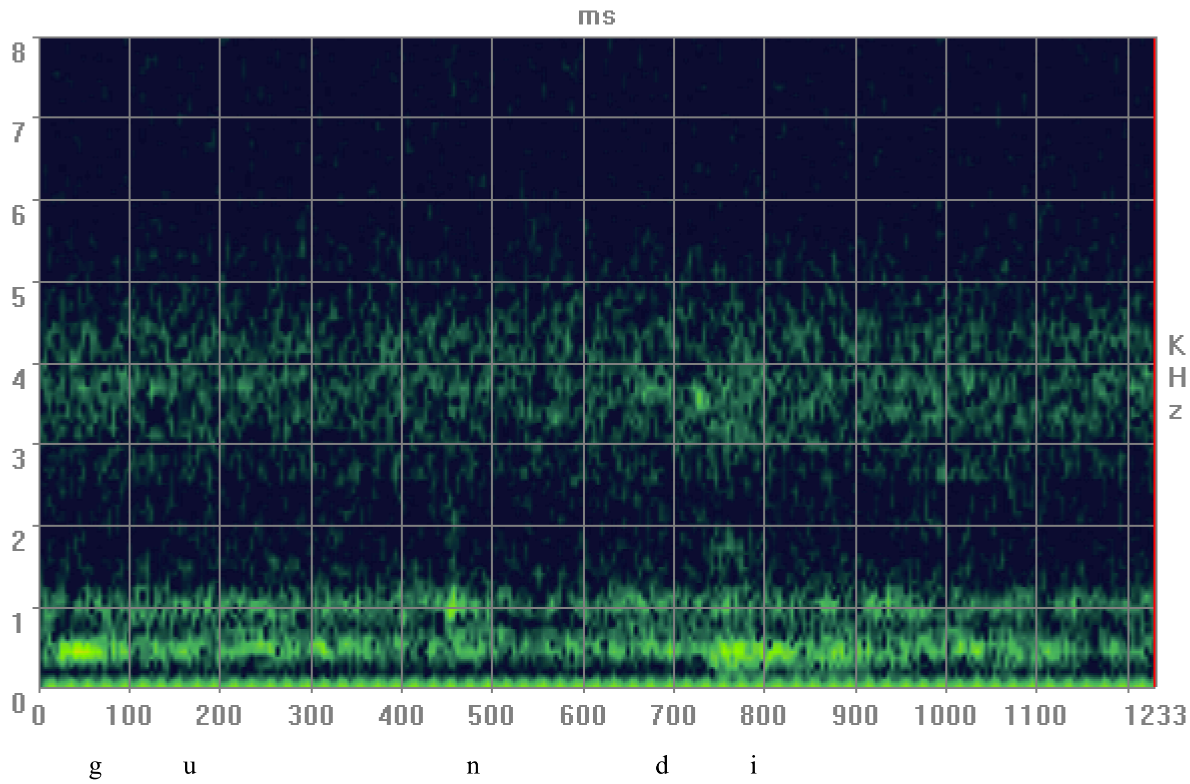

Figure 124: Spectrogram of the word [dʒundi] illustrating a shift from [g] to [dʒ] by an aphasic subject.

Furthermore, another pattern that has been noticed is the long pause at the beginning of initiating the utterance demonstrating a difficulty in the implementation ability. Thus, subject B3, as figure 125 indicates, started his utterance with an abnormally long delay, which lasted for 565msec before the onset of the first element.

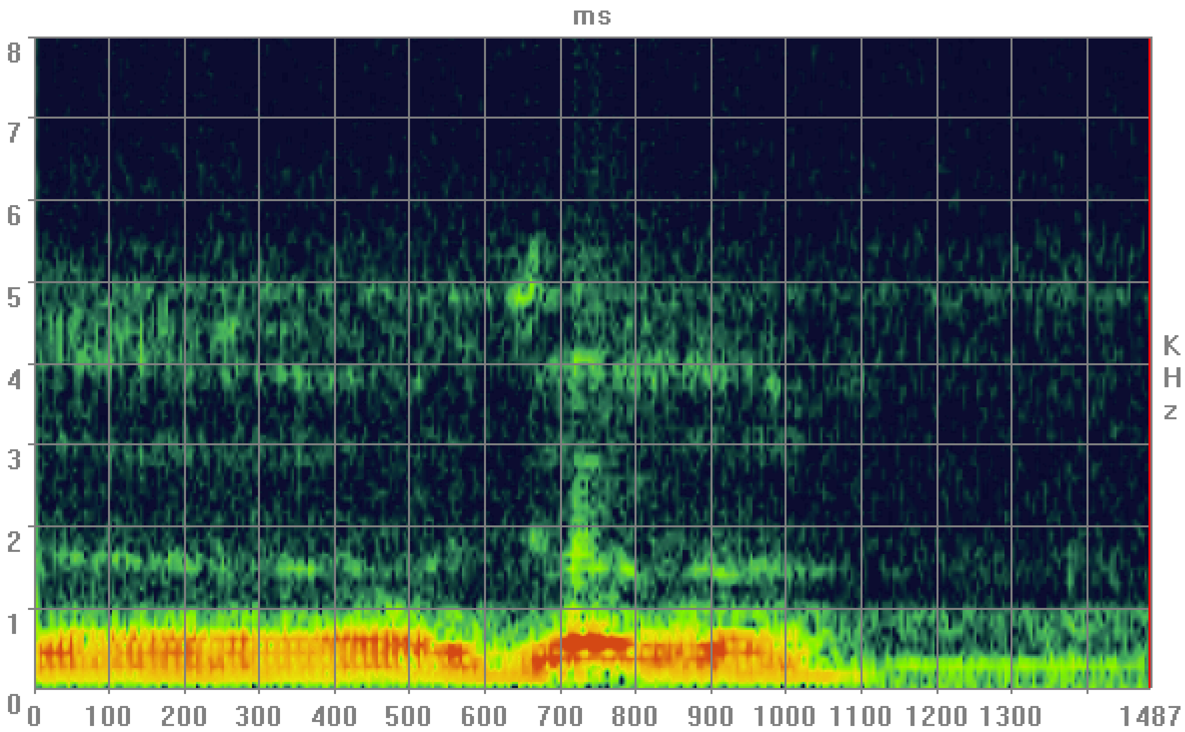

Figure 125: Spectrogram of the word [dʒazar] 'carrots' illustrating initiation difficulties by making a long pause before producing the word.

In conclusion, it is clear from the results that Broca's aphasics exhibited articulatory difficulty in the production of the affricate sounds. Thus, they tended to ignore such a complexity by substituting them for other sounds that are less difficult. However, with respect to the substitution errors, some of them are not acceptable for the Palestinian's dialect, e.g. [dʒ] → [g], whereas such are considered legal variations in other dialectal forms like those in Egypt. As a result, the close phonetic relationship between the error and the target element has not been observed. Furthermore, the results display that the complexity of speech production in phonetic context can result in severe articulatory impairments in Broca's aphasics.

5. EMPHATIC STOP SOUNDS IN ARABIC: THE STOP [tˤ] AS AN EXAMPLE

5.1. Introduction and definition

Emphasis is considered a significant phenomenon in Arabic. Different definitions of emphasis have been developed from Arab linguists as well as from modern western linguists. For example, Lehn characterized and defined emphasis in terms of co-occurrence of one or more of the following articulatory features:

> “(1) slight retraction, lateral spreading, and concavity of the tongue and raising of its back (more or less similar to what has been called velarization, (2) faucal and pharyngeal constriction (pharyngealization), (3) slight lip protrusion or rounding (labialization), and (4) increased tension of the entire oral and pharyngeal musculature resulting in the emphatics being noticeably more forties than the plain segments.”[261]

Considering this definition, it is apparent that it refers to several kinds of emphases at the level of articulation. However, its implementation might require an involvement of pharyngealization or bilabialization.[262] In this account, pharyngeal sounds are described as a process in which:

> “The root of the tongue assumes the shape of a bulge and is drawn back towards the vertical back wall of the pharynx to form a stricture. This radical bulge generally divides the vocal tract into two cavities, one below extending from the stricture to the glottis, the other above extending from the stricture to the lip.”[263]

Importantly, however, pharyngealised sounds indicate that the pharynx is the secondary articulator for sounds, articulated primarily with other speech organs at another place of articulation. Another definition refers to emphasis as “secondary pharyngeal articulation of certain consonants, usually stops and fricatives.”[264] However, as noted in this definition, some limitations can be noticed due to the fact that it includes only stop and fricative sounds and excluded other segments that might be emphasized. In addition, the definition of emphasis as established by Davis provides information concerning the involvement of pharyngealization

[261] Lehn, W. (1963): Emphasis in Cairo Arabic, pp. 30-31.
[262] Cf. Watson, J. (1999), p. 284.
[263] Delattre, P. (1971): Pharyngeal Features in the Consonants of Arabic, German, Spanish, French, and American, p. 129.
[264] Cf. Kahn, M. (1975): Arabic Emphasis: The Evidence for Cultural Determinants of Phonetic Sex-Typing, p. 39.

in terms of producing the emphatic sounds with "a primary articulation at the dental/alveolar region and with a secondary articulation that involves the constriction of the upper pharynx."[265] In contrast, current definitions argued against the strong involvement of the secondary articulation in the production of emphatic sounds.

> "Die Betrachtung der Verengung im gesamten Vokaltrakt und ein entsprechender Vergleich mit den radiokinematographischen Bildern anderer Laute macht es schwer, bei den emphatischen Konsonanten von einer zweiten Artikulation zu sprechen, wie dies in der Literatur des öfteren behauptet wird."[266]

In light of the previous reviews, it has become obvious that there is a clear difference in the way to define emphasis between the studies. With respect to the role of the pharynx in producing the emphatic sounds, McCarthy emphasizes this involvement by defining emphasis as a "constriction in the upper pharynx."[267] Watson points out that emphasis has two articulatory correlates "pharyngealization and labialization."[268] Other investigations displayed that most of the changes during the production of the emphatic sounds take place at the front part of the vocal tract. Metoui stated that :"Die Analyse […] zeigt deutlich, daß die größten artikulatorischen Veränderungen im vorderen Teil des Vokaltrakts stattfinden."[269]

Furthermore, in various studies of emphasis there was evidence for lip-rounding in the production process. In this sense, Watson[270] and Uldall[271] referred to lip-rounding or lip-protrusion during the production of emphatic sounds. Concerning the involvement of the lips, Metoui stated that: "Den größten Anteil an der Verringerung der Lippenöffnung trägt die Unterlippe."[272] In spite of the differences seen in the previous discussion, all the descriptions of the production of emphatic sounds address the involvement of the upper pharyngeal constriction and the back of the tongue. In general, the discussion, as mentioned above, leads one to conclude that the production of the emphatic sounds requires the involvement and the interaction of many muscles. In light of all previous descriptions and definitions of emphatic sound, this section aims to address this issue by the Palestinian Broca's aphasics in order to

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[265] Cf. Davis, S. (1995), p. 465.
[266] Metoui, M. (1998), p. 83.
[267] Cf. McCarthy, J. (1994): The Phonetics and Phonology of Semitic Pharyngeal, p. 38.
[268] Cf. Watson, J. (1999), p. 289.
[269] Metoui, M. (1998), p. 83.
[270] Cf. Watson, J. (1999), pp. 289-291.
[271] Cf. Uldall, E. (1992): Some Observations on the Haskins Laboratories X-Ray Film of Damascus Arabic, pp. 57-63.
[272] Metoui, M. (1998), p. 72.

explore whether they behave as the normal speakers and if not, what patterns they demonstrated. Thus, in the next discussion we will shed light on the acoustic features of the emphatic sound [tˤ] by comparing the aphasic results to those of the normal speakers. The sound [tˤ] was selected because the aphasic subjects have displayed specific difficulty during its production in addition to its frequent use during their spontaneous speech.

5.2. The acoustic characteristics of the stop [tˤ] as produced by the normal speakers and the aphasic subjects

Based on what has been previously mentioned about the nature of the emphatic sound's production, it would be reasonable to predict that our aphasic subjects will display abnormal acoustical patterns and articulatory difficulties during the production of [tˤ]. Tables 67 and 68 summarize the main acoustic features of the emphatic stop understudy [tˤ] by the normal speakers and the aphasics. In the case of noise frequency range, we can see that the average for [tˤ] by the aphasic subjects was concentrated at three peaks independently: 512/ 2050/ 5135Hz as figure 126 shows. In contrast, as figure 127 illustrates, the patterns of the normal speakers exhibited an expansion over a wide frequency bandwidth between 2054-7730Hz with the absence of dark zones at the spectrum. This wide frequency bandwidth is in line with results from Tunisian Arabic sounds.[273]In contrast, the primary concentration of energy for the consonant [t], as exhibited by the normal speakers, extended to 7000Hz, while by the aphasics was in low frequency between 2200-4500Hz.

Power bandwidth energy concentration (Hz)	Average energy distribution (dB)	VOT (msec)
2054-7730	20.54	14

Table 67: The acoustic features of [tˤ] as produced by the normal speakers.

[273] Cf. Metoui, M. (2001), p. 112.

Power bandwidth energy concentration (Hz)	Average energy distribution (dB)	VOT (msec)
508/ 2054/ 5146	24	41

Table 68: The acoustic features of [tˤ] showed by the aphasic subjects.

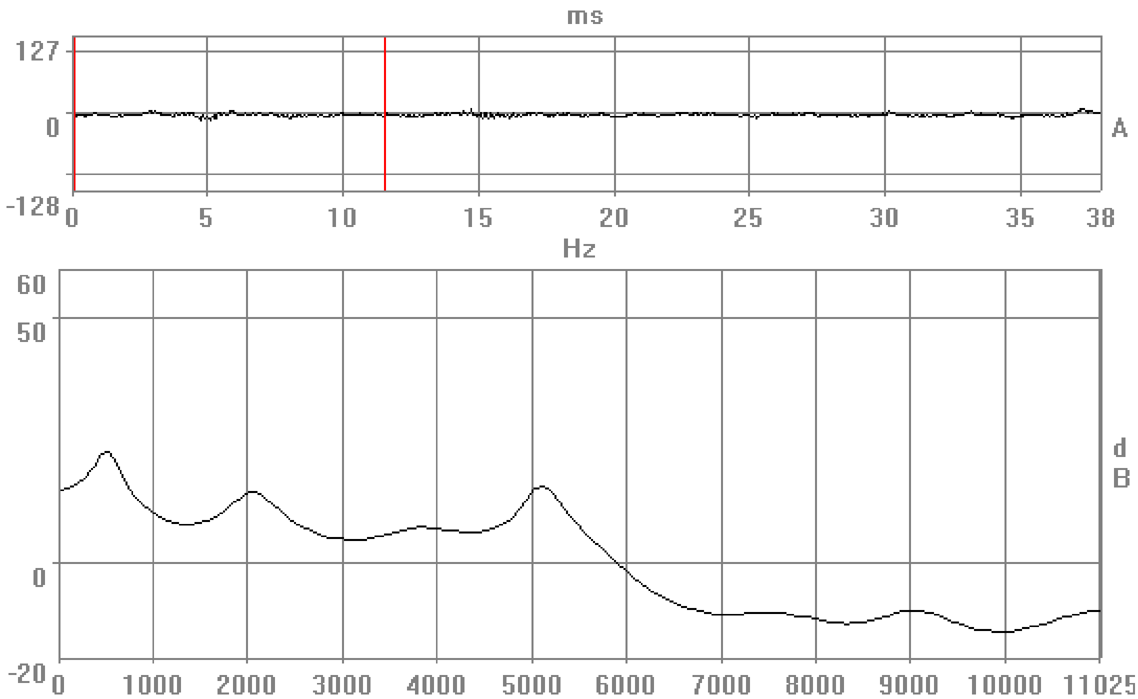

Figure 126: LPC illustrating [tˤ] from the word [tˤɑjib] 'delicious' as produced by an aphasic subject.

Thus, it was true for the aphasic patients and the normal speakers that higher noise frequency ranges from the emphatic [tˤ] in contrast to its non-emphatic cognate [t] were found. However, at the level of individual sounds, there are differences between the patterns exhibited by the aphasics and the normal speakers.

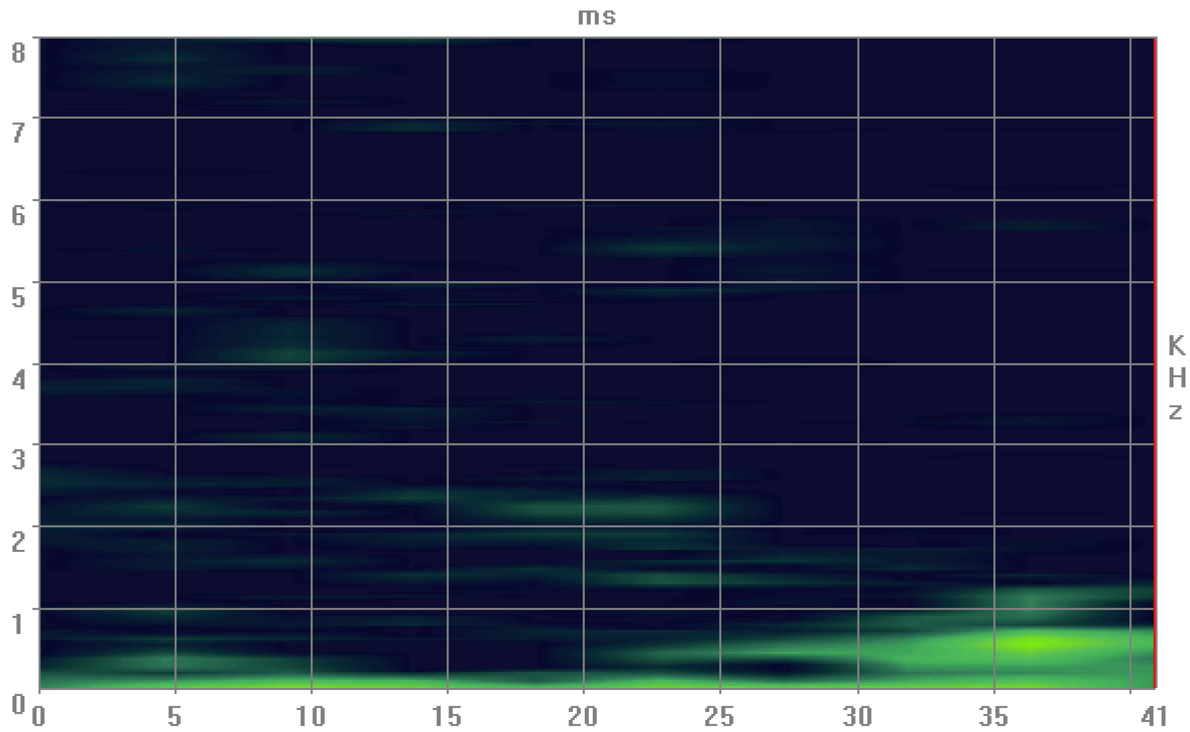

Figure 127: Spectrogram illustrating [tˤ] from the word [tˤɑl] as produced by a normal speaker.

Based on the results of the analysis in the preceding discussion, the mean of noise burst was generally low in productions of the aphasic patients compared to the normal speakers. Therefore, one would maintain that the place of articulation and its correlations could contribute to these differences. In this sense, shortening the front of the cavity during the articulation of [tˤ] and increasing the amount of the constriction produce increased ranges of frequency. However, the mean value of the apex where the energy was maximally concentrated was 7500Hz for the normal subjects in contrast to the aphasics whose mean apex was 5000Hz, as shown in figures 128 and 129.

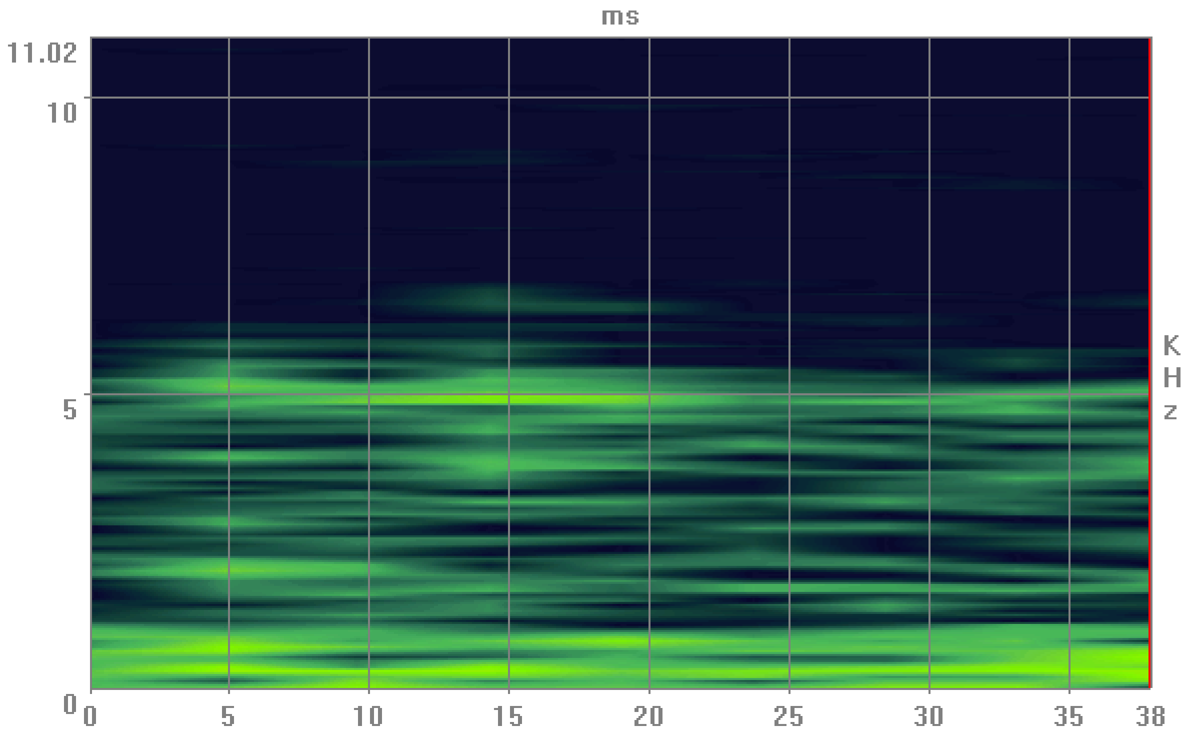

Figure 128: Spectrogram illustrating [tˤ] from the word [tˤɑjib] as produced by an aphasic subject.

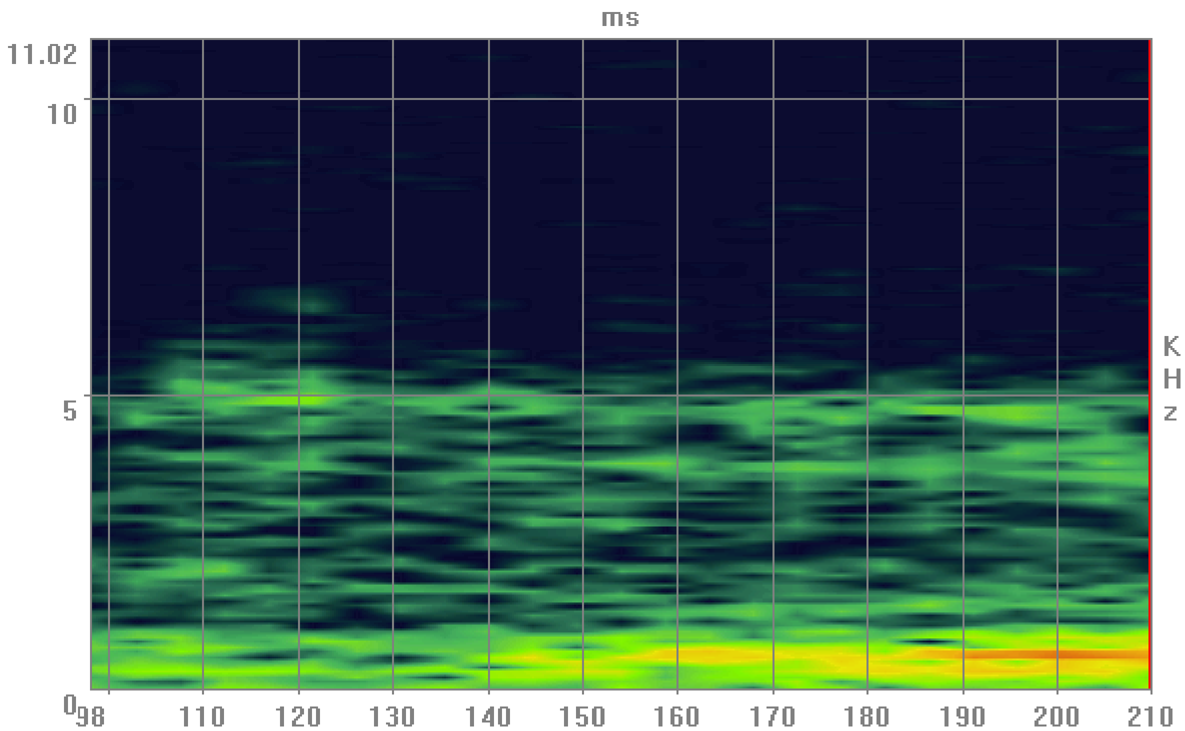

Figure 129: Spectrogram illustrating the syllable [tˤɑ] from the word [tˤɑjib] as produced by an aphasic subject.

In fact, the production of [tˤ] is a complex process, since more than one articulation process is involved in terms of main and secondary articulation. The emphatic sounds, as many investigations have indicated, are distinguished by remarkable complex movements in the vocal tract.[274] In light of this observation, the aphasic subjects are expected to exhibit tremendous difficulties, since they suffer from articulatory constraints, and consequently affecting the acoustic features. Results from the target short vowels in initial syllable positions indicate differences in the duration between the emphatic and non-emphatic environment in both groups. Thus, the mean vowel duration for the three short vowels produced by the normal speakers was (100 msec) in the emphatic environment and (116msec) in the plain context. In contrast to these values, the aphasic subjects displayed (160msec) in the emphatic environment and (125msec) in the plain one. In light of these values, it has become very obvious that the mean vowel durations of Broca's aphasics were greater than those of the normal speakers in the plain environment as well as in the emphatic one. In this respect, it is possible then that these deviations reflected significant temporal deficits in the voiceless stops in the emphatic and plain environments as well.

Formants are considered the resonant frequencies of one's vocal tract during speech production. In fact, from the functional point of view, they enable us to detect much about many elements or phenomena like vowel height, lip-rounding, palatalization and emphasis. The literature provides us with many acoustic rules that have already been established such as F1 which normally corresponds to a vowel's height so that of the higher the vowel, the lower F1. However, F2 is generally related to the posteriority of a vowel. The farther back the vowel the lower F2.[275] In general, it can be said that F2 frequency behaves inversely with tongue advancement and F1 frequency varies inversely with tongue height. With respect to theses acoustic correlations, it is predictable that any change in the vocal tract will affect the values of these formants. For example, vowels in pharyngeal environments are distinguished by a rise in F1 and a drop in F2.[276]

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[274] Cf. Metoui, M. (2001), pp. 174-176.
[275] Kent, R., & Read, C. (1992), p. 92.
[276] Pickett, J. (1998): Acoustics of Speech Communication: The Fundamentals, Speech Perception Theory and Technology, p. 42.

In Arabic, Al-Ani[277] investigated the effect of pharyngealization on formant values of adjacent vowels. He noticed that the pharyngeal [ħ] has much greater effect on the formants. Namely, he drew the conclusion that F2 is a distinguishable factor between the glottal [ʔ] and the pharyngeal [ħ]. However, Alwan[278] found that the pharyngeal consonants have a higher F1 compared to the uvular consonants.

In general, we expect to find significant differences in F2 values between the aphasic subjects and the normal speakers in target vowels occupying initial syllables. As can be seen in figures 130 and 132, the normal speakers in the emphatic environment [tˤ] demonstrated an obvious lowering of F2 contrasted to its cognate in the plain environments [t]. Thus, on average, the normal speakers displayed a lowering in F2 value in the emphatic environment for 630Hz compared to the same vowels in the plain environment. However, the aphasic patterns are inconsistent with those of the normal speakers. Thus, the aphasics displayed higher F2 value for vowels in the emphatic environment than did the normal speakers rising on average to 508Hz. In general, they exhibit higher F2 in emphatic environments with a 242Hz drop in the emphatic environment compared to the same vowels in the plain environment.

Vowel	F2 [t]	F2 [tˤ]
[a, ɑ]	1670	1180
[u]	1220	930
[i]	2520	1490

Table 69: F2 values (Hz) of the vowels in the same syllable in the plain [t] and the emphatic target consonant [tˤ] as produced by the normal speakers. [a] is in the plain environment of [t] and [ɑ] in the emphatic environment of [tˤ].

[277] Cf. Al-Ani, S. (1970): Arabic Phonology: An Acoustical and Physiological Investigation, pp. 60-72.
[278] Cf. Alwan, A. (1989): Perceptual Cues for Place of Articulation for the Voiced Pharyngeal and Uvular Consonants, p. 555.

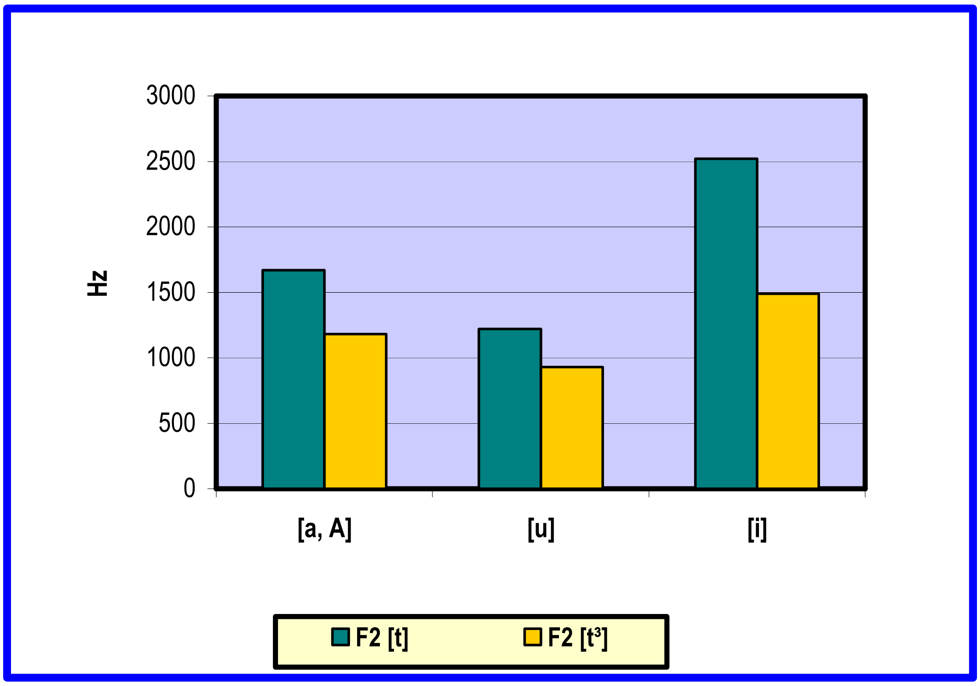

Figure 130: F2 values (Hz) for the vowels in the same syllable of the emphatic and plain target sounds as produced by the normal speakers. [a] is in the plain environment of [t] and [ɑ] in the emphatic environment of [tˁ].

This increase reflects particular problems in the production of emphatic sounds realized as articulation errors.

Vowel	F2 [t]	F2 [tˁ]
[a, ɑ]	1750	1600
[u]	2370	1733
[i]	1727	1790

Table 70: F2 values (Hz) of the vowels in the same syllable in the plain [t] and the emphatic target [tˁ] as produced by the aphasic subjects. [a] is in the plain environment of [t] and [ɑ] in the emphatic environment of [tˁ].

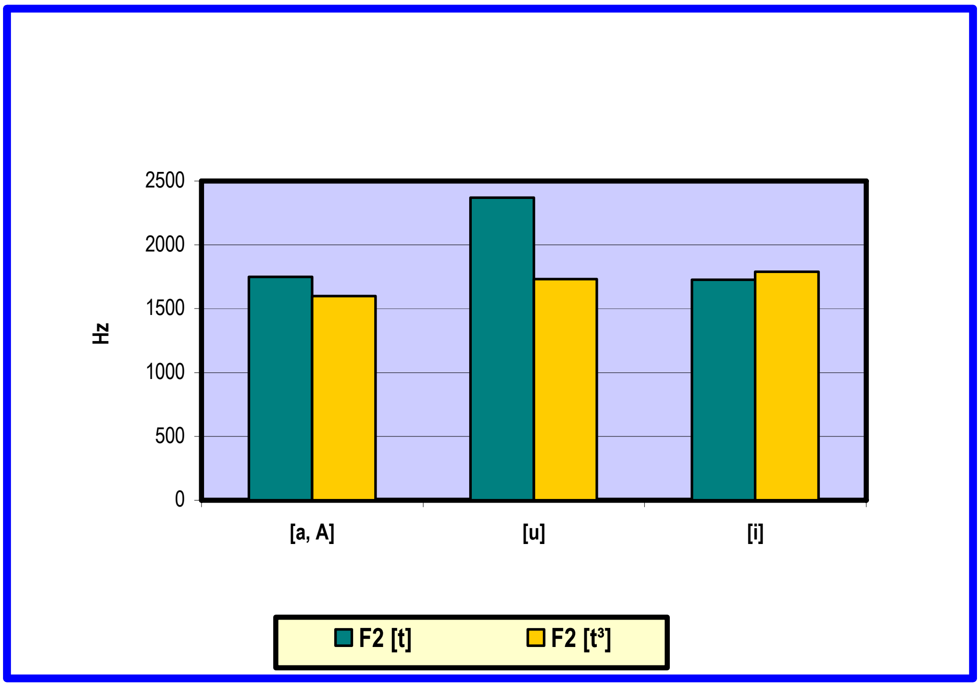

Figure 131: F2 values (Hz) for vowels in the same syllable in plain and emphatic environments as demonstrated by the aphasic subjects. [a] is in the plain environment of [t] and [ɑ] in the emphatic environment of [tˤ].

Vowel	Normal speakers	Aphasic subjects
[ɑ]	1180	1600
[u]	930	1733
[i]	1490	1790

Table 71: F2 values (Hz) of the vowels in the same syllable in the emphatic environment of [tˤ] as produced by the normal speakers and the aphasic subjects.

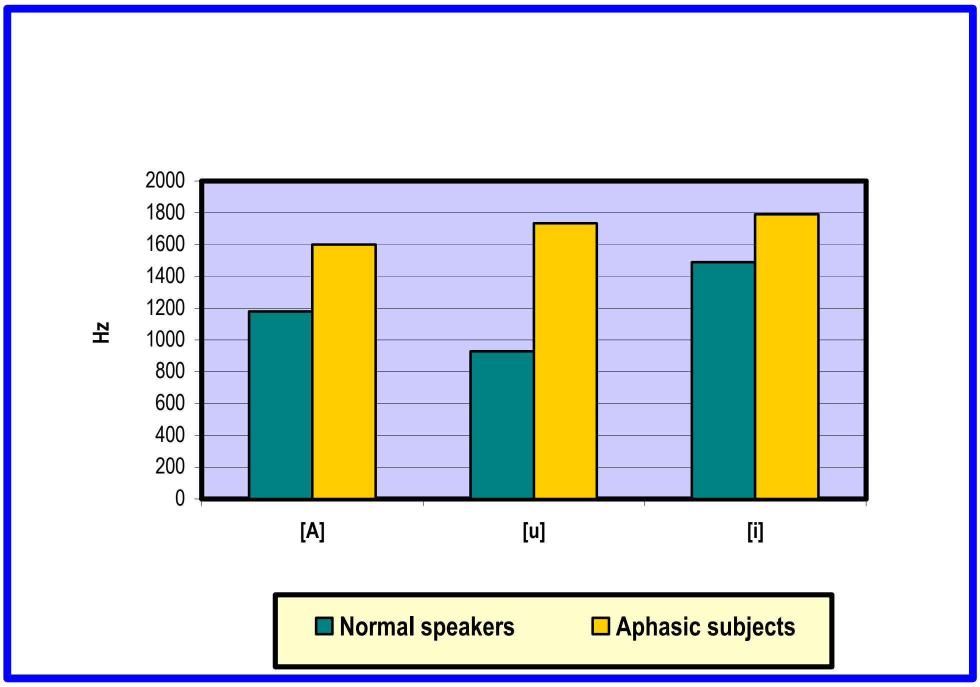

Figure 132: F2 values (Hz) for vowels in the same syllable in the emphatic environment of [tˤ] for the aphasics and the normal speakers.

In general, an obvious drop of F2 was found after [tˤ] compared to its non-emphatic counterpart [t]. Although there was a significant drop of F2, there were differences between the vowels themselves in the degree of this drop. For instance, the normal speakers produced the F2 of the vowel [u] 290Hz and the vowel [a] 490Hz higher after the voiceless stop [t] than after the emphatic [tˤ]. In general, these results suggest that F2 was found to be a distinguishable and crucial cue between the emphatic and the plain counterpart sound. Controversially, the acoustic patterns obtained from the anterior aphasic patients demonstrated contradicting results. Thus, as a point of comparison, the normal speakers displayed significant lowering in F2 value reaching in mean average 1200Hz in all vowels, while the aphasics raised it to 1982Hz suggesting a disability to produce this emphatic sound precisely. The differences can be easily seen in tables 72 and 73, which summarize the values for the first three formants in the emphatic and non emphatic environment as shown by the normal speakers and the aphasic subjects.

	Non-emphatic sound [t]			Emphatic sound [tˤ]			
Vowel	F1	F2	F3	Vowel	F1	F2	F3
[a]	586	1670	2800	[ɑ]	630	1180	2649
[u]	463	1220	2700	[u]	479	930	2870
[i]	367	2520	3000	[i]	451	1490	2700

Table 72: The mean average of the first three formants (Hz) in the emphatic [tˤ] and the plain environment of [t] for the normal speakers.

	Non-emphatic sound [t]			Emphatic sound [tˤ]			
Vowel	F1	F2	F3	Vowel	F1	F2	F3
[a]	501	1750	2604	[ɑ]	565	1600	2963
[u]	662	2370	3296	[u]	375	1733	3124
[i]	532	1727	2888	[i]	462	1790	2982

Table 73: The mean average of the first three formants (Hz) in the emphatic [tˤ] and the plain environment of [t] for the aphasic subjects.

As it can be seen in the tables above, the normal speakers in the emphatic environment tended to display a drop of F3 for all vowels compared to its non-emphatic counterpart [t], except for the [u] after [tˤ], which showed an upward shift in frequency values compared to [u] after [t]. However, the aphasic subjects display exactly the opposite trend. That is, they demonstrate a grater rise in F3 after [tˤ] than after [t] except for [u] after [t]. With respect to F1, it was found to be an unreliable cue for emphasis of the normal speakers, since the F1 value demonstrates no significant differences between the emphatic and the non-emphatic counterpart sound. Nonetheless, it is the case that the aphasic subjects behaved relatively similarly to the normal speakers, except with [u], which has a greater rise magnitude after [t] than the other vowels. It is important to note that the vowel [ɑ] is realized by the aphasic subjects as [a], since its formant values are within those for the vowel [a].

Of the results to note in the data from the normal speakers is the amount of emphasis on F2 value for the vowels after [tˤ]. The lowering effect of F2 can be seen in the following ranking starting from the lowest value for the normal speakers:
[u], [a] and [i].
However, the following ranking was demonstrated by the aphasics:
[a], [u] and [i].

Of importance for the present study is that the lowering of F2 in the vowel adjacent to the emphatic consonant is a reliable and a valid acoustic correlate of emphasis in normal speakers and revealed the disability of the Arabic aphasic subjects, at least in the current study, to maintain and sustain this acoustic rule. In contrast to the normal speakers, there is reason to emphasize the fact that the aphasics displayed not only higher F2, but also a deviated overall spectrum for an emphatic syllable in contrast to normal subjects whose spectrum is more compact than its plain counterpart. In the case of the normal speakers, as figure 133 shows, it seems likely that the emphatic sounds whose production is usually accompanied by secondary back articulation contributed to bring the first two formants (F1 and F2) close to each other with a notable lowering of F2.

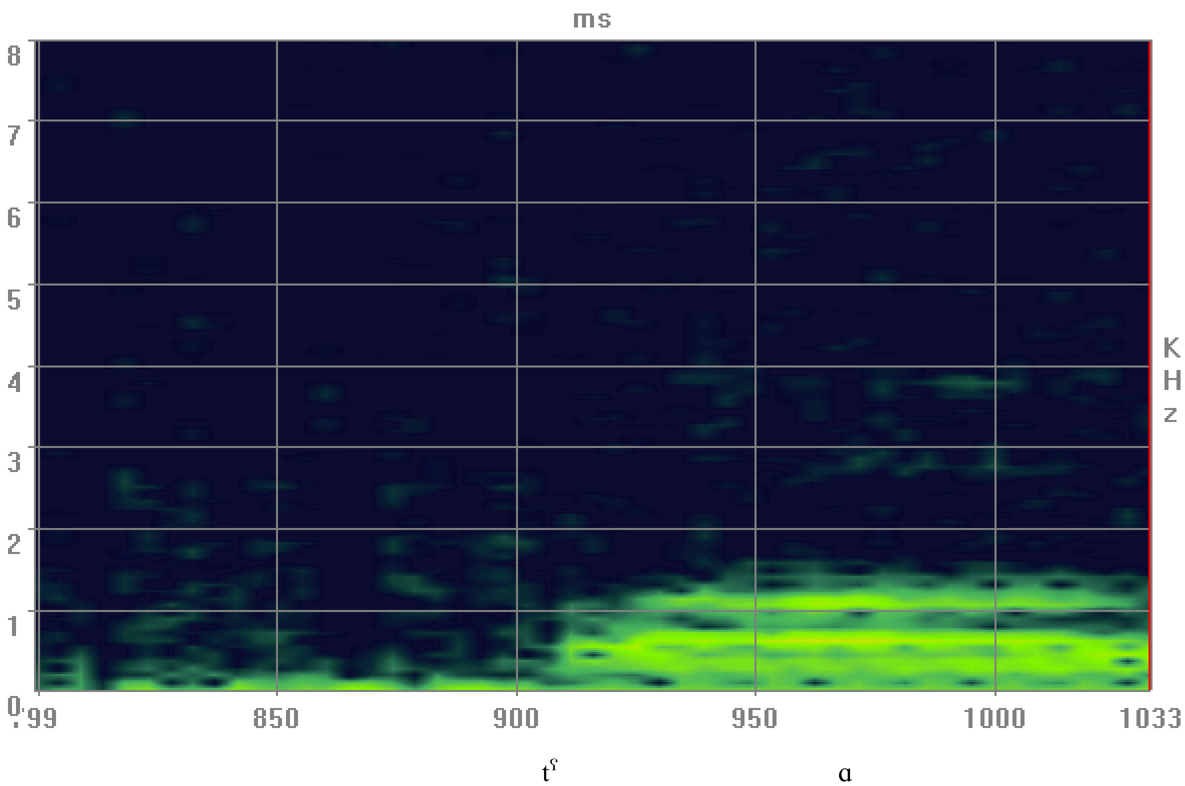

Figure 133: Spectrogram illustrating the syllable [tˤɑ] from the word [tˤɑl] as produced by a normal speaker.

However, it is of interest that in the non-emphatic environment [t] a remarkable distance between the first two formants was observed, as shown in figure 134.

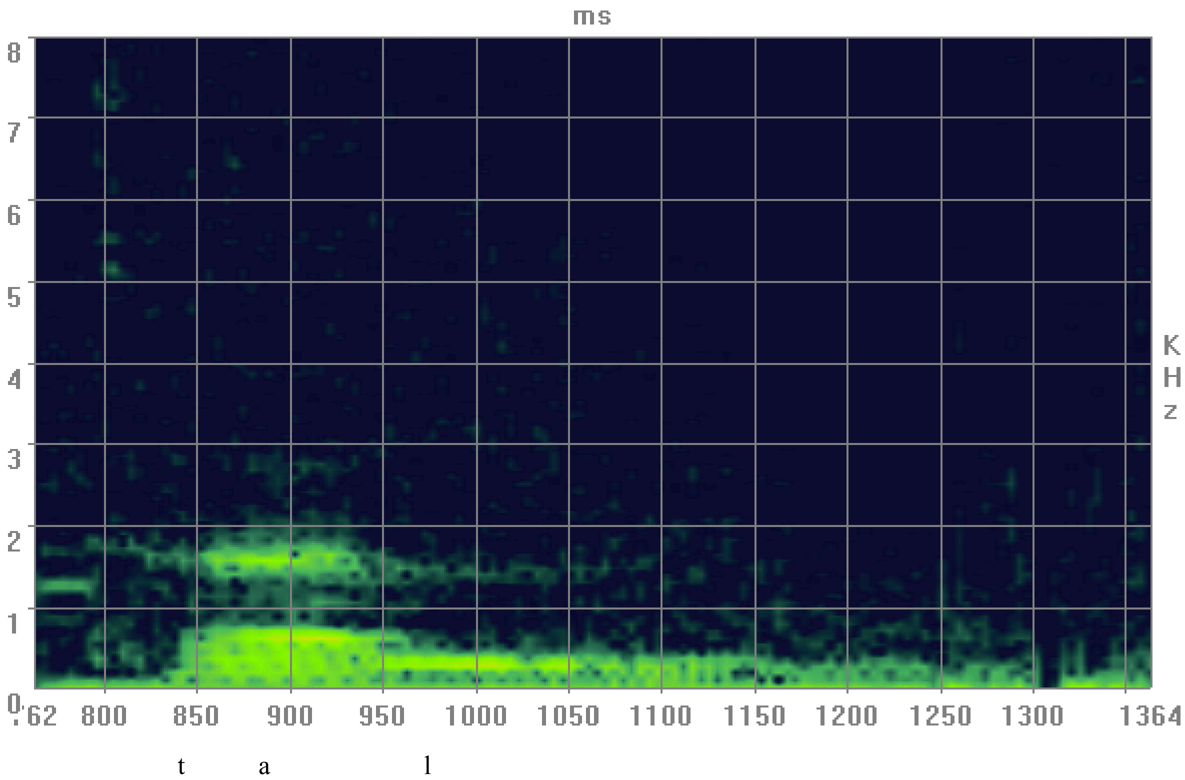

Figure 134: Spectrogram illustrating the syllable [ta] in the word [tal] as produced by a normal speaker.

Thus, the vowels in the syllable with the emphatic target consonant mainly displayed a more compact spectrum.

5.3. Discussion and conclusion

The results indicated that VOT for the emphatic [tˤ] by the normal speakers was (14msec) on average. This value is in agreement with VOT values reported in other studies.[279] The aphasics, however, produced the same sound with (41msec) displaying a significant difficulty in initiating this sound. Furthermore, based on the assumption that the VOT value could be associated with the extent of articulatory contact area, it might then be possible to expect that the release of the articulators will be decreased.[280] In this sense, back articulations increased the front cavity resulting in a slower release of the articulators. This manifests the "Bernoulli Effect" that contributed to pull the articulators together. The slowness in bringing the articulators to each other increases in time before an adequate and accurate transglottal pressure is built. Accordingly, there are reasons to suggest that, as the aphasics suffer from motoric difficulties and slowness in transition from one articulatory shape to another, an increase in the duration of the burst release realized in their high VOT value is predictable. Furthermore, this emphatic sound was characterized by a concentration of energy in low

[279] Cf. Metoui, M. (1998), p. 50.
[280] Cf. Taehong, C., & Ladefoged, P. (1999), pp. 211-214.

frequencies and spread over a wide frequency range. This finding agrees with results reported from Metoui, who indicated that this sound has "[…] ein Explosionsrauschen, das im allgemeinen über ein breites Frequenzband verteilet ist."[281]

Indeed, during the production of an alveolar consonant the tongue is involved in the implementation of the constriction, and consequently the nature and the degree of constriction affect the F2 transitions, which could be found either falling or rising from the consonant configuration to the vowel configuration in the sequence C-V. As a result, this suggests that the different places of articulation are associated with different formant patterns and various transitional changes. In short, there is some evidence to suggest that F2 is sensitive to changes in the front and the back of the cavity. In this account, Metoui indicated that: "Andere Regeln versuchen, die Veränderung der Frequenz des F2 mit den verschiedenen Verengungen im vorderen und hinteren Bereich des Vokaltrakts in Verbindung zu setzen."[282]

Regarding the third formant (F3), the normal speakers displayed quite a rising in its value compared to F2 in emphatic environment [tˤ] indicating an effect of emphasis on the third formant. However, they generally reversed this pattern within the non-emphatic counterpart [t]. On the contrary, the acoustic patterns of F3 in the aphasics' productions were in line with those of the normal speakers by showing greater rise in F3 after [tˤ] than after [t], except for [u] after [t]. Importantly, based on the results obtained from the normal speakers, there is considerable evidence to suggest that lowering of F2 and raising F3 in the emphatic sounds is a significant feature for distinguishing emphatic sounds. Furthermore, the difference between the F2 of a vowel following a plain consonant and the F2 of a vowel following the emphatic cognate [tˤ] was significant. From this part of the study, it could be concluded also that the frequency values of F2 and F3 for the vowels in an alveolar context are increased if the following vowel is a front vowel [i] and decreased if it is a back vowel [u]. In light of this observation, it is possible to suggest that the further back the vowel is the bigger the differences between F2 and F3 values. Concerning F1, when the results are grouped together according to the overall mean average of this formant, it can be seen that the normal speakers and the aphasics do not display significant differences.

[281] Metoui, M. (1998), p. 50.
[282] Ibid., p. 51.

With respect to the locus frequency, the F2 locus for [t] by the normal speakers ranges from 1865-2230Hz and for F3 it was between 2785-3200Hz. However, the locus frequency of F2 for [tˤ] was between 854-1500Hz, while for F3 it was between 2988-3400Hz. The aphasic patients, unsurprisingly, yield results inconsistent with these of the normal speakers by displaying a locus frequency of F2 for [tˤ] between 1829-1890Hz, whereas for F3 it was between 2940-3142Hz suggesting a clear overlap within the frequency locus of [t]. Also we have observed effects of vowels on the F2 locus of the alveolar consonants under study in the current section of the study [t] and [tˤ]. This is related to the coarticulatory effects of the contextual environment that creates different vocal tract's configurations. Thus, based on the patterns of the normal speakers, there is a decrease in F2 frequency locus when it is followed by a back vowel in the emphatic environment and an increase in frequency value when a high vowel [i] follows the consonant. In most of the cases, the aphasics usually opposed the findings obtained from the normal speakers. In this respect, for example, they exhibited a slight increase for F2 frequency locus in the environment of [tˤ] if followed by the back vowel [u], as compared to [i], where it displayed no significant effect after the F2 locus of the vocalic context. F3 transition for [tˤ], on the other hand, is found to be high. The shape of the transition is determined by the place of the locus to the frequency of the adjacent vowel in the sequence (C-V). In other words, if the frequency of the formant of the vowel exceeds the locus of the stop, the formant transition will then be considered high and vice versa. However, by approximated or similar values the transition is classified as neutral.

In general, these significant differences between formant frequencies demonstrated by the normal speakers lead us to conclude that these different transitions are associated with the place of articulation of the consonants and the tongue position involved in the production of the following vowel. Additionally, the formant's movement of F2 for the vowels after [tˤ] for the normal speakers is generally flat, as figures 135, 136 and 137 indicate, consistent with those reported from Tunisian Arabic.[283]

[283] Cf. Metoui, M. (2001), pp. 116-125.

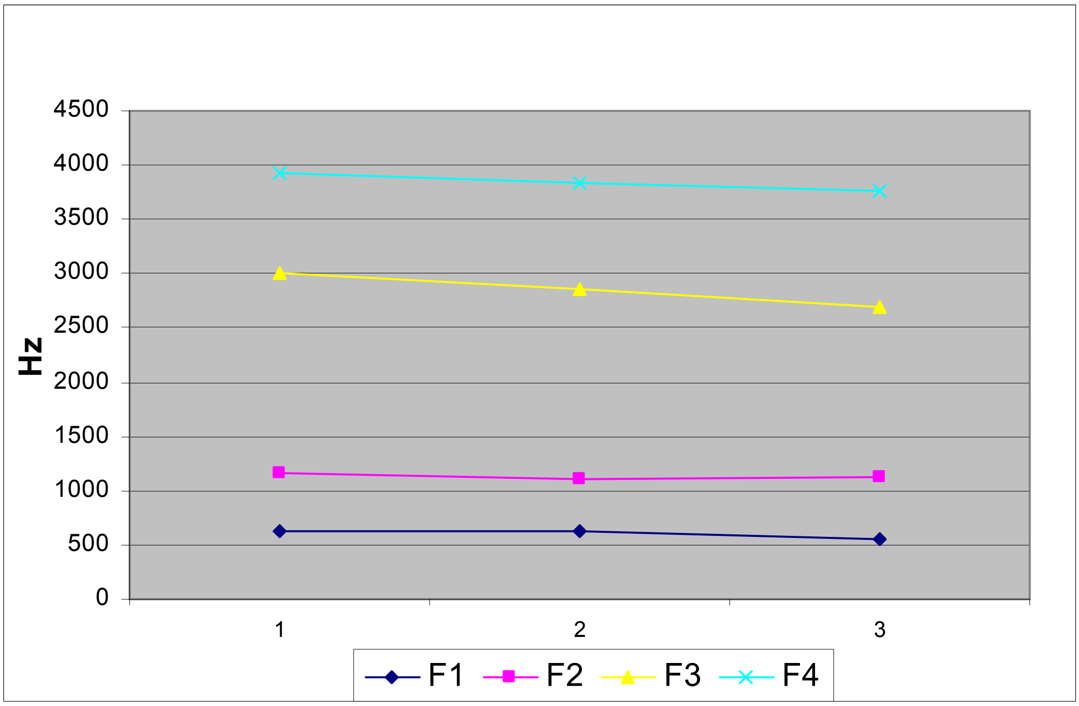

Figure 135: The formant's movement of the vowel [ɑ] in the emphatic environment [tˤɑl] as produced by a normal speaker.

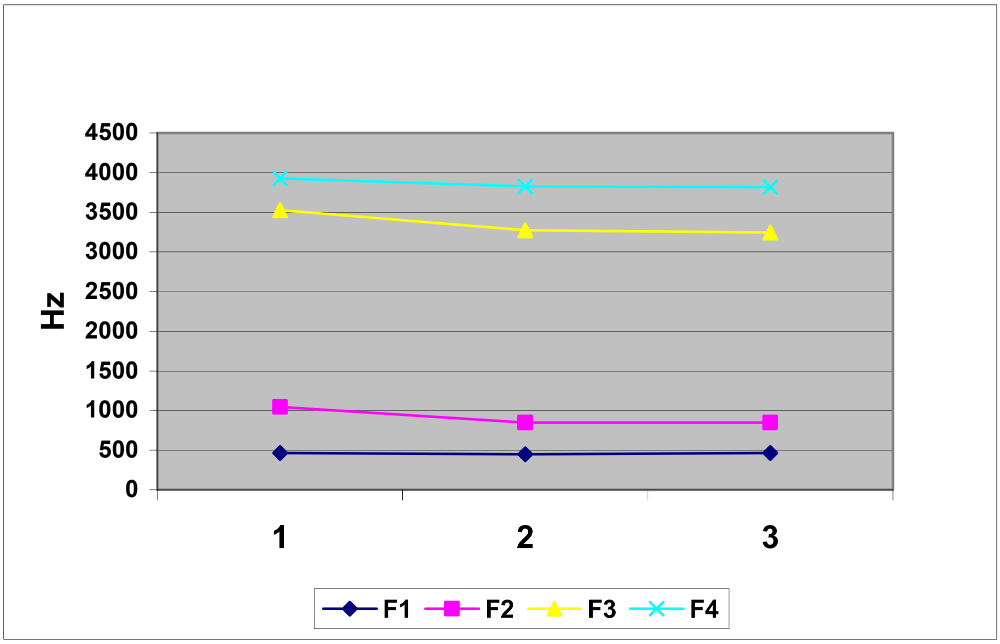

Figure 136: The formant's movement of the vowel [u] in the emphatic environment [tˤul] as produced by a normal speaker.

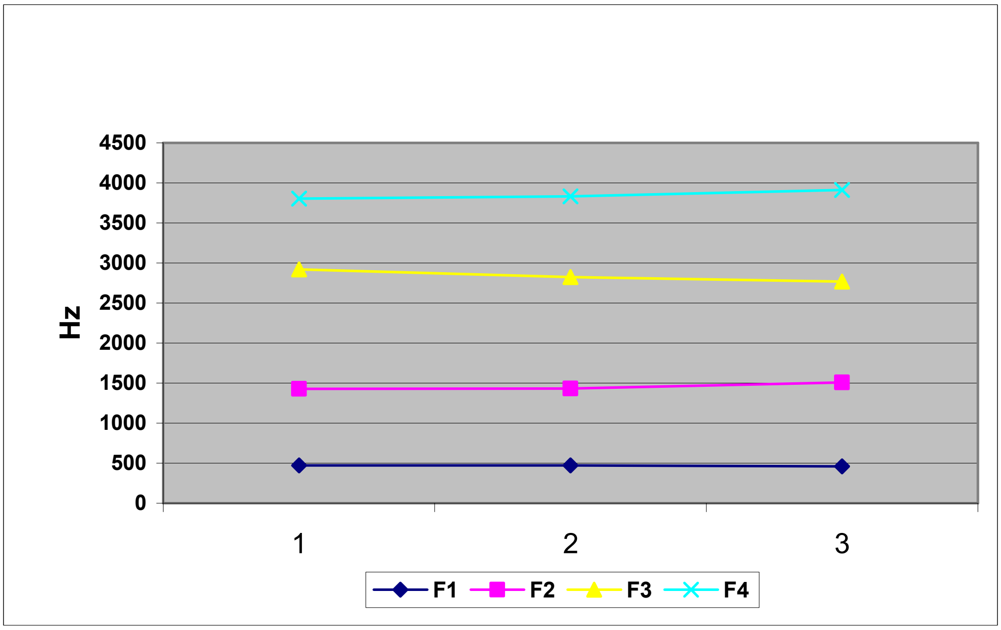

Figure 137: The formant's movement of the vowel [i] in the emphatic environment [tˤil] as produced by a normal speaker.

As it can be seen in figure 138, for example, the movement of F2 for [ɑ] which is realized as [a] by the aphasics is relatively flat, but with a tendency to rise during the movement towards the next configuration.

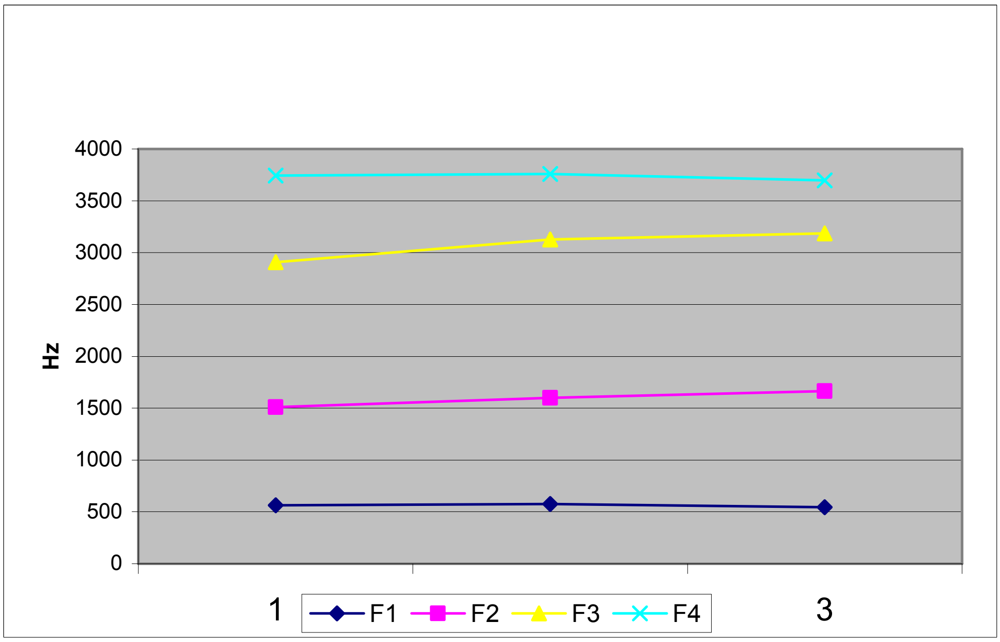

Figure 138: The formant's movement of the vowel [ɑ] in the emphatic environment [tˤɑl] as produced by an aphasic subject.

Furthermore, regarding the F2 for the vowel [u], it can be clearly seen in figure 139 that the aphasics did not lower it as did the normal speakers who showed F1 and F2 values close to each other. Concerning F3, there is also a significant difference between the patterns displayed by the aphasics and the normal speakers.

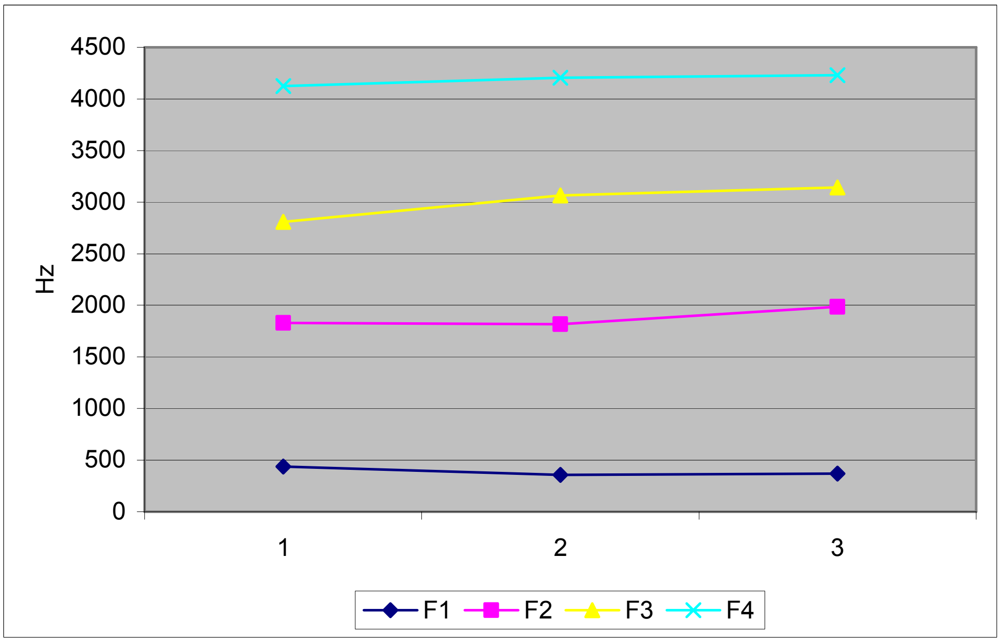

Figure 139: The formant's movement of the vowel [u] in the emphatic environment [tˤul] as produced by an aphasic subject.

So far, nonetheless, it is the case that there are remarkable differences between the acoustic patterns of the normal and the aphasic groups. In addition to the other acoustic parameters, it is worthwhile considering the characteristics of spectral burst. In this respect, the aphasics demonstrated a remarkable frication noise during the phase preceding the closure. In point of fact, in terms of the long frication noise of the emphatic consonants as exhibited by the non-fluent aphasics, there is some evidence to suggest that they displayed difficulty in moving the tongue quickly and precisely. In particular, this becomes essential in reaching a high position in the vocal tract mainly at the palatal part, which is involved in the production of [tˤ]. That is, they were not able to produce the required movements to arch the tongue in the correct place of articulation that extended to the tip of the tongue.

Support for this came from Metoui, who indicated that: “Bei [tˤ] bildet sich ein apiko-alveolarer Verschluß, der sich über einen breiten Bereich bis zur Vorderzunge erstreckt.”[284] With respect to tongue position and movement, based on the acoustic data, it would appear that the aphasics exhibit little freedom for moving the tongue in the right direction. Consequently, the consonant [tˤ] was found to be articulated in the same region as for [t].

In conclusion to this subsection, it will be recalled that one motivation for this difficulty in the aphasic patients is the way of producing the emphatic sound [tˤ]. That is, it is produced with main and secondary articulation; therefore, the aphasics displayed examples of de-emphasizing the emphatic sound reflecting a disability in implementing the secondary articulation. Consequently, they were unable to keep the acoustic-articulatory boundaries between the two sounds resulting in this categorical overlapping. It must be noted, though, that it is difficult sometimes to detect this pattern of deficit, the acoustic analysis permits analyzing speech signals and examining the relation or the correlations between the acoustical domain of speech production and the articulatory one. In this term, since the degree of constriction resulted in some transitions in the F2 values either falling or rising when the tongue moves from a consonant configuration to a vowel configuration, noticeable changes were observed. For example, the F2 of the vowel [ɑ] by the non-fluent aphasics being realized as [a] in the initial syllable [tˤɑ] was in mean average 1753Hz, whereas it reached 1165Hz for the normal speakers revealing a 588Hz difference. On the other hand, by examining the F2 of [a] after [t] by the same aphasic subject, it was 1790Hz. In this sense, during the production of [tˤ] the tongue is shaped in many positions that challenge the ability of Broca’s aphasics to execute such movements simultaneously.

Furthermore, one of the most remarkable characteristics of this sound is the huge contact area involved in its production compared to other sounds.[285] Based on this notion, it seems reasonable that the aphasics were unable to execute precise articulatory movements over the whole of the contact area, reflecting motor deficits. Importantly, as already noticed, the manner of production of the emphatic sounds is problematic for Broca’s aphasics. Basically, the production of this emphatic sound involves the back of the tongue body. However, there

[284] Metoui, M. (1998), p. 71.
[285] Cf. Metoui, M. (2001), pp. 174-176.

are some investigations that have minimized the need to strong constriction at the pharyngeal wall: “Zwar können diese Laute auch ohne starke Verengung im pharyngalen Kanal erzeugt werden.”[286] In addition, in his study on emphatic sounds in Arabic, Metoui addressed the involvement of the epiglottis in their production by reporting from “[...] eine Verengung in der epiglottalen Region ist allerdings oft, vor allem in der Umgebung von [a, ɑ] zu beobachten.”[287]

The motoric difficulty might have also contributed to make the contact area not to have the convex curvature of the tongue being formed from the tip and the front of the tongue that form together a longitudinal groove on the back of the tongue.[288] Controlling speech movements requires integration of different types of information by the brain including the synergy of muscle commands and movements that are coded in order to place the speech articulators appropriately. This articulatory transformation is fully coordinated in order to facilitate effective and stereotyped movements. In light of this description, it seems that the aphasic subjects are unable to perform such movements accurately, thus increasing the variability and inconsistency of their productions.

To conclude, in view of the results mentioned in the preceding discussion, lowering of F2 for the vowels in the same syllable in the emphatic environment, as shown by the normal speakers, provides support for the view that this lowering is a prominent acoustic correlate of emphasis in Palestinian Arabic. In contrast, the aphasic subjects did not exhibit significant F2 lowering. Therefore, it was noticed that the non-fluent aphasic subjects exhibited a deficit in implementing and maintaining this acoustic rule. Furthermore, emphasis involves in general the retraction of the root of the tongue leading to narrowing the back cavity, and consequently enlarging the oral cavity. Another feature characterizing the emphatic [tˤ] is the narrowed distance between the F1 and F2 compared to its non-emphatic cognate [t], affecting as result the formant’s movement and transition. In the case of the aphasic patients, instead, the aphasics demonstrated a reversal of the pattern than that noticed for the normal speakers by displaying a wide distance between the first two formants.

[286] Metoui, M. (1998), p. 83.
[287] Ibid.
[288] Cf. Metoui, M. (2001), p. 176.

The results of the current study indicate that the complexity of speech production of the emphatic sounds can display a set of impaired articulatory abilities by the anterior aphasics. In this regard, because of the complexity of producing the emphatic consonant they were unable to produce it precisely, providing support for motor deficits. Furthermore, the aphasic subjects exhibited a long VOT compared to the normal speakers. Importantly, they exhibited overlapping between the F2 locus for [t] and [$t^ʕ$].

In addition, the results in the present study display an influence of the stop sounds on the formant frequencies of the Arabic vowels. It has been found that the second and third formants of vowels are influenced by the place of articulation of the emphatic stop consonant under study [$t^ʕ$]. Furthermore, the tongue position and the place of articulation of the stop consonants have an impact on the transitions of the second and third formant. In general, the alveolar consonants [t] and [$t^ʕ$], as displayed by the normal speakers, showed rising in the second and third formants with front vowels and drop in the case of the back vowels. These differences in the formant transitions emphasize the role of the coarticulatory effects on the acoustic signal.

6. COARTICULATION

6.1. Introduction and definition

Coarticulation indicates that sounds are not produced separately in isolated gestures, but in a complex configuration. In fact, it might be considered one of the most important features of connected speech. It is a process that is highly correlated with connected speech factors such as speech style and communicative situations. It refers to the degree of the dynamic transitions between adjacent segments in a particular context. This phenomenon was of special interest for many researchers in recent years. In this account, Metoui stated that "Kaum ein Begriff hat in den letzten 20 Jahren so viel Diskussion erfahren wie der Begriff Koartikulation."[289]

Literature shows significant differences in dealing with this phenomenon from different points of view.

> "Als Ursache der artikulatorischen Variabilität wird in der phonetischen Literatur häufig die natürliche Trägheit der artikulatoren genannt, daneben aber auch die physiologischen Unterschiede zwischen den Menschen und ihren physiologischen Zuständen sowie sprachliche Kontexte und Umgebungseinflüsse."[290]

Coarticulation could be indicative of the correlation between the articulatory and acoustic properties of a segment, a consonant or a vowel which is found to be functionally different in a segmental context. Consequently, it can be defined in terms of "[…] the influence of one speech segment upon another; that is, the influence of a phonetic context upon a given segment."[291] It is undeniable, nevertheless, that during the speech event the articulatory movements run continuously and not discretely. In this respect, two main types of coarticulation can be identified: the perseveratory coarticulation runs from left-to-right and the anticipatory one runs from right-to-left. In fact, anticipatory coarticulation was of special interest for the researchers because it is considered to be an indicator for the planning of upcoming speech segments.[292] A possible consequence of such phenomenon is that it sheds light on the nature of the speech sequencing process. Anticipatory coarticulation involves the

[289] Metoui, M. (2001), p. 41.
[290] Ibid.
[291] Daniloff, R., & Hammarberg, R. (1973): On Defining Coarticulation, p. 239.
[292] Cf. Modarresi, G., Sussman, H., Lindblom, B., & Burlingame, E. (2004): An Acoustic Analysis of the Bidirectionality of Coarticulation in VCV Utterances, p. 292.

motion of the lips, tongue and velum. It is defined by lip-rounding during consonant production that precedes a rounded vowel. Because of such coarticulatory influences, for example, in producing the syllable [su] the lip-rounding starts at the consonant [s] in anticipation of the rounded vowel [u]. However, no lip-rounding is observed when producing the syllable [si]. Thus, labial coarticulation reflects "the fact that anticipatory coarticulation may reveal low linguistic units are temporally organized in speech."[293] Notably, coarticulation refers to variations in speech because it draws a picture of how a segment in a context systematically affects different phonetic realizations of a single phonological category. In particular, it reflects the dynamic transitions between the adjacent segments. Consequently, coarticulation completely depends on the phonetic environment and "a speech sound spoken in isolation cannot be coarticulated because there are no adjacent sounds, or context to exert coarticulatory influence."[294] In addition, languages display different patterns and directions of coarticulation. Some studies emphasized this point by indicating: "Je nach untersuchter Sprache können die koartikulatorischen Einflüsse unterschiedlich stark sein und unterschiedlicher Richtungen nehmen."[295]

The desire for increasing ease of articulation by causing shift of movements towards the surrounding context is considered as one of the motivations of coarticulation.[296] In perhaps, the more popularly cited view, coarticulation is thought to be motivated by economic aspects in order to minimize the articulatory efforts: "Sprechökonomische Ursachen spielen bei der Artikulation eine große Rolle."[297] The possible relation between coarticulation in speech motor control and other areas of movement control are found to be problematic in motor speech disorders and could also be addressed by studying speech disorders. With respect to speech production, models differentiating between the types of coarticulation processes have been established in terms of the nature of the motoric process whether it is active or passive in nature. Accordingly, if a coarticulatory effect is planned and controlled from highly motoric levels, then it is considered to be an active highly programmed process. However, depending on the physical characteristics of the articulators, the process may be accounted as passive and not motor planned initiated. On the whole, anticipatory coarticulation, which requires an initiation of a gesture before the sound whose influence extends to the previous segment, is an

[293] Hardcastle, W., & Hewleit, N. (1999): Coarticulation Theory, Data and Techniques, p. 152.
[294] Daniloff, R., & Hammarberg, R. (1973), p. 239.
[295] Metoui, M. (2001), p. 126.
[296] Cf. Neppert, J., & Pétursson, M. (1986), p. 231.
[297] Metoui, M. (2001), p. 42.

active process and based, therefore, on a motor planning controlled process.[298]It is worthy to note that anticipatory coarticulation is associated with the preplanning of upcoming speech segments. As a result, impairments in this stage provide evidence for the misselection of upcoming sounds leading to impairment in the coordination of articulatory gestures. It can be safely said that look-ahead models and coproduction models have dominated literature on anticipatory coarticulation. The look-ahead[299] model of anticipatory coarticulation considers a phoneme as a bundle of features. Based on this model, coarticulation established by initiating movements for a particular feature of a later segment can be achieved as long as the current segment does not utilize that feature. Thus, for instance, in a phonetic environment that contained a final rounded vowel but the preceding sounds did not use the rounding feature then the production of the feature "round" would be realized as early as the first vowel.[300] Accordingly, this model argues that only a subset of the vocal tract configuration can be functionally utilized by the targeted segment. For example, due to the utilization of subcomponents of the vocal tract, vowel specification of the tongue body height but not velum height was used in vowels.

However, based on results reported from other studies,[301] there is some evidence to suggest that vowels display a kind of target specification of velum height. The fact that vowels make use of the same features would suggest that the look-ahead model would not be able to predict vowel-to-vowel anticipatory coarticulation. On the other hand, the coproduction model[302] tends to assume that vowels and consonant gestures are distinguished by fixed time courses which can overlap in time with the time courses of neighbouring gestures. Öhman drew the conclusion that vowels and consonants use largely independent subsets of the vocal tract musculature and not all the articulatory features are activated. His results were interpreted in terms of developing a physiological model of coproduction. In fact, by considering the starting of lip-rounding in the coproduction model, in particular, it will be shown that beginning of lip-rounding for the final vowel will be time-locked oriented and related simultaneously to the acoustic onset of the vowel. In this way, within this framework consonants and vowels are produced from different muscle apparatus. Those muscle groups are represented neurally in a separated way controlled by a motoric network.

[298] Cf. Neppert, J., & Pétursson, M. (1986), p. 237.
[299] Cf. Guenther, F. (1995): Speech Sound Acquisition, Coarticulation and Rate Effects in a Neural Network Model of Speech Production, pp. 594-602.
[300] Cf. ibid., pp. 600-615.
[301] Cf. Fowler, C., & Saltzman, E. (1993): Coordination and Coarticulation in Speech Production, pp. 177-182.
[302] Cf. Öhman, S. (1966): Coarticulation in VCV Utterances: Spectrographic Measurements, p. 167.

In fact, significant differences between the two previous models can be found regarding time course. Basically, while the coproduction model considers the target time courses for segments as fixed and not influenced by context, the look-ahead model is seen in the time course of a segment as a dynamic parameter influenced by the context. On the other hand, the Hyper and Hypoarticulation theory[303] (H&H theory) argues that speakers continuously tend to adapt their speech to what listeners need in a given moment of the communicative situation. In fact, this theory "basiert auf der Annahme, daß Sprechen und Hören mittels biologischer Prozesse geformt werden."[304]

Given the close relationship between hyperarticulation and hypoarticualtion, more redundant parts of the speaker's output can be produced in a less precise way (hypospeech) than other pieces of speech that bear new information (hyperarticulation). According to this theory, the mind of the speaker should always take the listener's needs into account during the speech event. With respect to this notion, it is thought that speakers tailor their productions to this internal representation of what the listener usually needs. Aside from this hint, little evidence was found for this theory especially when speakers are under time task pressure.[305] In fact, from a functional point of view, the concept of effort decrease is related to the communicative situation where more demands on the listener are imposed resulting in the speaker revaluating his speech style by producing intelligible output (Hyperspeech). Basically, Lindblom[306] considered speech production as a dynamic balance process that is motivated by the desire of the speaker to be easily understood with more intelligible speech, on the one hand, and the need to achieve productions with less articulatory effort and the plasticity factor, on the other hand.

In conclusion to this subsection, it must be noted, though a huge body of research has been conducted on coarticulation, it is difficult to draw any definite conclusion about a comprehensive coarticulatory theory that takes into account all the theoretical and functional aspects of this phenomenon such as function, neuroanatomical aspects and variability across languages.

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[303] Cf. Lindblom, B. (1990), pp. 405-407.
[304] Cf. Vollmer, K. (1997): Koartikulation und glottale Transparenz, p. 40.
[305] Cf. Horton, W., & Keysar, B. (1996): When Do Speakers Take into Account Common Ground?, p. 91.
[306] Cf. Lindblom. (1990), pp. 413-420.

6.2. Neurolinguistic studies on coarticulation in aphasia

Several studies on coarticulation in aphasia revealed controversial results. There has been some debate about the magnitude and extent of anticipatory coarticulation between groups of fluent and non-fluent aphasic patients compared to normal control subjects. For example, Katz [307] found no evidence of a deficit in anticipatory coarticulation in an acoustic and perceptual analysis of monosyllabic stimuli produced by anterior and posterior aphasic subjects.

In addition, there is evidence from electromyography (EMG) studies that Broca's aphasics demonstrated anticipatory coarticulation patterns.[308] In contrast, Tuller and Story[309] found less evidence for anticipatory labial coarticulation in Broca's aphasics compared to normal speakers. A similar point has been made by Ziegler and von Cramon,[310] who found minimal coarticulatory cues in the speech of apraxic patients. Mayer[311] gave further evidence for coarticulation limitations among motor speech disorder patients. Basically, he found reduced vowel-to-vowel anticipatory coarticulation significantly noticeable in the acoustic patterns of non-fluent speech.

> "When intrasyllabic, CV, labiolingual coarticulation is considered, the results of recent studies provide approximately equal support for the two hypotheses of aphasic impairment (i.e., systematic delay" *vs*. variable, with normal extent."[312]

A possible explanation for these conflicting findings might be due to the methods that have been applied including acoustic or perceptual measures or to individual subject differences. Clearly, though various studies have been conducted on coarticulation in aphasia, it is hard to draw a final result about the patterns observed in the aphasics across different languages. Therefore, in light of this notion, the current chapter aims to address the issue of coarticulation in the Palestinian Arabic anterior aphasics based on acoustic data.

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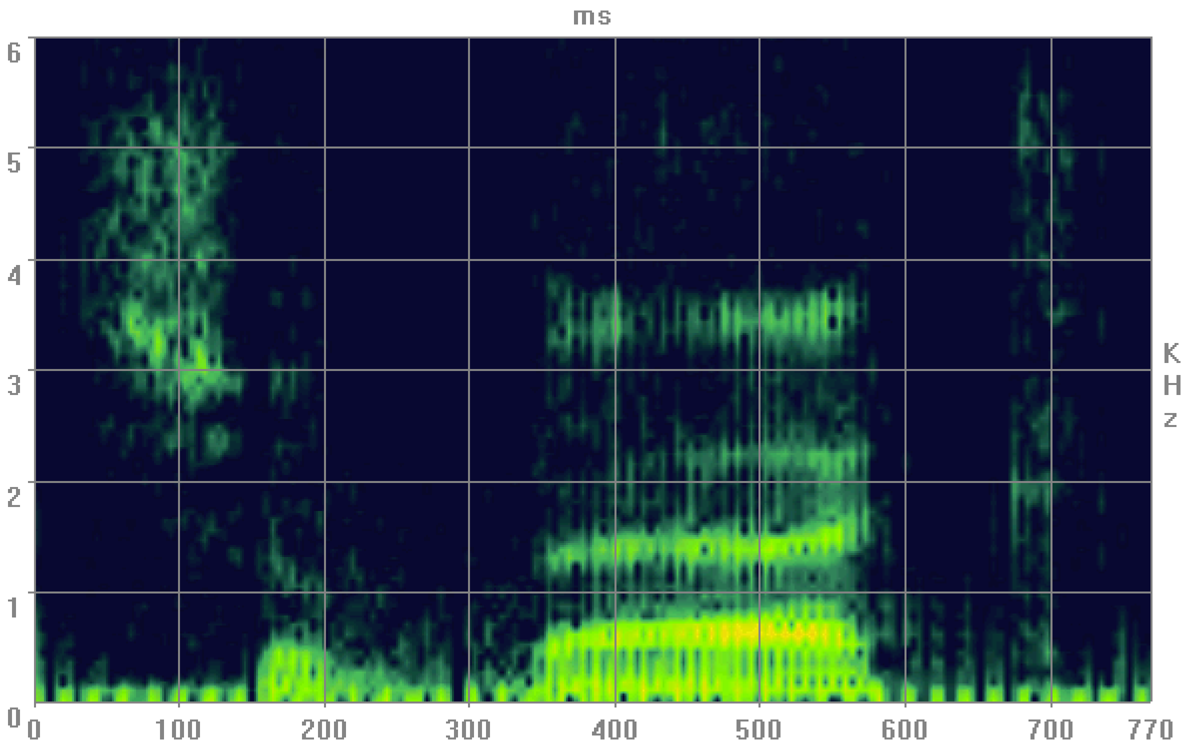
307 Cf. Katz, W. (1988): Anticipatory Coarticulation in Aphasia: Acoustic and Perceptual Data, p. 361.
308 Cf. Sussman, H., Marquardt, T., MacNeilage, P., & Hutchison, J. (1988): Anticipatory Coarticulation in Aphasia: Methodological Considerations, p. 377.
309 Cf. Tuller, B. , & Story, R. (1988): Anticipatory and Carryover Coarticulation in Aphasia: An Acoustic Study, pp. 750-769.
310 Cf. Ziegler, W., & Von Cramon, D. (1985): Anticipatory Coarticulation in a Patient with Apraxia of Speech, p. 117.
311 Cf. Mayer, J. (1995): A Representational Account for Apraxia of Speech, pp. 82-84.
312 Katz, W. (2000): Anticipatory Coarticulation and Aphasia: Implications for Phonetic Theories, p. 324.

6.3. Results of the normal speakers and the aphasic subjects

It seems likely that the acoustic parameters are actually correlated with coarticulation. It will be recalled that the acoustic correlations of the lip-rounding are associated with lowering of the formant frequencies.[313] It is found, therefore, that the formant frequencies are related to the length of the vocal tract. Since lip-rounding takes place at the end of the vocal tract, a lowering in the formants is noticed. Lip-rounding effect is more clearly seen on F2 and F3 than F1.[314] Generally speaking, F1 is related to a vowel's height. The higher the vowel is the lower F1. However, F2 generally corresponds to the backness of a vowel. The farther back the vowel is, the lower F2.[315] The spectrogram of a normal speaker in figure 140 clearly shows the formant transitions of the vowel [u] after the fricative [ʃ]. Furthermore, the significant lowering of F2 to about 1600Hz can also be seen. Evidence for strong lip-rounding that starts during the production of [ʃ] is observable in the significant drop of F2 in anticipation of the vowel [u]. In addition, the transition of [u] to [b] is distinguished also by lowering of F2 and rising of F3.

313 Cf. Neppert, J., & Pétursson, M. (1986), p. 110.
314 Cf. ibid.
315 Cf. ibid.



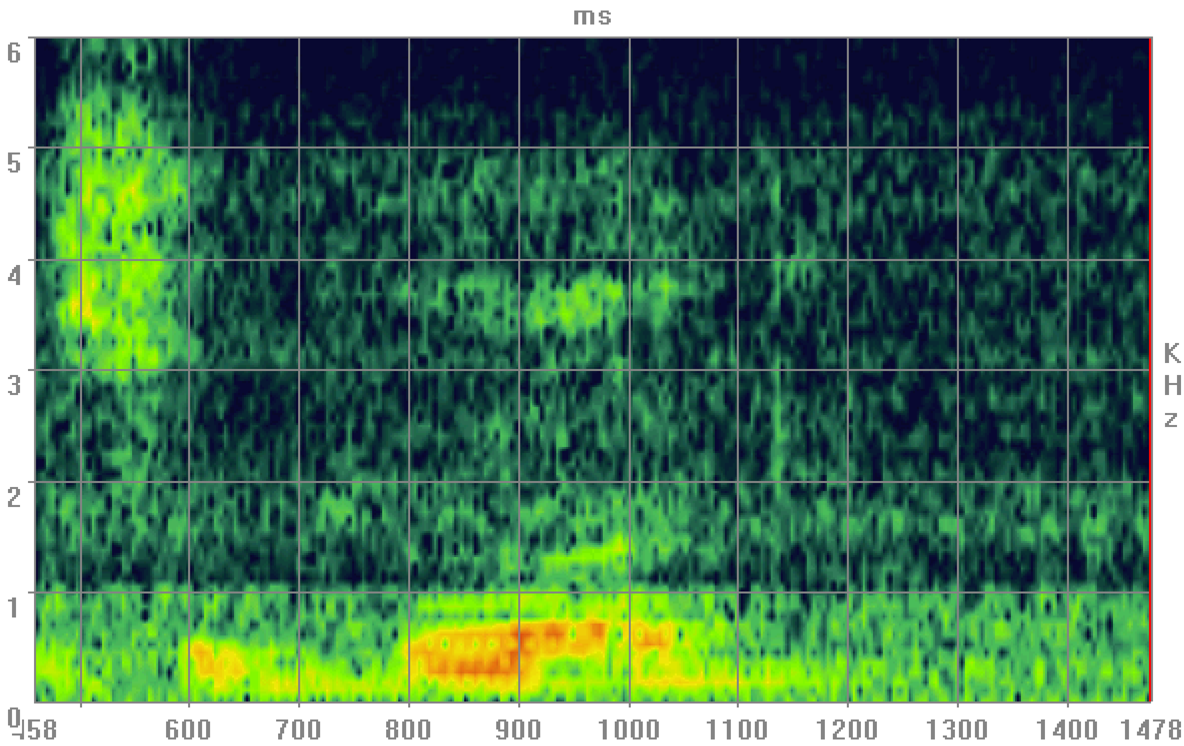
ʃ u b a: k

Figure 140: Spectrogram of the word [ʃuba: k] 'window' as produced by a normal speaker.

Normal Subjects	F2	F3
N1	1600	2864
N2	1654	2870
N3	1670	2890

Table 74: F2 and F3 values (Hz) in the phonetic environment [ʃu] for three normal speakers (N) indicating normal coarticulation patterns.

Accordingly, as table 74 exhibits, the normal speakers displayed significant indications for lip-rounding in anticipation of the rounded vowel [u] affecting consequent F2 and F3 values. In contrast, by comparing the patterns exhibited by the aphasics, significant differences can be seen. For example, the spectrogram in figure 141 exhibits clearly different formant movements and values compared to those by the normal speakers.



ʃ u b a: k

Figure 141: Spectrogram of the word [ʃuba: k] as produced by an aphasic subject.

In figure 141, we also see evidence in support of the coarticulatory limitations affecting the spectral shape as given by Broca's aphasics. It can also be noticed that the transition from [ʃ] to [b] is also characterized by an abruptness of the amplitude. Moreover, the energy spreads in a wide range bandwidth in contrast to the normal speakers. The intensity average for [ʃ] by the aphasics is 57dB, whereas for the normal speakers 66.2dB displaying low pressure in Broca's productions. Consequently, they exhibit low amplitude in those frequency ranges compared to those of the normal speakers, as shown in figure 141. Applied to the cases considered in the current study, Broca's aphasics show weak concentrations of energy compared to the normal speakers, who exhibited dark areas even at high frequency ranges. Notably, for example, the normal speakers display these dark areas in the frequency range 3000Hz, whereas for the aphasic subjects they were randomly distributed. Based on coarticulation patterns of our aphasic patients, it is hard to speak of formant transitions especially from [b] to [a] compared to the normal patterns. However, a transition can be seen from [a] to [k]. The lack of the dynamic movement of transitions would suggest a lack in the movement of the tongue indicating coarticulatory limitations.

Aphasic subjects	F2	F3
B1	1850	3100
B2	1985	3210
B3	1888	3170

Table 75: F2 and F3 values (Hz) in the phonetic environment [ʃu] for three of Broca's aphasic subjects (B).

In contrast to table 74, Broca's aphasics, as shown in table 75, display a significant increase in F2 and F3 under the same phonetic environment as that of the normal speakers. Consequently, it is hard to speak of anticipatory coarticulation in Broca's aphasics. This might suggest that sounds produced by the anterior aphasics are independent from the phonetic context.

In addition, the normal speakers in the labial environment [bu] show significant lowering of F2 and F3 compared to Broca's aphasics. In fact, the aphasic patients as shown in figure 142 exhibit more significantly high F2 (1800) and F3 (3110Hz), whereas for the normal speakers it was 1400Hz for F2 and 2900Hz for F3. The coarticulation between the labial consonants and the high vowel [u] influenced F2 and F3 significantly. The coarticulatory patterns of the normal speakers fit with those reported for Tunisian Arabic. In this account, Metoui stated that "Bei [bu] […] ist […] eine Absenkung des F2 […] zu verzeichnen und ein F3–Anstieg."[316]

[316] Metoui, M. (2001), p. 119.

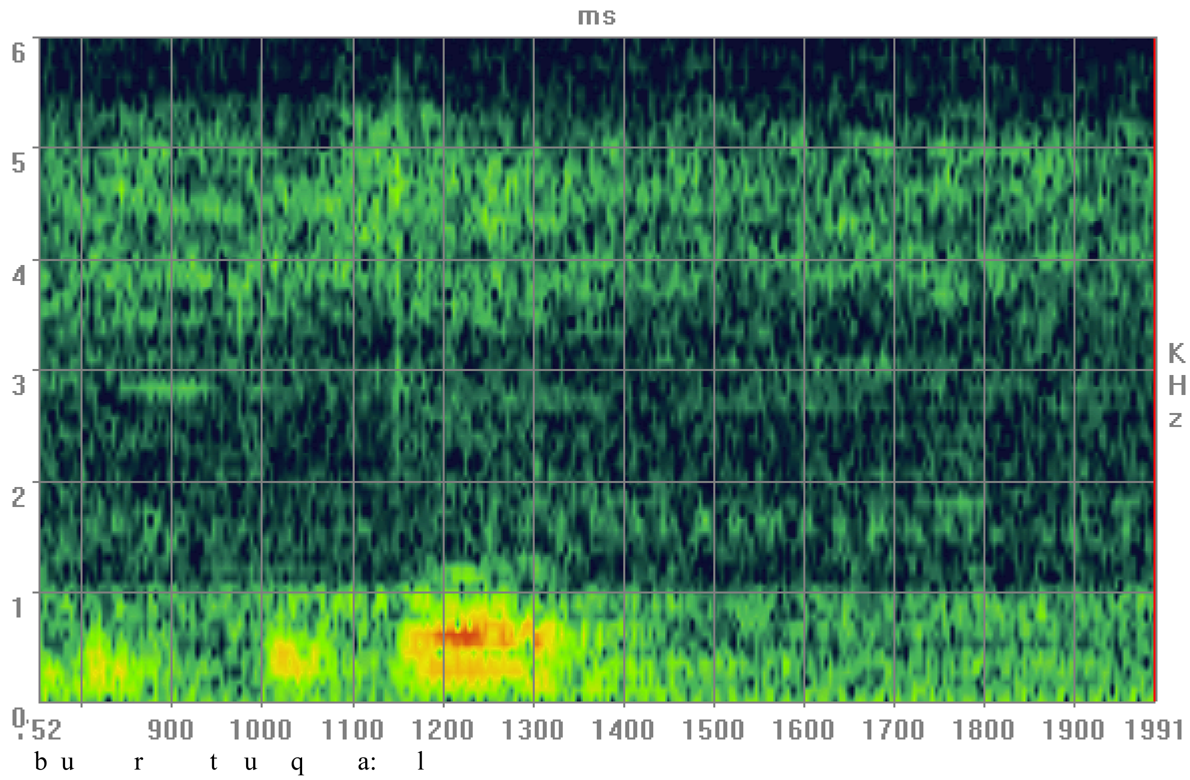
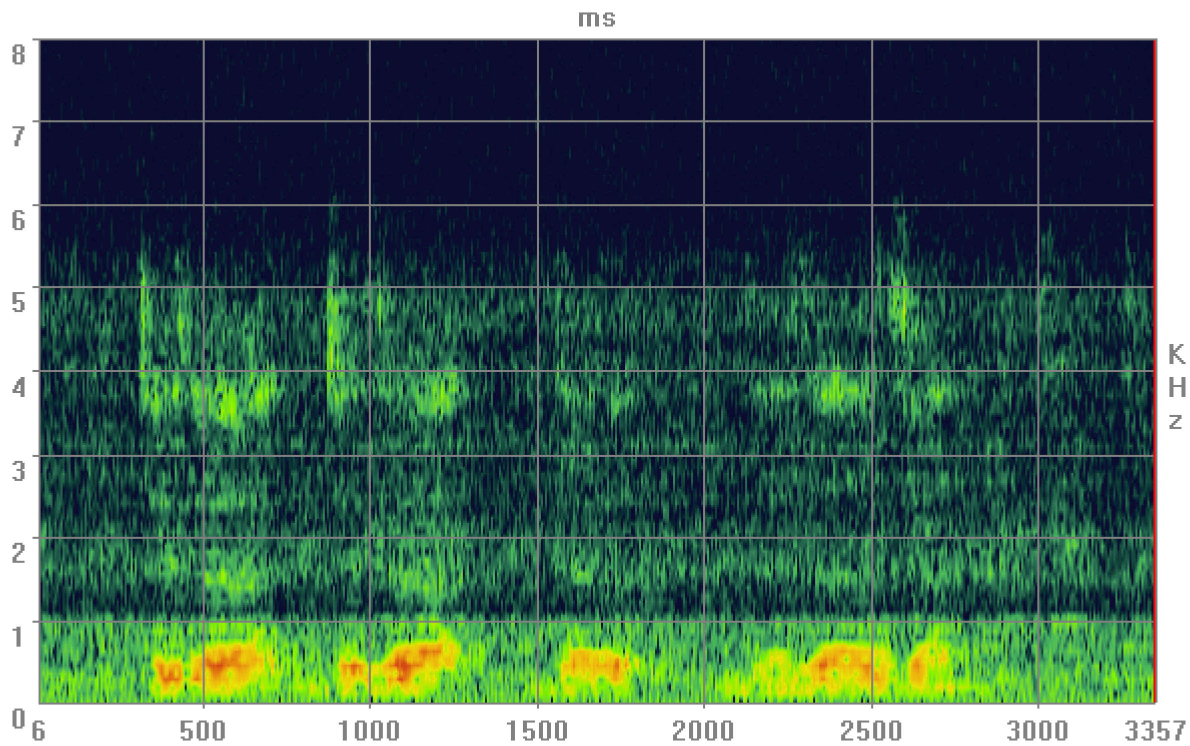


Figure 142: Spectrogram illustrating an impairment in the production of the word [burtuqa:l] 'orange' as produced by one of the aphasic subjects.

6.4. Neurolinguistic discussion of the results

Anticipatory coarticulation requires starting lip-rounding during consonant production preceding a rounded vowel. This notion may be particularly relevant to the fact that the lack of formant frequency lowering in the environment [bu] or [ʃu] could suggest that those patients realized [u] independent of the phonetic context. Furthermore, the tendency towards a centralization of the vowels and the tightly-packed formants could suggest coarticulatory limitation in prevocalic environment. The expanded vowel space would contribute to strongly enhance the intelligibility of speech. Thus, it can be said that this is correlated with efficient and precise timing of the articulatory movements of the adjacent segments, leading to effective coarticulation. In this view, coarticulation might be considered a reliable factor of studying speech intelligibility through conducting articulatory adjustments and keeping to the spatiotemporal aspects of the speech production process. This seems to be a significant indicator of the anterior aphasic's inability to maintain fine-grained adaptations and modifications in articulators making their speech less intelligible. Furthermore, the results can also be interpreted in terms of Lindblom's model that emphasizes the intercorrelation between the speaker and the hearer. In this account, the speaker aims at ease of articulation, whereas the hearer focuses on sufficient contrast between the segments in order to have intelligible speech. Thus, though coarticulation is motivated by the desire to decrease the efforts of the speaker, it seems likely that certain acoustic information in a specific phoneme is contained in order to perceive it independently and precisely. Taking these observations as a starting point to highlight the nature of coarticulation deficiency in Broca's aphasics, it can be noted that those patients are not able to maintain the acoustic boundaries, and consequently show deviations outside those acoustic boundaries.

Indeed, the findings obtained from the current study also shed light on the nature of errors in Broca's aphasics. Notably, they displayed initiation problems at the level of the utterance or single sound. Those initiation problems are associated with their coarticulatory problems, as shown in figure 143. For example, one of the aphasic subjects should have to elicit the word [dadʒa:dʒah] 'chicken' but he failed many times initiating the correct gesture for the targeted sound [dʒ]. Once again, the spectrogram in figure 143 indicates that the patient made different attempts to get to the appropriate oral articulation.



d a dʒ d a dʒ d a dʒ a: dʒ a h

Figure 143: Spectrogram illustrating initiation difficulties in producing the word [dadʒa:dʒah] 'chicken' by an aphasic subject.

One possibility is that, although the phono-morphological structure of the word contributed to trigger such difficulty, the context-sensitivity might be considered a critical cue for segment production by the aphasic subjects. In other words, sounds vary with the context, and consequently they have problems with assigning the appropriate muscle command for the target phoneme. Accordingly, those patients might have problems with adjusting the temporal and the spatial parameters of speech production to fit the context in which the phoneme is found.

> "Contextual factors affect the dynamics of motor control by exerting an influence on the mode of coalition of neural structures involved during a particular phase and on the skill required for the planning, programming and execution mechanism."[317]

Further effect of lexical frequency on coarticulation might come into play. Lindblom[318] addressed this issue in terms of the "neighbouring activation model." In fact, this model indicates that high-frequency words are easier to perceive correctly and precisely. The frequent words are quite simple to access and are more subjected to coarticulation than the less frequent ones as many studies have shown.[319] However, in the case of word frequency effect, there is still no clear evidence for its influence on coarticulation in Broca's aphasic patients. Those patients might, for example, likely display limitations in applying coarticulatory strategies when they are more effortful by facing less frequent words.

In fact, it is specifically of importance to address the influence of the perceptual consequences of the lexical effect on coarticulation. In addition, the motor complexity might have a negative impact on the spatiotemporal parameters of the articulator movement. Specially, this difficulty is increased with the combination of sound clusters and more than one articulator involved in producing the sound. For example, as shown in figure 143, it was difficult to produce the word [dadʒa:dʒah] 'chicken,' since it consists of a combination of two affricate sounds [dʒ]. These sounds might require increased motoric processing and linguistic demand that might be difficult for Broca's aphasics to accomplish. This may also be partly due to the fact that increasing the number of the articulators involved in the production of the segment

317 Van der Merwe, A. (1997): A Theoretical Framework for the Characterization of Pathological Speech Sensorimotor Control, p. 6.
318 Cf. Lindblom, B. (1990), pp. 409-412.
319 Cf. Munson, B., & Solomon, N. (2004): The Influence of Phonological Neighbourhood Density on Vowel Articulation, pp. 1056-1057.

requires more activation of coordination system. Metoui's study provides evidence for the need of more coordination: "Der Koordinationsbedarf ist dabei umso höher, je größer die Zahl der beteiligten Artikulationsorgane ist."[320] Therefore, as the previous results indicate, phonetic errors of Broca's aphasics should be studied in terms of the linguistic and motoric complexity of the utterances. In this respect, results obtained from the current study exhibit that Broca's aphasics display difficulties in producing some sound categories like the affricate and the emphatic sounds, suggesting that sound structure and motor complexity will be challenged for those patients due to the fact that this requires more motor control plan for accurate productions. In this respect, McNeil et al. indicated that "the more complex or difficult the task, the greater is the processing load and the outlay of effort."[321] This observation emphasizes that language and the motoric aspects of the speech event are integrated in speech production mechanism and hardly separated. Clearly, the influence of context complexity, sound structure and motor complexity that triggered coarticulation possibilities should be addressed during evaluation of the aphasic patients.

Interestingly, anticipatory errors were observed also in Broca's aphasics. For example, figure 141 displays that the aphasic patient correctly performed oral gestures for producing the plosive voiced consonant [b], but lacking the voicing gesture associated with the voiced [b]. Therefore, it would be argued that in such errors timing deficits related to the laryngeal mechanism might be responsible for this error. Furthermore, the devoicing deficit could also be related to the influence of the phonetic environment. Consequently, the [b] is aspirated to be realized as the voiceless plosive [p]. This kind of impairment is considered an example of anticipatory error that leads to anticipate the feature "voiceless". Once again, we would also maintain that such deficits are related to the laryngeal abduction-adduction mechanism. However, other explanations might also be considered in this case in terms of the influence of the adjacent voiceless [k] associated with the question of interarticulatory coordination and illegal regressive coarticulation. The initiation and maintenance of laryngeal timing correlated with a number of features such as the adjustments of the vocal folds that determine the degree of abduction or adduction as well as the appropriate configuration of the glottis. On this view, those are related directly to control mechanisms that might be deviant in Broca's aphasics. As mentioned in the previous discussion to this subsection that coarticulation abnormalities in

[320] Metoui, M. (2001), p. 247.
[321] McNeil, M., Odell, K., & Tseng, C. (1991): Toward the Integration of Resource Allocation into a General Theory of Aphasia, p. 35.

Broca's aphasics might be related to the issue of the interarticulatory organization of consonantal sequences, more studies should be conducted in order to have a better understanding of the organization mechanism of interarticulatory timing. On the other hand, syllabic homogeneity and rhythm could contribute to the temporal organization deficit. This would in turn "result in a "harmonization" of the pattern of devoicing gestures with the global syllabic rhythm of an utterance."[322]

The timing of articulatory gestures in speech is associated with representations of segments and suprasegmental features of the speaker's plan at the sentence-level. Consequently, in this way, this harmonization processes contributed to the phonetic implementation of the utterance. Again, the results could maintain that the coarticulatory patterns of Broca's aphasics are correlated with laryngeal-articulatory coordination. The very fact that anticipatory coarticulation required a simultaneous coordination and fine programming between more than one independent articulator is further evidence that these strategies are being distorted in the anterior aphasics. The patterns of variability might give further support that initiation deficits in Broca's aphasics imply neural organization deviations that underlie the speech production process due to the fact that coarticulation refers to the degree of the dynamic transitions between adjacent segments in a particular context. In fact, many models have been proposed to account for the coarticulation of various neuromotoric and phonolinguistic aspects.

Motor program-based theory[323] emphasizes the central control of movement. In other words, the movement commands are centrally programmed and controlled from the related motoric brain structure. In light of the initiation difficulties for Broca's aphasics, it might be hard to accept the previous concept of the theory, since it does not account for the adaptation of movements to the context that may be noticed during the ongoing attempts to reach the correct articulation. On the other hand, dynamic system models or action theories give more importance to information of the environment in the control of movement.[324] Consequently, actions are associated with the context and environment. On this basis, we would predict that the coarticulatory deficits with rising F2 values would suggest that Broca's aphasics produce sounds independent of their phonetic context.

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[322] Cf. Hoole, P., Schröter-Morasch, H., & Ziegler, W. (1997) : Patterns of Laryngeal Apraxia in Two Patients With Broca's Aphasia, p. 87.
[323] Cf. Magill, R. (1998): Motor Learning: Concepts and Applications, pp. 50-70.
[324] Cf. Kelso, J., & Tuller, B. (1981): Toward a Theory of Apractic Syndrome, pp. 234-241.

According to Kelso et al.,[325] movement is due to synergic selective processes based on coordination between the neural and anatomic structures like the musculature apparatus. Thus, this would mean that coordination would not preassigned by the motor program. However, the dynamic and motor program models have difficulty answering the question whether deficits in Broca's aphasics are related to impairments at the phonetic or phonological level. For instance, they exhibited impaired VOT productions by showing overlapping between the places of articulations of the stop consonants. We would, therefore, argue that those theories would not take into account the role of the temporal factors in speech production, and consequently disable to specify the nature of errors in Broca's aphasics.

Given the fact that anticipatory coarticulation errors and initiation difficulties highlight the motoric nature of the deficits, we would suggest that a distinction between motor program and motor planning that might operate separately in speech production process should be established. Therefore, at the articualtory level, the correction attempts performed by the aphasics would indicate adaptations to the motor planning. In fact, the traditional models such as the motor program and dynamic theories used motor programming and motor planning as synonyms. However, Van der Merwe[326] presented a model that responds to the necessity of establishing a distinction between motor programming and planning and the sensorimotor control. According to her model, in the linguistic-symbolic planning phase selection and sequencing of phonemes are achieved based on the phonotactic rule that the language allowed. It is considered to be the planning stage for language components of the target utterance such as phonology, morphology and syntax. Consequently, deficits at this stage are considered to be phonological in nature, a feature prominent in Wernicke's aphasia. Neither the anticipatory errors nor the initiation difficulties of our Broca's aphasics took place at this level. This emphasizes the fact that this stage is not motoric based.

[325] Cf. Kelso, J., Tuller, B., & Harris, K. (1983): A Dynamic Pattern' Perspective on the Control and Coordination of Movement, pp. 137-145.
[326] Van der Merwe, A. (1997), p. 6.

Motor planning refers to the planning of the motor goals of the articulator spatially and temporally. The spatial aspects include the place and manner of articulation. From the point of view of the deficits displayed by Broca's aphasics, it is important to understand the aspects of spatial parameters in order to get a better knowledge of the mechanism of this system. This is due to the fact that "the spatial relationships of structures are important in the development of hypotheses about how movements occur."[327]

The temporal aspect includes different parameters such as segment duration, rate of speech and the coarticulatory possibilities which are associated with temporal and spatial coordination between the articulators. Also, the duration of the articulator as a temporal parameter is an important component of motor planning stage due to the fact that it aims to get the appropriate acoustic output leading to precise achievement of the articulators. Thus, the speech production process aims to achieve fast, precise, flexible and efficient movements. Accurate mappings between acoustic signal and articulator movements are essential for correct production. Therefore, damage to the articulators will affect the acoustic signal that is governed and performed by a given set of motor commands. To maintain the ability to produce the acoustic signal, a mapping between acoustic, phonetic, orosensory and motor frames[328] with time is required that in turn found to be deviated in Broca's aphasics. It appears that, for example, the motor plan for the [ʃ] sound, as shown in figure 141, includes different activities such as jaw and tongue movement and velar lifting as motor goals. During the motor planning these movements should be adapted to the phonetic environment in which the sound is to be produced. In fact, coordination and adaptation of movement demanded accurate integration between the temporal and spatial parameters of movement.

We would also contend that Broca's aphasics were neither temporally nor spatially able to keep to these adaptations leading to coarticulation deficits. For instance, the motor goals for [ʃ] in the phonetic environment [ʃuba:k] 'window' require starting lip-rounding during the production of [ʃ] in anticipation of the rounded vowel [u], which was deviant in the aphasic subjects, as the formants' transitions show in figure 141 for example. This refers to a deficit in planning for the anticipatory coarticulation. In addition, a full presentation of motor planning

[327] Moll, K., Zimmermann, G., & Smith, A. (1977): The Study of Speech Production as a Human Neuromotor System, p. 111.
[328] Cf. Smalla, S., &. Nusbaum, H. (2004): On the Neurobiological Investigation of Language Understanding in Context, p. 308.

demands an efficient coordination system that achieves optimal movement of the articulators during speech production, leading to the conclusion that this function is deviant in those patients. This implies: "daß die Koordination von Strategien im Sinne der Bewegungsoptimierung für alle beteiligten Artikulatoren geschieht."[329]

This would suggest that this stage takes place prior to motor programming and it is associated with the articulator rather than the muscle. The patterns obtained form Broca's aphasics in this part of the current study emphasize that motor planning is processed separately from motor programming because those patients display distorted articulation. In this way, the results give evidence for the neurolinguistic role of Broca's area in speech planning in addition to other brain structures like the supplementary motor area (SMA). Speech motor planning is likely to be responsible for the identification and arrangement of the segments which should be implemented concurrently and sequentially. We would predict, on this basis, that deficit in this stage would result in pauses and hesitations that predominate over their productions.

Motor programming, as Van der Merwe[330] indicated, refers to the strategy that is adopted in order to convert the motor plan into motor program. This would mean that motor programming is a muscle-based stage in which the selection and the sequencing of programming for the movement for the articulator's muscles are carried out. Specially, in this stage a specification of the muscles is performed "in terms of spatial-temporal and force dimensions such as muscle tone, rate, direction and range of movement."[331] Given this, the spatial and temporal characteristics of the muscles must also be accurately achieved in order to get precise movements of the articulators. Motor programming[332] is usually controlled by the basal ganglia, the SMA and the fronto-limbic system. It is important to indicate that motor planning and programming are implemented before the execution of movement. During the execution phase the plans and programs are achieved in terms of actual movements that are realized acoustically. Motor execution is controlled mainly by the motor cortex in addition to the cerebellum and basal ganglia. Thus, impairments at the execution level cause different types of dysarthria.

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329 Metoui, M. (2001), p. 251.
330 Cf. Van der Merwe, A. (1997), pp. 16-18.
331 Ibid., p. 16.
332 Cf. Grillner, S., Hellgren, J., Ménard, A., Saitoh, K., &. Wikströn, A. (2005): Mechanisms for Selection of Basic Motor Programs – Roles for the Striatum and Pallidum, p. 364.

Generally speaking, coarticulation is not a spatial adjustment of gesture, but it is simply an integration of temporal and spatial aspects of the articulators. It must be noted that speech can not be separated from language and it is not only a motoric output.

> "Although one could become completely occupied in the study of speech as motor behaviour or conversion of articulation into a sound pattern, speech is, after all, of greatest interest because of its primacy as language modality."[333]

As has been previously mentioned, coarticulation is a dynamic process influenced by the phonetic environment. However, with respect to the deficiency in the motoric gestures, this prevents appropriate positioning of the tongue body, leading to deviations in the tongue adjustments in anticipation of the upcoming segment. This results in a drop in the overlap of adjacent gestures, and consequently blocking the coarticulation process. It is further of interest to indicate that Broca's aphasics displayed limitations in the degrees of freedom of movements, referring to the amount of integration of movements of several articulators temporally and spatially in order to produce a particular segment. Kent refers to this by indicating that: "the tongue, lips, jaw, velum, larynx and respiratory system all possess several possible types of movement with respect to range, direction, speed and temporal combinations with one another." [334]

Generally, coarticulation contributes to increasing the efficiency of articulator movements of speech sound, which should be minimized in size because of the contextual effect in order to reach efficient sequence. In contrast, patterns obtained form Broca's aphasics indicate that their articualtory movements are distinguished by slow motion movement that influenced the coarticulatory possibilities of articulator movements. There is evidence to suggest that this impairment in Broca's aphasics is associated with motor planning deficit that influenced the articulatory process. Therefore, these limitations could be related to the compensatory strategies that the non-fluent aphasic speakers adopted during the indirect phonetic encoding mechanism resulting in the prolongations and the long durations of the phonetic segments. During the running speech several modifications and anticipatory influences in the vocal tract took place. The articulation process is an integration of different parameters. Metoui indicated

[333] Kent, R., Adams, S., & Turner, G. (1996): Models of Speech Production, p. 33.
[334] Cf. Kent, R. (1990): The Acoustic and Physiological Characteristics of Neurologically Impaired Speech Movements, p. 378.

that: “Dieser Prozeß wird von einem Ereignis gestartet, hat eine definierte Eingabe und eine definierte Ausgabe und vollzieht sich in einer Zeitspanne.”[335]

It is also worthy to note that the anterior aphasic impairments do not display global loss in the articulatory system. Rather, the problem seems to be in some parts of the articulatory subsystem. Consequently, for example, they revealed deficits in the temporal control of articulation and in the integration of articulatory movements as well. As a result, such coordination impairment through the inability to integrate the sound-transition or coarticulatory aspects of speech could lead to coarticulatory deficits. Keller[336] indicates that the temporal parameters and coordination of articulators are an important part of the speech motor control process.

Applied to the results being considered in the current part of study, the deviant coarticulation, once again, would suggest that those patients exhibit temporal impairments including motor planning and timing. Support for this idea comes from other aspects of speech production of Broca’s aphasics. Data from their productions displays deficits in temporal parameters including timing or integration of movements of the articulatory system. Thus, based on this data, those patients display laryngeal control impairments. For example, their VOT patterns, as presented in the current study, are found to be longer than those by the normal speaker, supporting the idea of poor temporal control. In this respect, several acoustic measures and temporal patterns were examined in anterior aphasic productions that might interact with the deficit in anticipatory coarticulation. Their vowel duration, for instance, was longer than of the normal subjects. In addition, they exhibited laryngeal control deficiencies presented in voicing. Results obtained from this study are inconsistent with those from Katz,[337] who indicated that anterior aphasics show anticipatory lip-rounding in their speech planning as that of the normal speakers. He reported also from a kinematical electromagnetic articulatorograph study that the anterior aphasics display lip rounding, but they differ in time course.[338] In fact, deviations in anticipatory coarticulation support the neurolinguistic role of Broca’s area being responsible for speech planning. Consequently, Broca’s aphasia might be redefined as a deficiency in time planning of speech articulators suggesting that patients diagnosed with

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[335] Metoui, M. (2001), p. 39.
[336] Cf. Keller, E. (1990): Speech Motor Timing, pp. 343-346.
[337] Cf. Katz, W. (1988), p. 340.
[338] Cf. Katz, W., Machetanz, J., Orth, U., & Schoenle, P. (1990): A Kinematic Analysis of Anticipatory Coarticulation in the Speech of Anterior Aphasic Subjects Using Electromagnetic Articulography, p. 573.

Broca's aphasia are suffering from mapping of coarticulated representations into motor output.

Substitution errors produced by Broca's aphasics could be interpreted in terms of interarticulatory timing that refers to the timing between the movements of different articulators. Similarly, deviant VOT patterns in Broca's aphasics indicate a timing deficit of articulatory movements that occurs during the motor plan of specific utterance required to produce the target segment. Pauses, syllable segregation and unusual prolongations are also part of those spatiotemporal impairments.

Motor equivalence might also be considered a critical aspect of speech production that should be addressed in Broca's aphasic deficits. This term refers to the fact that sound can be achieved with different articulatory movements. Several factors contributed to this parameter such as speech rate, degree of coarticulation and motor coordination. Motor equivalence is associated with coordination that: "flexibly accomplished by the nervous system, perhaps to see what might be impossible, namely, achieving a given functionally significant goal exactly the same way in the same way each time."[339]

Lindblom[340] indicated that this process is associated with plasticity of the articulators that is regulated by a feedback system. Basically, this system is able to compensate for the deviations in the articulatory system. Taking this into account, initiation difficulties indicate that Broca's aphasics exhibit production viabilities, but deviations from the normal boundaries of timing adjustments of motor equivalence in their output are noticed and consequently cause substitution and articulation distortion errors in addition to coarticulatory deficits. Coarticulation can be defined in terms of what Lindblom referred to as "sufficient contrast."[341] Broca's aphasics then display phonetic categorical overlapping and are not capable of keeping to this "sufficient contrast" as shown, for example, in figure 143. Regardless of the motor involvement in speech production, it is of greatest importance to address the role of the cognitive and language components in the transformation process of the message into an acoustic signal, which is found to be neglected in the previous models.

[339] Cf. Abbs, J. (1988): Neurophysiological Process of Speech Movement Control, p. 160.
[340] Cf. Lindblom, B. (1990), pp. 423-428.
[341] Cf. ibid., pp. 423-427.

For instance, it appears that the phonetic variability can also be influenced by social factors such as speech style, which was not found to be well addressed in Lindblom's model.

Speech characteristics of Broca's aphasics with deviations in anticipatory coarticulation would suggest that segments were produced separately by displaying deficits in transitioning from one speech sound to the next. The speech production and coarticulation patterns of anterior aphasics, in turn, correspond with a broad deficit in geometrical structure of the vocal tract accompanied by initiation and sequencing of articulatory movement difficulties. In this account, some studies indicated that: "[...] so daß der Output aus Beziehungen zwischen den Bewegungen der Organe und den dazugehörigen geometrischen Transformationen des Vokaltrakts bestehet."[342]

Let us return briefly to the temporal dimension of Broca's aphasia. It is thought that deficits such as the long VOT duration, deviant anticipatory coarticulation, high variability in the formant frequencies and long vowel durations support the idea that anterior aphasics are distinguished by phonetic errors and temporal abnormalities. Thus, this emphasized that those patients have deficits in coordination the timing of the articualtory movements, readjusting the articulators and preplanning for the upcoming segment. We would maintain that coarticulation deficits in Broca's aphasics would suggest that they display motor sequencing impairments that are involved in producing segments, demanding a precise coordination between independent articulators.

Through various instrumental techniques, it has been possible to gain insight into the neuromotoric commands happening at the phonetic level. However, neuroanatomical, Magnetoencephalograph (MEG), Positron Emission Tomography (PET) and Functional Magnetic Resonance Imaging (fMRI) studies do not relatively display a particular lesion location model of coarticulation in Broca's aphasia.

[342] Metoui, M. (2001), p. 248.

Nevertheless, in addition to the role of Broca's area in speech planning, PET studies give evidence for a concurrent primary motor cortex and left anterior insula activations during articulation.[343] In other PET studies, activations in lateral premotor cortex and anterior insula during articulation in repetition of single words were reported.[344]

> "The neurological basis for coarticulation appears broadly distributed throughout perisylvian cortex and underlying white matter, possibly involving critical linkages between prefrontal/frontal and parietal cortex."[345]

Control of speech movement requires a complex integration and an interaction of different types of information controlled by the brain like auditory, sensory- motor integration and muscle command representations. This addresses the degree of the presentation of those components in Broca's aphasics. Coarticulatory deviations compared to normal speakers also address the issue of unit production. For example, if the research proved that the anterior aphasics display intact intrasyllabic coarticulation while they have segment production impairment, then this would suggest the importance of the syllable as a unit in speech production. However, if not, the importance of the gesture as a unit of production comes into play. In light of theses notions, coarticulation emphasizes that speech production is a dynamic process and not a product of a single articulator: "[...] da mehrere, starre, bewegliche und sehr bewegliche und bewegliche, Organe sowie mehrere Muskeln involviert sind."[346]

As a result, some caution has arisen in dealing with some theories that focus on behaviour of a single articulator.

> "Ansätze, die auf der ausschließlichen Beschreibungen des Vokaltrakts als einem Satz von Röhren beruhen, scheinen keine Korrekte und adäquate Nachbildung der Sprachproduktion zu ermöglichen."[347]

At the conclusion of this section, it should be said that coarticulation deficits in Broca's aphasics are generated at the motor planning level in which those patients demonstrated

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[343] Cf. Fox, P., Huang, A., Parsons, L., Xiong, J., Zamarippa, F., Rainey, L., & Lancaster, J. (2001): Location Probability Profiles for the Mouth Region of Human Primary Motor-Sensory Cortex: Model and Validation, p. 200.

[344] Cf. Wise, R., Greene, J., Buchel, C., & Scott, S. (1999): Brain Regions Involved in Articulation, p. 1057.

[345] Cf. Katz, W. (2000): Anticipatory Coarticulation and Aphasia: Implications for Phonetic Theories, p. 329.

[346] Metoui, M. (2001), p. 238.

[347] Ibid.

spatial and temporal impairments. In fact, from a functional point of view, they displayed deficits in integration of articulatory movements in the temporal control of articulation in addition to the spatial one. In addition, the speech patterns related to coarticulation could be associated with impairments in the phasing of movements and the spatial configurations of articulatory movements.

The results indicate that contrary to the traditional speech production models a distinction between motor programming and motor planning should be considered. Thus, one could suggest that linguistic and motor programmings are implemented at two different levels of the speech production process. Based on the patterns of Broca's aphasics, the results would address the issue of the role of economy as the only reason for coarticulation. For example, other factors would contribute to coarticulation like contextual-sensitivity and word frequency. Generally speaking, it is of further interest to examine the contextual factors that might have negative impact on the spatiotemporal parameters of speech processing resulting in coarticulation deficits. The results display in general that Broca's aphasics exhibit deviations in anticipatory coarticulation compared to the normal speakers.

Many of the differences between previous studies and the current data concerning coarticulation have been found. For example, the findings of this study fit with several pieces of data[348] showing that anticipatory coarticulation was not remarkable in Broca's aphasics[349] compared to the normal speakers. In contrast, the Katz[350] findings are inconsistent with the findings in the current study. The coarticulation process is based on an integration of different neuromotoric activities which might be impaired in Broca's aphasics. With respect to the degree of coordination and timing, the results indicate that those aphasics display difficulty in interarticulatory coordination inhibiting their ability to initiate and produce speech sounds precisely. The findings also give evidence that Broca's aphasics demonstrate problems that emerge at the phonetic level in outputting selected sounds and not selection problems. One could reason that where the system fails for anterior aphasics is in the mapping of coarticulated representations into motor output.

The findings from the current study also suggest that methods of speech therapy should focus on the integration level between the sounds while establishing a hierarchy complexity. That

[348] Cf. Tuller, B., & Story, R. (1988): Anticipatory and Carryover Coarticulation in Aphasia: An Acoustic Study, pp. 765-769.

[349] Cf. Baum, S. (1998): Anticipatory Coarticulation in Aphasia: Effects of Utterance Complexity, p. 357.

[350] Cf. Katz, W. (1988), pp. 359-365.

is, the speech pathologist should take into account the complexity of the words by beginning from the mono-syllabic to disyllabic words and so on. One important factor that must be considered is that motor programming and planning in addition to the execution phase should be within the boundaries of the motor equivalence. In this view, Broca's aphasics did not correspond to the normal patterns.

7. CORRELATIONS BETWEEN "F0" AND EMOTIONAL CUES OF BROCA'S APHASIC SPEECH

7.1. Introduction

Prosody has received a lot of interest because it is considered a main aspect of communication. Its communicative functions include both emotional and linguistic aspects. In fact, prosody serves as a facilitator for different aspects of information processing such as decoding lexical meaning, conveying emotional intent and comprehension of new information.[351] In fact, prosody considered "an integral part of human communication. It is combined with phonological, morphological, syntactic, and semantic aspects of speech to form a complete message."[352]

Three physical parameters contribute to prosody: fundamental frequency, duration and intensity. These are perceived by the hearer as pitch, speech rate and loudness. These parameters carry both linguistic and paralinguistic aspects of the speech event. Variations in fundamental frequency (F0), intensity and duration are considered to be the most crucial cues for prosody. In fact, from an acoustic point of view, the fundamental frequency refers to the number of periodic movements in the vocal folds per second.[353] Average pitch refers to the average level that the person usually speaks that can be judged by listeners as low or high. However, pitch variability indicates the degree that speakers vary their pitch around the average pitch. Pitch contour is an indicator for the intonation patterns of the speaker such as contour slope and final lowering. Contour slope represents the overall trend of the pitch range for the utterance and final lowering.[354]

It is obvious that pitch is used to convey several aspects of speech act. For example, it can serve as an indicator for sentence modalities such as distinguishing questions from statements or the emotional states of the speaker. In this respect, the style of speech also affects the pitch directions and its patterns. It has been noted that, for instance, in happy emotional states utterances were found to be faster, louder and having a broader F0 range than those in sad

[351] Cf. Pell, M., & Baum, S. (1997a): The Ability to Perceive and Comprehend Intonation in Linguistic and Affective Contexts by Brain-Damaged Adults, pp. 198-199.

[352] Mildner, V. (2004): Hemispheric Asymmetry for Linguistic Prosody: A Study of Stress Perception in Croatian, p. 358.

[353] Cf. Feinberg, D., Jones, B., Little, A., Burt, D., & Perrett, D. (2005): Manipulations of Fundamental and Formant Frequencies Influence the Attractiveness of Human Male Voices, p. 562.

[354] Cf. Levitin, D., & Rogers, S. (2005): Absolute Pitch: Perception, Coding and Controversies, p. 26.

emotional styles.[355] Functionally, two main types of prosody are distinguished: linguistic prosody and emotional prosody. Linguistic prosody conveys linguistic functions such as statements, interrogatives and imperatives. On the other hand, emotional prosody conveys emotional contents and the speaker's emotional states such as happiness, sadness and anger. It is notable that the physiological and the physical conditions of the speaker contribute to identify the emotional changes of the speaker. In fact, a large body of literature describes the relationship between speech and emotion taking into consideration the fact that speech conveys information about the speaker's emotional state.[356] There is no doubt that stroke has a negative impact on the life of a patient in multiple aspects. Regardless of the neurological deficits, patients might display emotional disturbance in their social environments. In this regard, many investigations have indicated that lesions caused by a stroke may affect the ability of a patient to correctly perceive and produce emotions in a social context.[357]

In light of this notion, pitch variations considered as a psychological component convey much information about the speaker's gender, his or her speaking style, habits, emotional status and accent. Generally, voice quality is a confusing term, since it is associated with different parameters. Consequently, it sometimes points out the laryngeal qualities or a particular phonation type. However, it could be extended to a wide sense by referring to the general vocal image of a speaker. It has become very obvious that the intonation patterns also reflect the coarticulation capabilities[358] of speakers, which were found to be deviant in Broca's aphasics, as the previous part of the current study indicated (chapter 6).

In this chapter of the current study focus will be on identifying some of the intonational patterns and the acoustic cues of emotional state of Broca's aphasics. For the purpose of this study, only declarative statements, interrogatives and sentences that signal happiness, anger and sadness will be studied since they are produced most often by Broca's aphasics. The stimuli consisted of sentences and phrases selected from spontaneous speech of the Broca's aphasics and the normal speakers.

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355 Cf. Lieberman, P., & Michaels, S. (1962): Some Aspects of Fundamental Frequency and Envelope Amplitude as Related to the Emotional Content of Speech, p. 924.

356 Cf. Cowiea, R., & Cornelius, R. (2003): Describing the Emotional States that Are Expressed in Speech, pp. 5-27.

357 Cf. Braun, M., Traueb, H., Frischc, S., Deightonb, R., & Kesslerb, H. (2005): Emotion Recognition in Stroke Patients with Left and Right Hemispheric Lesion: Results with a New Instrument— the FEEL Test, pp. 193-200.

358 Cf. Fowler, C. (2005): Parsing Coarticulated Speech in Perception: Effects of Coarticulation Resistance, p. 210.

7.2. "F0" parameters relevant for the speech of Broca's aphasics

The results showed that the declarative sentences produced by the normal speakers were distinguished by falling intonation, whereas the interrogative utterance by rising intonation. Direct WH-questions do not produce a rise in intonation, but rather a fall. It is remarkable that Broca's aphasics were able to show final falling pitch for a WH-question as clearly seen in figure 144. Similarly, the same patterns were found by the normal speakers.

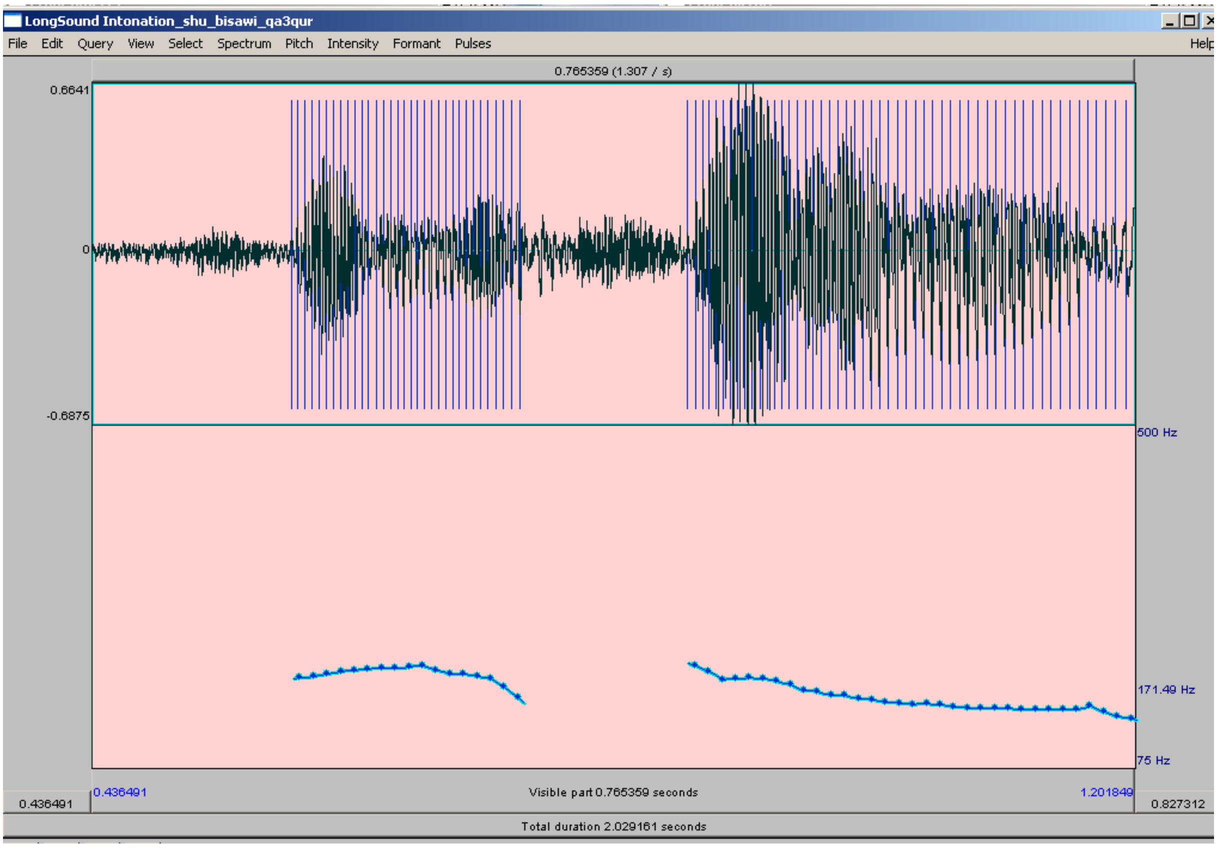

Figure 144: An illustration of final falling pitch for a WH-question in the sentence [ʃu: bisawi] as produced by an aphasic subject.

It is also noted that the energy in the declarative sentences starts nearly from zero and then rises gradually until it reaches its maximal range. The declarative sentences are given the lowest amplitude by the aphasic subjects as well as the normal speakers. However, the aphasics show higher amplitude values than the normal speakers do. On the other hand, for example, the energy of producing WH-questions by Broca's aphasics starts from a higher value compared to the normal speaker and they displayed low amplitude at the end of the utterance compared to the beginning which reached relatively close to zero, as figure 145 shows. Contrary to the patterns observed in Broca's aphasics, the normal speakers reached approximately the point where it starts from the beginning of the utterance, as shown in figure 146. The pattern obtained from Broca's aphasics could be related to the ability to control the breath stream during the production, which could be decreased as long as the utterance increased.

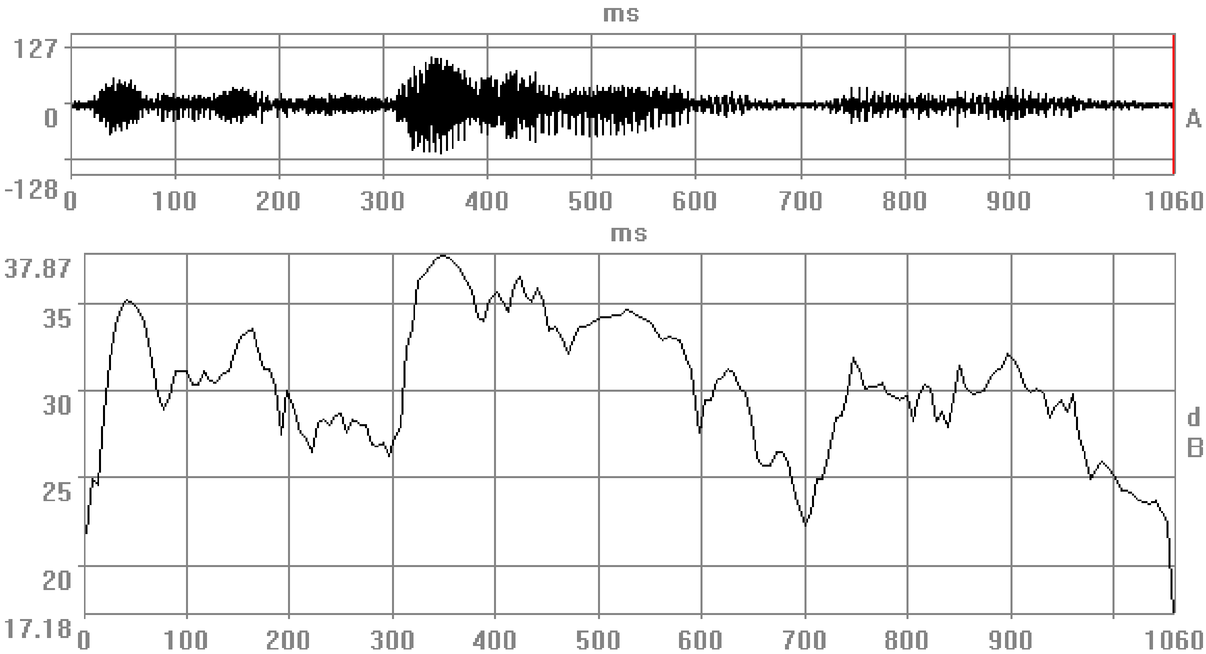

Figure 145: The amplitude pattern for the sentence [ʃu: bisawi ha:ð] as produced by an aphasic subject.

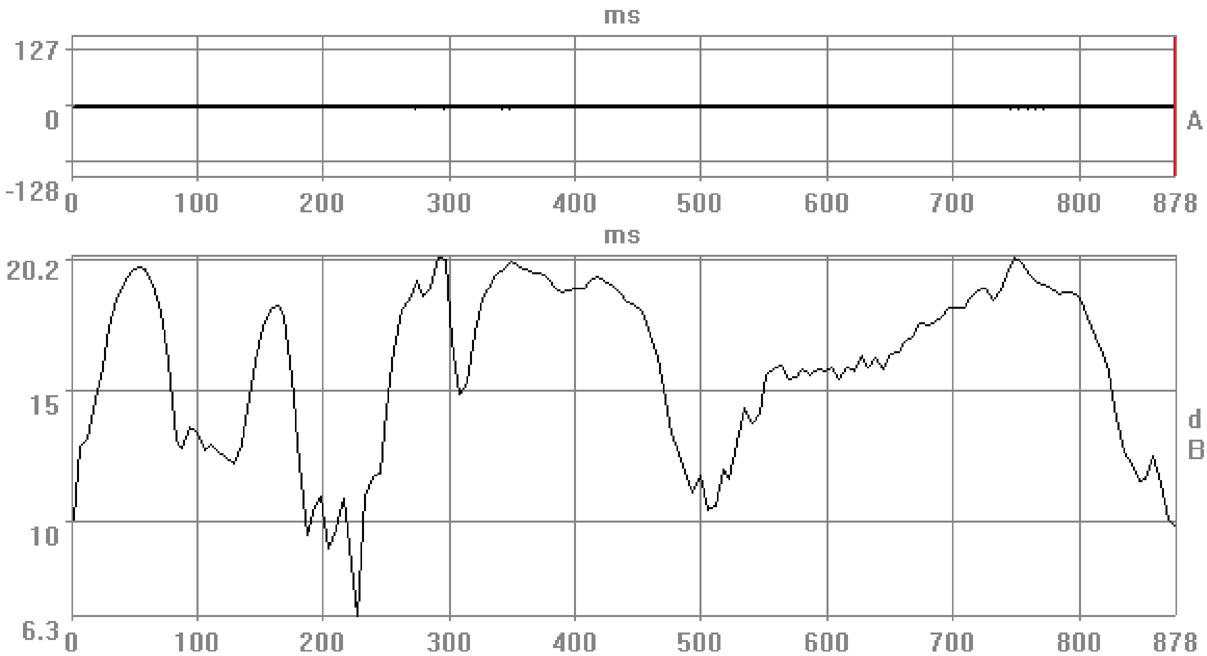

Figure 146: The amplitude pattern for the sentence [ʃu: bisawi ha:ð] as produced by a normal speaker.

In this regard, some of their productions are distinguished by long pauses and frequency perturbations. Indeed, from a functional point of view, the differences in F0 contour shape, F0 range and endpoint F0 enable Broca's aphasics to produce linguistic intonation patterns such as distinguishing statements from questions. In addition, this would also indicate their ability to display a relative control over differences in F0. The results emphasize the fact that anterior aphasics have the ability to signal the intonational contrast at least in short sentences. However, as one might predict, this ability will decrease as the complexity of the sentence increases.

Notably, as figure 147 indicates, Broca's aphasics displayed differences in F0 variation including shape and F0 peak. Thus, they were able to display F0 range variability despite the flat pattern in different situations. Furthermore, Broca's aphasics displayed a sentence terminal F0 fall contour quite similar to the pattern observed by the normal speakers in declarative statements. Basically, this acoustic parameter is distinguished by a rapid fall of F0 at the last word of the utterance. In this way, the patterns observed in the aphasic subjects in short sentences exhibit larger peak fall at the final word than on the first word. This is similar for the normal speakers.

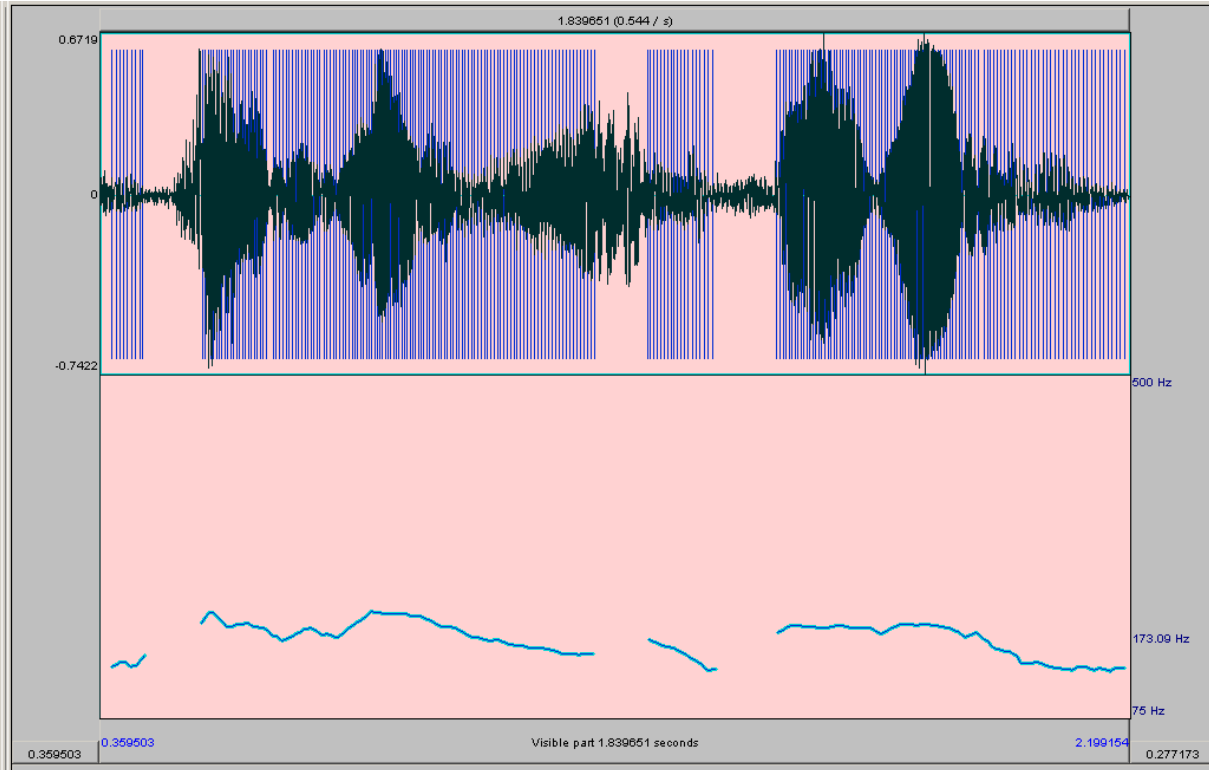

Figure 147: An illustration for sentence terminal F0 fall as produced by an aphasic subject.

Broca's aphasics were also able to display the F0 declination that refers to the tendency for F0 to gradually drift downward in the course of the utterance. F0 declination is thought to be style-dependent. Downtrend in fundamental frequency (F0) and subglottal pressure have often been observed for running speech.[359] Another feature tested was sentence final lengthening. It is considered as a prosodic component of the language structure. Phrase-final lengthening indicates the strength of prosodic boundaries. This parameter shows that the largest lengthening took place at the end of the utterance. This phenomenon has also been observed in other languages like French.[360] The very fact that Broca's aphasics display longer duration for words in initial positions than those in final positions is further evidence that those patients are not able to display phrase-final lengthening, and consequently exhibit prosodic impairments. For example, as clearly shown in figure 148, the duration of the first word was 825msec, whereas the word in final position was 540msec despite the fact that the first word consisted of two syllables and the last one consisted of three syllables.

[359] Cf. Lieberman, P., & Michaels, S. (1962): Some Aspects of Fundamental Frequency and Envelope Amplitude as Related to the Emotional Content of Speech, p. 927.

[360] Cf. Hirst, D., & Di Cristo, A. (1984): French Intonation: A Parametric Approach, pp. 555-565.

The literature indicates that increasing duration is associated with stress.[361] In this account, increasing the duration of the words in the initial position by the aphasics could suggest that they increased the stress on words that were already marked for stress. Consequently, increasing stress caused a remarkable increase in the amplitude values of those words. However, one might assume that the longer duration of the first words compared to final words is caused by word stress, which is associated with sentence initiation. To test this assumption, the duration of words in medial positions were measured. Similar to the earlier findings, the results also indicated that Broca's aphasics display longer duration for medial words than those in final positions. With regard to this fact, in reference to figure 149, the second word's duration was 746msec, whereas the last word's duration was 540msec. Clearly, based on those impairments by Broca's aphasics, there is some evidence to suggest that those findings strongly indicate planning and timing deficits. The normal speakers demonstrated longer duration for words in final positions rather than those in initial or medial positions.

Contrary to the normal speakers, Broca's aphasics display abnormal patterns of phrase-final lengthening by producing words in initial positions longer than words in final positions. Once again, this impairment sheds light on the nature of their errors, since segmental lengthening is related to speech planning and timing. It seems that Broca's aphasics exhibit problems with tasks that are verbally and articulatorly demanding. We would therefore argue that Broca's aphasics might tend to lengthen the first words to take enough time to plan for the upcoming segments.

[361] Cf. Curtin, S., Mintz, T., &. Christiansen, M. (2005): Stress Changes the Representational Landscape: Evidence from Word Segmentation, p. 254.

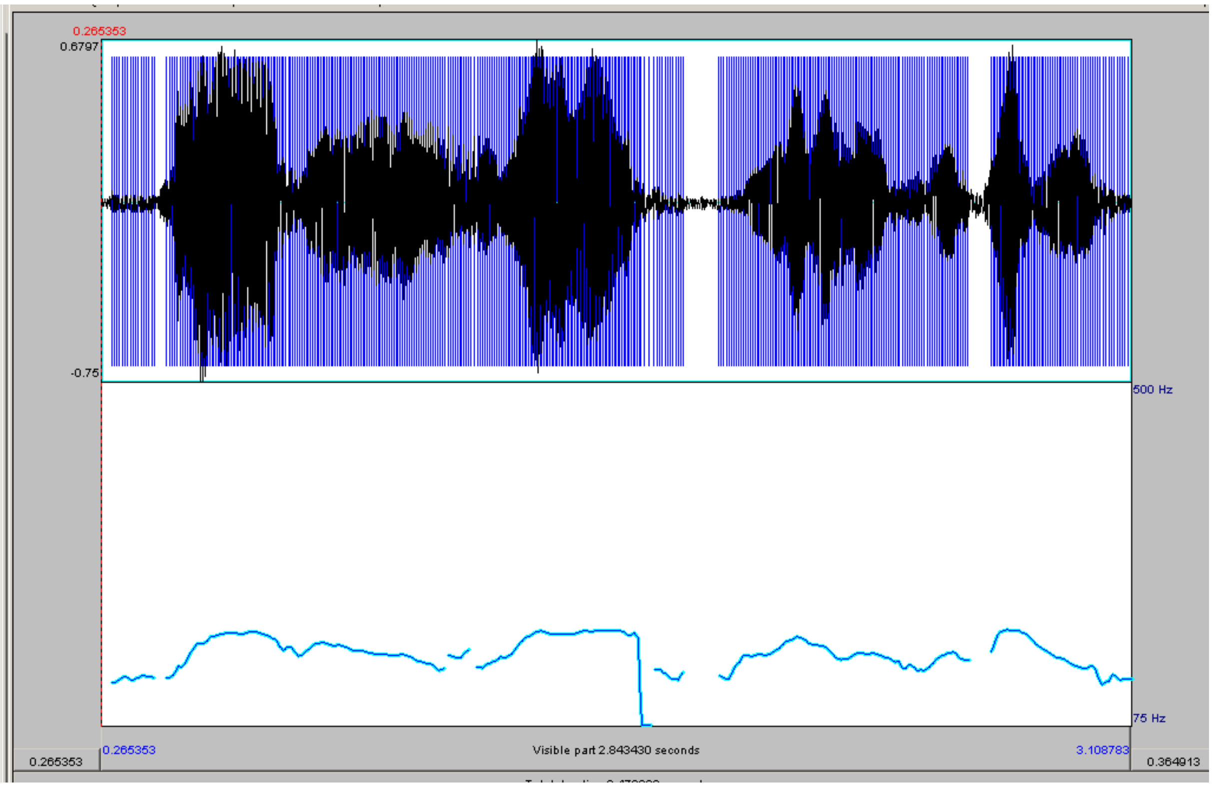

Figure 148: An indication for sentence-final lengthening deficit in the sentence [ha:ð walad ga:ʕid bikannis] as produced by an aphasic subject.

The other interesting observation that has been found is the effect of the vowel quality on F0, duration and intensity. Generally speaking, it has been noticed in the current study that the low vowel [a] is distinguished by lower F0, higher amplitude and longer duration. On the other hand, the high vowels generally show higher F0, shorter duration and lower amplitude than the low vowels. In general, this tendency was also found among the aphasic subjects, but with a different magnitude compared to the normal speakers. Consequently, this would suggest that vowel height has an impact on the pitch and its correlations particularly when the vowel occupies the nuclear position. Applied to the cases and observations being considered in the current study, the patterns obtained from Broca's intonational patterns suggest that some of their prosodic aspects are preserved, while other properties contradict those of the normal patterns.

On the whole, it must be noted that Broca's aphasics were able to show the fall of terminal F0 and preserve its declination. However, they failed to display final utterance lengthening. In addition, long durations, long pauses, frequent hesitations, agrammatism and phonetic errors contributed to their dysprosodic patterns. For instance, the spectrogram in figure 149 shows the long interval between syllables and the frequent hesitations suggesting a disturbance at the motor planning and timing level. Also, it is noted that sentence duration was greater for the aphasic subjects reflecting slow speech style and phonetic limitations.

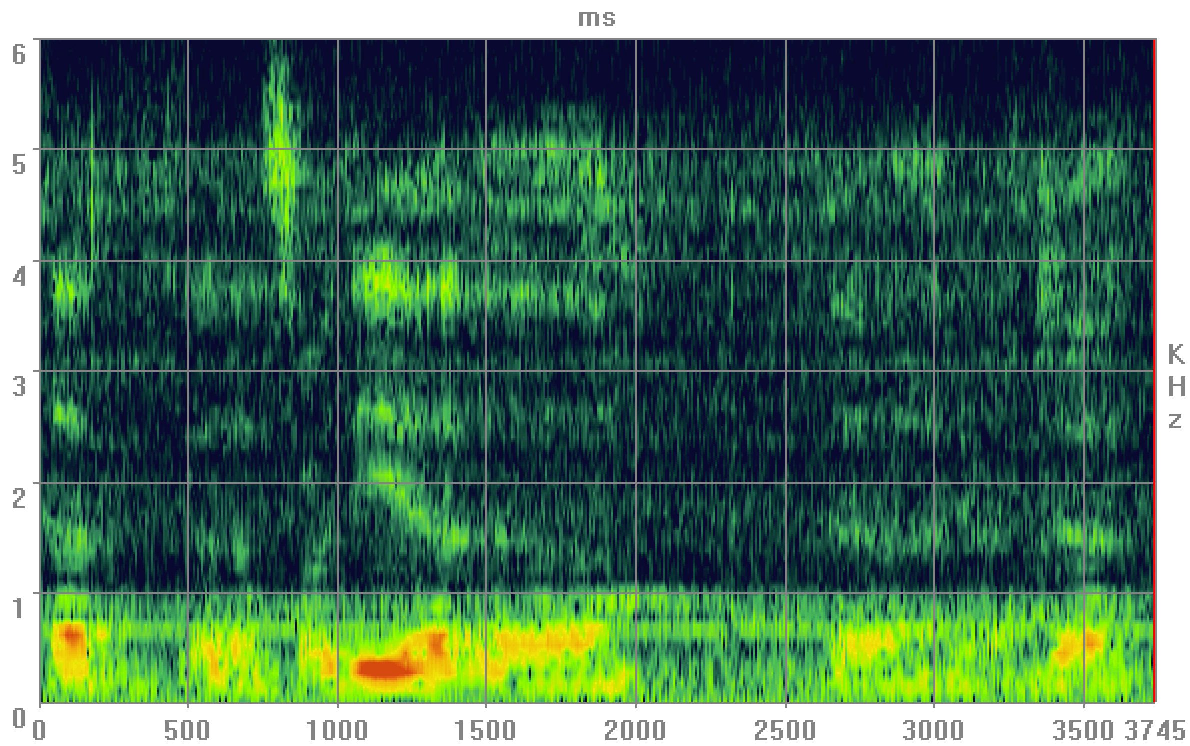

Figure 149: Spectrogram exhibited frequent hesitations and long pauses while producing the sentence [χa:lti sʕu:dijih aʒat].

Despite the articualtory difficulties, fundamental frequency patterns of Broca's aphasics appeared to be relatively normal with a higher range than normal speakers. In this account, the appropriate signalling of interrogative sentences and appropriate terminal falling contours suggest that the global prosody parameters are relatively intact. The aphasic subjects displayed relatively spared rising and falling intonation patterns and their intonation was found to change in conversational speech. This indicates relatively normal patterns of pitch excursions as a function of the syntactic structures of the sentence. In this regard, syntax complexity would contribute to dysprosodic patterns. The characteristics of the anterior aphasic production including slow rate, remarkable pauses and interruptions are still part of the general picture of their dysprosodic speech. To conclude this subsection, it can be said that the anterior aphasics exhibited remarkable prosodic aspects like F0 fall in final positions and F0 declination. Furthermore, they were able to show the falling pitch pattern from the beginning to the end of statements and a rising pitch in a question. F0 parameters were relatively spared except over long utterances. However, they did not show utterance final segmental lengthening, which is considered an indication for speech planning.

7.3. Acoustical correlates of emotional cues as strategic signals by Broca's aphasics

After a stroke, Broca's aphasics suffer from several emotional impairments including depression. From a neuroanatomical point of view, the temporal limbic system, especially the amygdale, is responsible for the aspects and modulations of such emotions as laughing, anger, fear and sadness.[362] In fact, it is a complicated issue to establish a comprehensive definition of emotion and there is no consensus in the literature on a particular definition. Emotions are sophisticated cognitive processes with both conscious and unconscious aspects.

> "Emotions may be seen as being organized on a variety of levels. Neurophysiologists are interested almost by definition in the neural organization of emotion, Darwinians are interested in the evolutionary organization of emotion, Jamesians are interested in the bodily organization of emotion, cognitive-emotion theorists are interested in the psychological organization of emotion, and social constructivists are interested in the social-psychological and sociological organization of emotion."[363]

Emotions can be expressed in different communicative forms and cues such as verbal cues, physiological cues, facial cues and body movements. Many factors come into play in attempting to define emotions. For example, they are generally complex integrations of different components such as social, physical and cultural. The cultural aspect is a crucial factor, since emotions are culturally related and culturally variable. Nevertheless, some aspects of emotions are considered to be universal.

In this account, Gouk and Hills[364] indicate that "there is no overarching definition of emotions that applies to all periods and all places." In this regard, many questions can be raised such as what distinguishes an emotion from another and where are "the boundaries of emotions to be drawn."[365] In fact, some studies displayed five prototypes underlying all emotion categories such as anger, sadness love, joy and fear.[366] For instance, joy can be subcategorized into pride

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[362] Cf. Ochsner, K., & Gross, J. (2005): The Cognitive Control of Emotion, pp. 242-243.
[363] Cornelius, R. (1996): The Science of Emotion. Research and Tradition in the Psychology of Emotion Research and Tradition in the Psychology of Emotion, p. 211.
[364] Gouk, P., & Hills, H. (2005): Towards Histories of Emotions, p. 17.
[365] Richards, G. (2005): Emotion into Words —Or Words into Emotions?, p. 51.
[366] Cf. Shaver, P., Schwartz, J., Kirson, D., & O'Connor, C. (1987): Emotion Knowledge: Further Exploration of a Prototype Approach, pp. 1061-1084.

and contentment. In their study, Cowie & Cornelius[367] revised recent proposals of such categories. Several criteria have been applied for categorizing and identifying the basic emotions. For example, this identification, as Plutchik[368] mentioned, could be based on neural, evolutionary, psychoanalytic and developmental approaches as well as facial expression approaches. As one predicted, the emotional status and language and speech deviations will have an impact on the acoustical features of the acoustic signal.

> "[...] dann nämlich beruhen messbare akustische Veränderungen direkt auf bestimmten artikulatorischen Merkmalen, die ihrerseits durch jeweils emotionsspezifisch neurophysiologische Reaktionen und motorischen expressives Ausdrucksverhalten hervorgerufen werden."[369]

It is not within the scope of the current section to enter the debate about the criteria or the neurocognitive basis for emotions. Rather, we shall address the influence of the emotional state of Broca's aphasics on the acoustical parameters including the formant patterns and F0 by selecting different sentences from spontaneous speech of five male Broca's aphasics signalling happiness, anger and sadness. The sentences ranged from seven to ten syllables.

Regarding the affect of the emotional status on F0, based on table 76, the normal speakers produce sadness situations with the lowest F0 and angry situations with the highest F0. However, as shown in figure 78, the aphasic subjects display higher F0 values in all three categories reflecting presumably a decrease in the smoothness of the motor control.

[367] Cf. Cowie, R., & Cornelius, R. (2003): Describing the Emotional States that Are Expressed in Speech, pp. 5-28.

[368] Cf. Plutchik, R. (1994): The Psychology and Biology of Emotion, pp. 107-139.

[369] Kehrein, R. (2002): Prosodie und Emotionen, p. 128.

Emotion	Min. range	Max. Range	Mean F0	Deviation
Happiness	112,2	185,7	154	63,5
Sadness	114,5	129,6	120	15,1
Anger	119,2	205,6	177	96,4

Table 76: An illustration of F0 (Hz) in terms of minimum and maximum range, mean F0 and deviation as produced by the normal speakers.

Emotion	Min. range	Max. Range	Mean F0	Deviation
Happiness	132,6	200,7	175	68,1
Sadness	78,1	306,4	147	228,3
Anger	140,1	237,6	203	97,5

Table 77: An illustration of F0 (Hz) in terms of minimum and maximum range, mean F0 and deviation as produced by Broca's aphasics.

Subjects	Happiness	Sadness	Anger
Aphasic subjects	175	147	203
Normal speakers	154	120	177

Table 78: F0 average (Hz) for sentences signalling happiness, sadness and anger emotions by the normal speakers and the aphasic subjects.

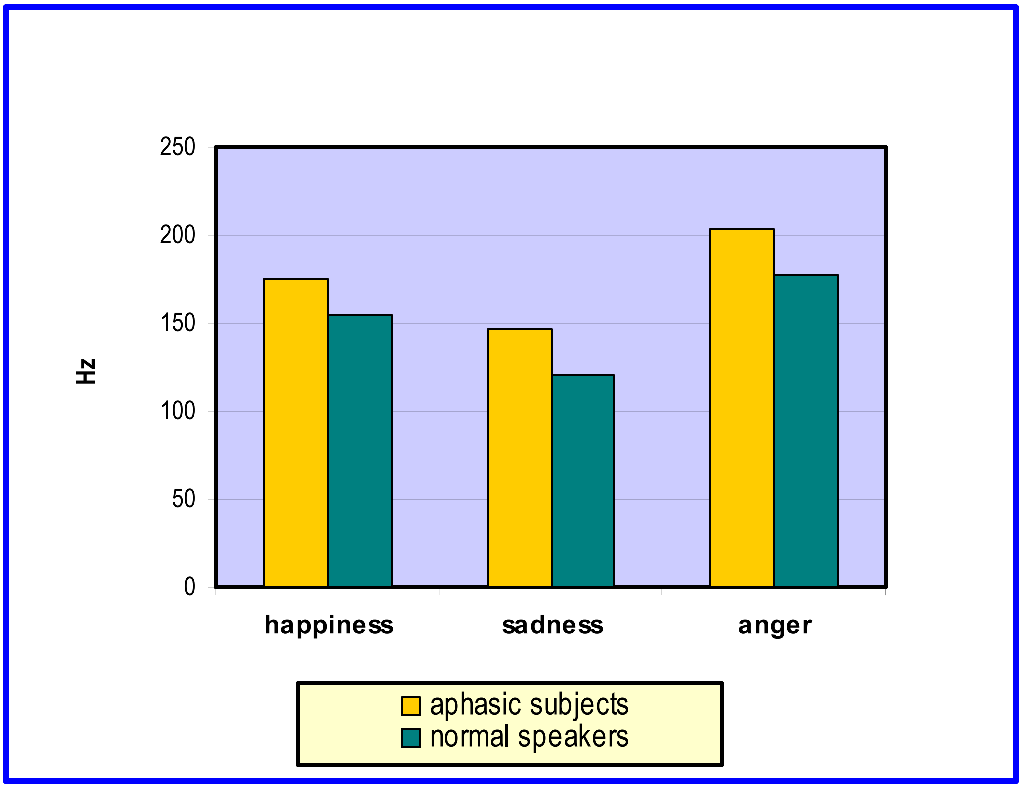

Figure 150: F0 average (Hz) for sentences signalling happiness, sadness and anger by the normal speakers and the aphasic subjects.

Broca's aphasics demonstrate big differences between the minimum and maximum range of F0. One might argue that sadness would have negative impact on Broca's aphasics. As shown in table 78, the aphasics exhibit high deviation under sadness status compared to the normal speakers. It seems likely that this effect could be correlated with their awareness of their errors making them more frustrated. Notably, the effect of the different emotions on F0 as exhibited by the normal speakers and aphasic subjects was similar in terms of producing anger with the highest F0 value and sadness with the lowest. The preliminary results of the current study also address the effect of emotion on the acoustic signal and indicate that the values of F0 exhibited by Broca's aphasics differ from one emotional state to another as those shown in the patterns of the normal speakers. In addition, utterances spoken in sad situations exhibited lower amplitude than those in angry and happy sentences. It also seems that this emotion has other effects on the general shape of F0 patterns. Significant differences can be found when comparing the production of interrogative sentences between sad and happy emotional states exhibited by one of the aphasic subjects. For example, as figure 151 indicates, the average F0 for producing the question under sadness was 172Hz, whereas the natural condition produced an average F0 of 184Hz. However, the F0 averages are still higher than those by the normal speakers. Furthermore, the amplitude average was also different. It was on average 63dB under sadness and 73dB in the normal situation.

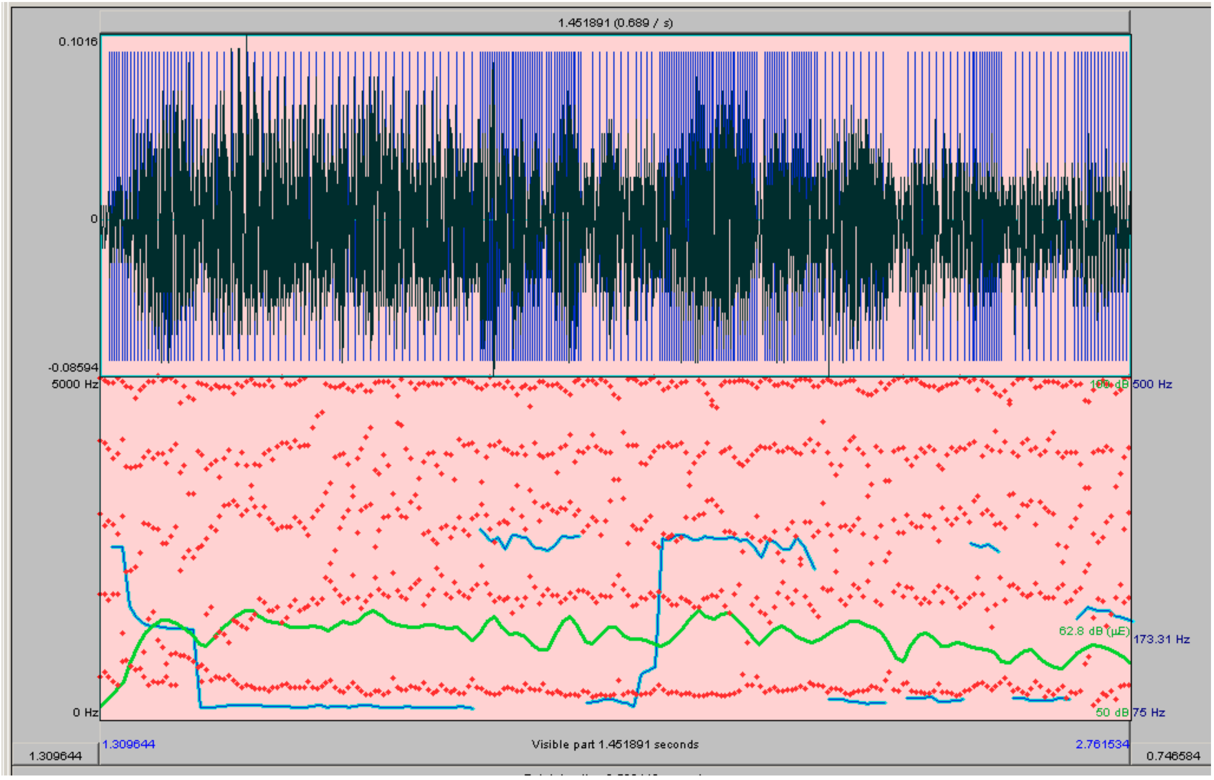

Figure 151: An illustration for the F0 average and amplitude for the WH-question [wɛ:n] under sad status as produced by an aphasic subject.

There was an interesting effect of sadness on the formants and their transitions. Broca's aphasics displayed a general tendency to produce higher F1 under a sad emotional state in comparison to a happy speaking style. The study found evidence of large bandwidth of F1. This could be physiologically interpreted in terms of the opening patterns of the glottis and glottal air pressure. Increasing the opening time of the glottis caused an increase in the amplitude of F1. However, the increase in glottal airflow during the closed phase caused a larger F1 bandwidth. Regarding F2, no significant differences between the two environments were found. F3 and F4 values were found to be significant. F3 was significantly higher in sad condition than in natural one. Similarly, the same result was found by the normal speakers. Also, the normal speakers exhibited lower F4 in sad situations than in happy sentences. The different effects of sad emotions on the formant frequencies of the aphasic subjects could reflect problems mimicking the exact tongue movements that influenced the formants particularly the first three formants. Thus, the main acoustic correlation of the influence of sadness on the aphasic's speech compared to the natural speech status seemed to be distinguished by a significant increase of F1 and F3 and a decrease of F4 with a slight increase of F2 on the other hand. Our results suggest that voice quality of aphasic speech under sad status could be correlated with a narrowing of the pharynx caused by a contraction of the middle constrictor muscle leading to raising the larynx. Raising the larynx is accompanied by a more hyperfunctional phonation. Some evidence for this observation comes from a large bandwidth of F1. This could be related physiologically to the opening patterns of the glottis and to glottal air pressure. Increasing the opening time of the glottis causes an increase in the amplitude of F1. However, the increase in glottal airflow during the closed phase caused a larger F1 bandwidth. In this account, it seems that sadness affects the activity of the motor abilities of the pharynx by increasing the degree of narrowing. In addition, other indications can be found in the general shape of the LPC by exhibiting a flatness pattern as shown in figure 152. In fact, this flattening is caused by a decrease in the amplitudes or a lowering of the frequencies of the higher formants.

Considerable decrease in the energy at high frequency is clearly observed. In addition to these findings, laboured speech and articulation impairments are also added to the general picture of their language profile. Together, the sadness effect on the prosodic patterns of Broca's aphasics would suggest that sadness places more demand on the implementation of the motoric gestures and the larynx activity.

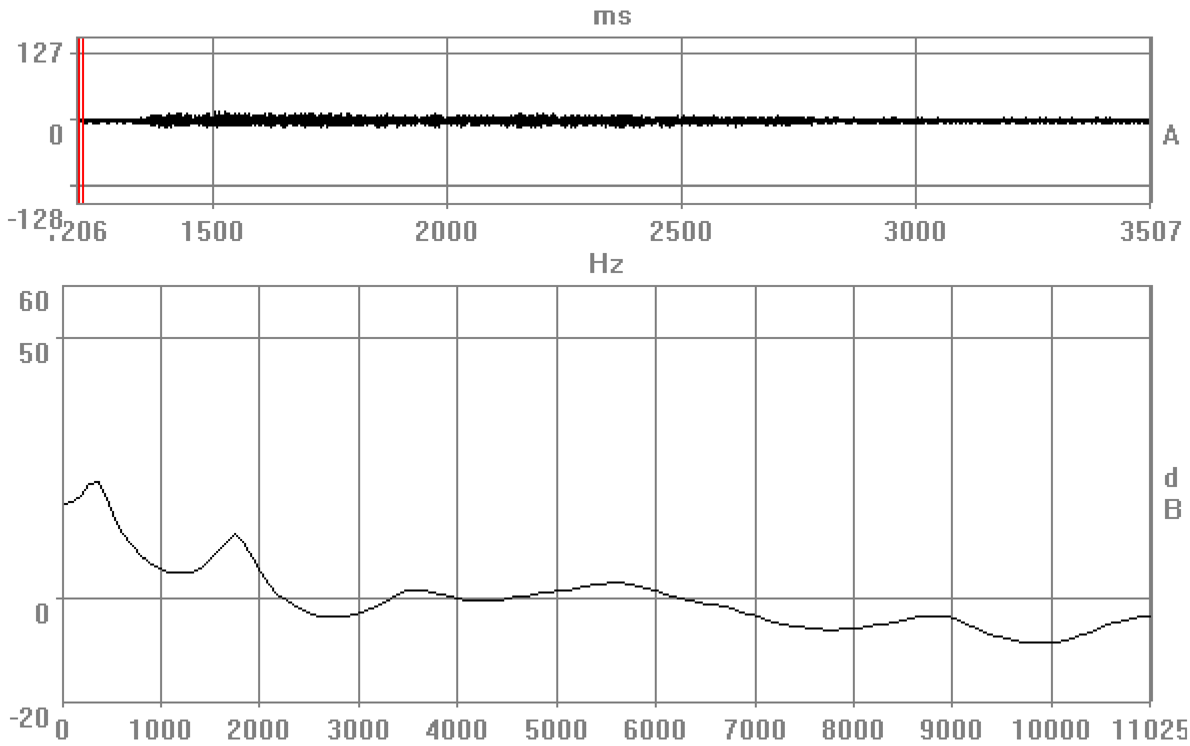

Figure 152: LPC exhibited flatness pattern for [wɛ:n] under sad emotion as produced by an aphasic subject.

The significant difference in F3 and F4 may reflect the typical quality of a vowel related to individual voice differences resulting from actions of the resonances. However, the lowest formants signal the identification of the vowel character, while the high formants contributed to the tonal qualities.

> "No doubt that formant 3 (F3) is much less responsible than formants F1 and F2 for the linguistic colour of vowels. Formant 3 is mainly to be considered as one of the many higher resonances. Being the lowest of these, it has the most perceptible effect as a whole these high resonances above formant 2 have very little effect on colour, they mostly add intelligibility without changing the colour and are probably responsible for voice quality."[370]

Thus, the influence of sad emotions on the aphasics clearly affected their voice quality appeared acoustically, for example, in the formant values. As the results indicate, the differences between F1 and F2 for the vowels produced by Broca's aphasics were not significant when produced under happy and sad emotional states. Specifically, this suggests that the first two formants determine vowel quality. However, the difference was significant

[370] Cf. Delattre, P. (1951): The Physiological Interpretation of Sound Spectrograms, p. 872.

in the higher formants indicating that those formants depend mainly on the speaker. On the other hand, this particularly emphasizes the fact that F3 and F4 give information on personal voice characteristics that could be influenced under certain emotional states. In this regard, the spectrograms 153 and 154 exhibit that the formant structures do not agree in the higher frequency bands in the vowel [ɛ:] in the word [wɛ:n] produced under sad and happy situations.

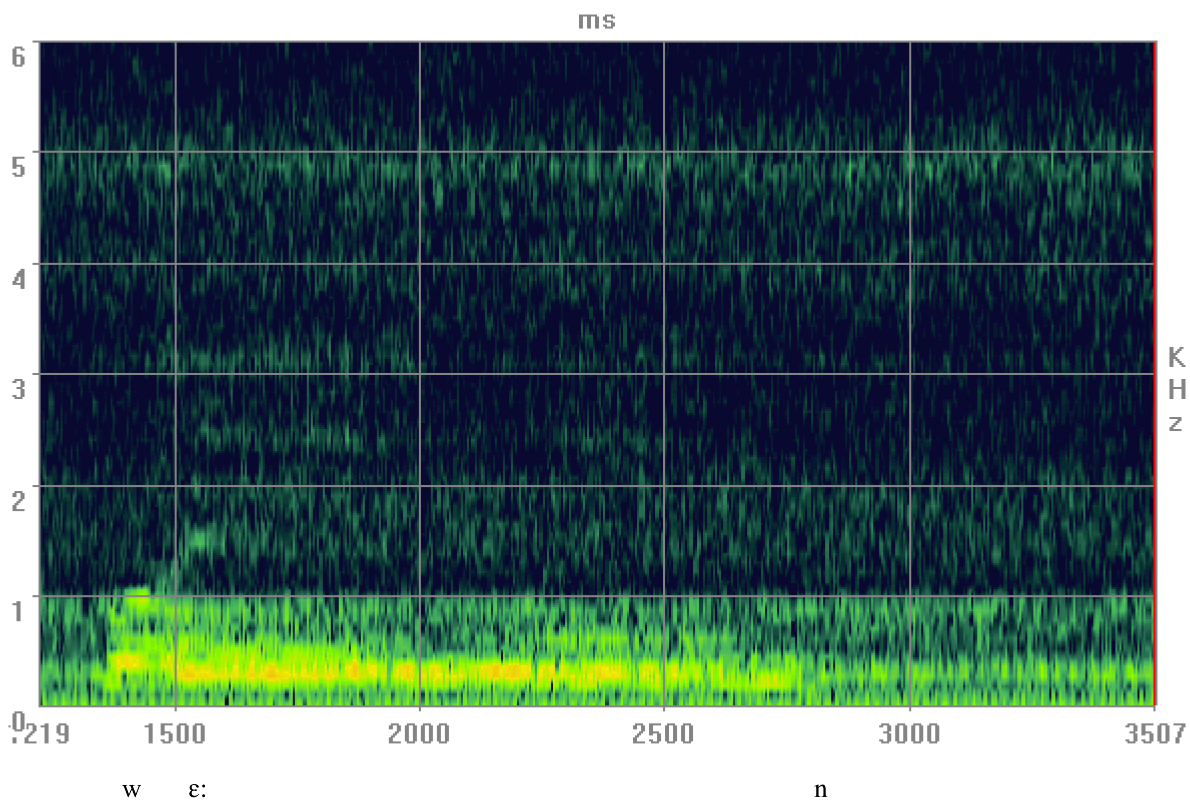

Figure 153: Formant structures in the word [wɛ:n] produced under sad status by an aphasic subject.

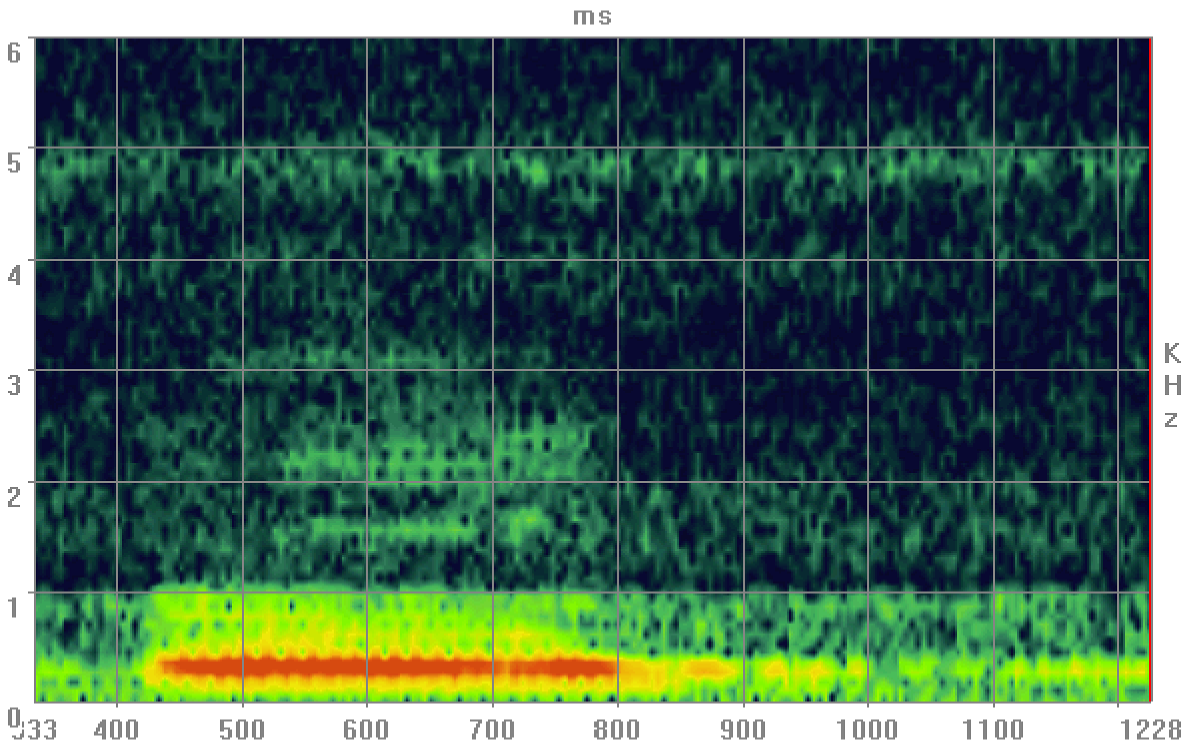

Figure 154: Formant structures in the word [wɛ:n] produced under happy status by an aphasic subject.

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The spectrograms actually exhibited that these higher spectral regions determine the speaker-specific information. This may imply the fact that higher resonances carry perceptually important information on speaker individuality. Support for these results comes from speaker identification by machine. In a study based on measuring the steady-state of certain vowels in a recorded sentence by a male speaker of American English, Sambur[371] indicated that the values of the higher formants were the most important acoustic cues for automatic identification of the speakers.

With respect to the intonation patterns under sad emotions, we noticed a significant decrease in the mean F0 and F0 range. The F0 weakness compared to natural voice could suggest a more hyperfunctional voice production. Sad states produced speech with low-pitched and little high frequency energy. In general, it was clear that emotions have great impact on F0 and the aphasic subjects were able to modulate F0 to signal happy and sad emotions. They showed more F0 variability and higher F0 range when they produced the utterances in happy states than in sad contexts. On the other hand, as figure 155 illustrates, utterances that signal

[371] Cf. Sambur, M. (1975): Selection of Acoustic Parameters for Speaker Identification, pp. 176-180.

anger are distinguished by higher amplitude and higher F0 compared to utterances spoken in happy or sad situations.

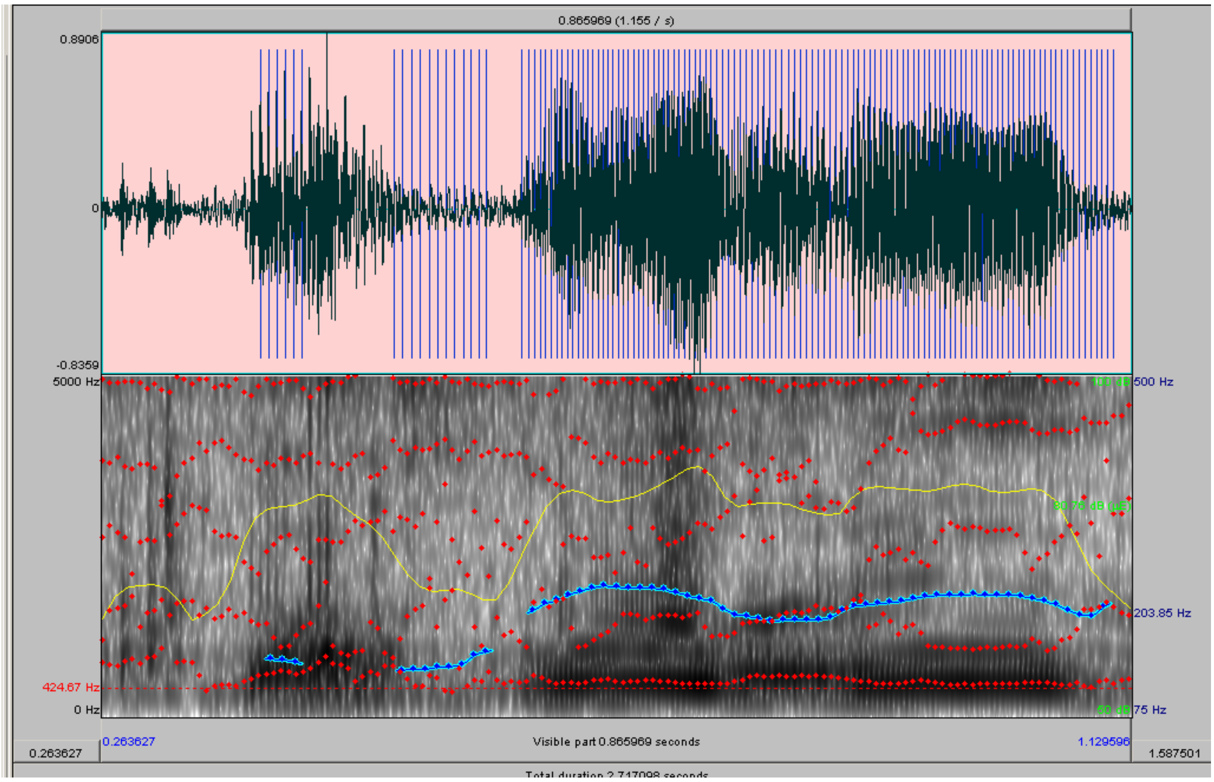

Figure 155: An illustration of intonational pattern of a sentence signalling anger [maħtˤu:tˤ hɛ:k] as displayed by an aphasic subject.

The fact that Broca's aphasics showed abnormal patterns of sentence final lengthening and spared F0 range and F0 variations between declarative and interrogative sentences could suggest the selectivity of the impairment by processing two types of intonation in different mechanisms. Consequently, the abnormal pattern of utterance final-lengthening suggests a breakdown in the prosodic structure component of intonation, whereas having intact fundamental frequency range and F0 variations give evidence of an intact tonal melody.

Summary of the main patterns of acoustic cues of sadness, happiness and anger emotions obtained from utterances of Broca's aphasics can be seen in table 79.

Sadness	low mean F0, high deviation between maximum and minimum F0, low amplitude, low intensity, high mean F1, wide bandwidth of F1, high mean F3, low mean F4, flatness shape of LPC, concentration of energy at low frequencies, falling F0 contours, slow speech rate, long vowel duration, quiet talking, plentiful pauses, monotonous speech, voicing irregularity and tremor voice.
Anger	high mean F0, high minimum F0 range, high amplitude, high intensity, rising F0 contours, high F1, much concentration of energy at high frequencies, much more melodic than in sad situation, much more precise articulation, fast speech rate compared to sadness and highly glottal fluctuations.
Happiness	low maximum F0 compared to other emotions, high mean F0, much F0 variability, low F0 deviations, medium high frequency energy, falling F0, high amplitude, shorter vowel duration compared to sadness, utterance are much more melodic and speech rate faster compared to sadness.

Table 79: Summary of the main acoustic features of the three emotional states under study as manifested by Broca's aphasics.

7.4. A neurolinguistic discussion of the results

The traditional picture of language processing indicates that the left hemisphere of the brain is primarily responsible for processing verbal, structural functions and other linguistically related functions such as pragmatics and dialectal aspects of prosody, while the right hemisphere is significantly concerned with processing the emotional prosody, gestural and particular verbally related features such as thematic and inferencial. Several pieces of data from neuropathology studies have established that language is a lateralized function of the left hemisphere.[372] With support from functional neuroimaging techniques, different studies have shown that the left hemisphere is dominant for linguistic functions. For example, Positron Emission Tomography (PET) studies[373] have indicated an increase in the brain activations of the hearers manifested by increase in regional cerebral blood flow (rCBF) in different parts of the left hemisphere during language production.

Different investigations have explored the nature of prosody in terms of its neurolinguistic and neuroanatomical nature. Consequently, various hypotheses have been developed to explore the role of the left and right hemisphere in processing both linguistic and affective prosody. Based on the right hemisphere hypothesis,[374] the aspects of prosody are lateralized in the right hemisphere. However, the functional lateralization hypothesis[375] indicates that there is a continuum from the emotional (affective prosody) to the linguistic functions of prosody and processing shifts from the left hemisphere that dominate linguistically based functions to the right hemisphere that deals more with affectively-based prosodic tasks. In other words, tasks that relate to linguistic functions are processed in left hemisphere, whereas those that convey emotional contents are processed in the right hemisphere. On the other hand, the subcortical processing hypothesis claims that prosodic functions are related to subcortical processing and are not lateralized to one or another hemisphere.[376]

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[372] Cf. Weems, S., & Reggia, J. (2004): Hemispheric Specialization and Independence for Word Recognition: A Comparison of Three Computational Models, p. 554.

[373] Cf. Zatorre, R., Meyer, E., Gjedde, A., & Evans, A. (1996): PET Studies of Phonetic Processing of Speech Review, Replication and Reanalysis, pp. 21-28.

[374] Cf. Mitchell, R., Elliott, R., Barry, M., Cruttenden, A., &. Woodruff, P. (2003): The Neural Response to Emotional Prosody, as Revealed by Functional Magnetic Resonance Imaging, p. 1411.

[375] Cf. Van Lancker, D. (1980): Cerebral Lateralization of Pitch Cues in the Linguistic Signal, pp. 230-241.

[376] Cf. Cancelliere, A., & Kertesz, A. (1990): Lesion Localization in Acquired Deficits of Emotional Expression and Comprehension, pp. 133-144.

The acoustic cues hypothesis argues that the fundamental frequency is lateralized in the right hemisphere and the durational pattern in the left hemisphere.[377] The roles of the left hemisphere (LH) and right hemisphere (RH) in processing the prosodic information including affective and linguistic prosody have received a great deal of attention over the last several decades. However, the neurobehavioural data on speech prosody show disparate findings and fail to give a specific understanding of the involvement of the cerebral hemispheres in governing our ability to receive the suprasegmental information.

Several investigators give support to the role of the RH in perception of prosodic units at phrase and sentence-level structures based on lesion deficit and functional neuroimaging studies.[378] However, others have emphasized the role of the left hemisphere in the perception of prosodic units based also on neuroimaging data.[379] Other researchers have concluded that both left-hemisphere-damaged (LHD) and right-hemisphere-damaged (RHD) patients might display impairments in processing the affective prosody. For example, some studies have indicated a link[380] between right unilateral brain lesions and particular impairment in processing of affective prosody in RHD, while other investigations do not support this view.[381]

In light of the whole discussion, it should be pointed out that the results obtained from the current study would give more support for a lateralization of prosody that depends on function. [382] In fact, the concept of this hypothesis is based on the idea that when prosody related to linguistic function is processed by the left hemisphere, whereas if it indicates emotional content then the right hemisphere is involved. The findings of the current study confirm this idea, since Broca's aphasics exhibit impairment in linguistic prosodic production with some prosodic properties intact like the distinction between different sentence modalities (declarative vs. interrogative). It is also noteworthy that the absence of F0 declination as the complexity of the sentence increased and the abnormal durational patterns in final-sentence

[377] Cf. Baum, S., & Pell, M. (1997): Production of Linguistic and Affective Prosody after Brain Damage, p. 196.
[378] Cf. Plante, E., Creusere, M., & Sabin, C. (2002): Dissociating Sentential Prosody from Sentence Processing: Activation Interacts with Task Demands, p. 401.
[379] Cf. Gandour, J., Dzemidzic, M., Wong, D., Lowe, M., Tong, Y., Hsieh, L., Satthamnuwong, N., & Lurito, J. (2003): Temporal Integration of Speech Prosody Is Shaped by Language Experience: An fMRI Study, pp. 318-334.
[380] Cf. Blonder, L., Bowers, D., & Heilman, K. (1991): The Role of the Right Hemisphere in Emotional Communication, pp. 1115-1125.
[381] Cf. Bradvik, B., Dravins, C., Holtas, S., Rosen, I., Ryding, E., & Ingvar, D. (1990): Do Single Right Hemisphere Infarcts or Transient Ischaemic Attacks Result in Aprosody?, pp. 61-68.
[382] Cf. Van Lancker, D. (1980), pp. 259-274.

lengthening indicate a strong involvement of the left hemisphere in linguistic prosody processing. Consequently, as the results indicated, when the prosodic task serves a linguistic purpose, which is dominated by the left hemisphere, our patients then display impairments in increasing the length of the sentence and abnormal timing patterns. It has been established that the durational parameters are a function of the left hemisphere (LH) and the spectral (specifically F0) components a function of the right hemisphere (RH).[383] In light of this observation, the abnormal durational patterns of Broca's aphasics affect their rhythmic patterns as the sentence complexity increases, leading one to maintain that their prosodic disorders are related to phonetic-motoric deficits rather than an inability to apply phonological rules.

These results are consistent with other studies that have exhibited that Broca's aphasics display impairments in some prosodic properties, but not in all linguistic functions of prosody.[384] Thus, it must be pointed out that the patterns obtained from Broca's aphasics show impairments in the ability to decode linguistically defined specific categorical components of prosodic patterns. On this view, the high mean F0 of Broca's aphasics could also be related to deficit in the control of temporal parameters. Consequently, these different observations could imply that Broca's aphasics display phonetic and timing impairments rather than phonological deficits. Different results indicated that RHD patients show deficits when the task associated with affective aspects of language processing.[385] In spite of this, although the current study has no RHD subjects, there is some evidence from the current study to support the involvement of the right hemisphere in processing the affective prosody, since our Broca's subjects were able to signal affective emotional distinctions. Furthermore, support for this finding has been reported from various studies. For instance, Robin et al.[386] found that the RHD patients display significant impairments in processing spectral information.

[383] Cf. Pell, M., & Baum, S. (1997b): Unilateral Brain Damage and Acoustic Cues to Prosody: Are Prosodic Comprehension Deficits Perceptually Based?, p. 195.
[384] Cf. Baum, S., & Pell, M. (1999): The Neural Bases of Prosody: Insights from Lesion Studies and Neuroimaging, p. 588.
[385] Cf. Gandour, J., Larsen, J., Dechongkit, S., Ponglorpisit, S., & Khunadorn, F. (1995): Speech Prosody in Affective Contexts in Thai Patients with Right Hemisphere Lesions, p. 422.
[386] Cf. Robin, D., Tranel, D., & Damasio, H. (1990): Auditory Perception of Temporal and Spectral Events in Patients with Focal Left and Right Cerebral Lesions, p. 539.

Additionally, functional imaging studies have generally indicated that listening for emotional tone resulted in significantly more activity in the right hemisphere.[387] It has been shown in various investigations that right and left brain lesion patients display impairments in identification of affective prosody.[388]

Different questions can be raised about the production and perception of affective prosody by the aphasics whether they processed independently with two different mechanisms or whether there is impairment in the transcallosal interactions between speech centres located in each hemisphere. Despite all of theses observations, prosodic processing has a complex nature correlated with different subskills and parameters which can be affected independently by brain-damaged patients. A wide range of different hypotheses concerning the hemispheric lateralization of prosodic processing has been developed, each with different degrees of supportive evidence. Still, many questions are open and contradictory results are available about the involvement of the subcortical regions in prosody processing.

In conclusion, it is reasonable to assume that physiological and the psychological problems appeared in Broca's aphasics influenced the suprasegmental features and the acoustic signal. Applied to the cases and findings considered in the current study, such effects will be realized in the acoustic parameters as F0 manifested in pitch, intensity, formant shifts and the spectral slope. Despite the general picture of Broca's aphasic speech being dysprosodic because of their slow rate of speech, the long pauses, hesitations and interruptions in the production of utterances, the declination line of intonation is retained. The data gives considerable evidence that Broca's aphasics retain some of the prosodic properties such as the natural terminal falling F0 and F0 declination in short simple sentences. However, they were impaired in long sentences due to their syntactic complexity. F0 terminals as rise or fall by Broca's aphasics would indicate that these are cues for detecting linguistic-prosodic meanings. This is consistent with other studies which have indicated that prosodic problems of Broca's aphasics might be associated with syntactic function and linguistic planning.[389]

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[387] Cf. Buchanan, T. Lutz, K., Mirzazade, S., Specht, K., Shah, N., Zilles, K., & Jancke, L. (2000): Recognition of Emotional Prosody and Verbal Components of Spoken Language: An fMRI Study, p. 227.

[388] Cf. Van Lancker, D., & Sidtis, J. (1992): The Identification of Affective-Prosodic Stimuli by Left and Right-Hemisphere-Damaged Subjects: All Errors Are not Created Equal, pp. 963-968.

[389] Cf. Danly, M., & Shapiro, B. (1982): Speech Prosody in Broca's Aphasia, p. 188.

Furthermore, the results in the current study indicate that their fundamental frequency range is higher than that of the normal speakers. Additionally, patterns of phrase-final lengthening are inconsistent with those shown by the control subjects. With respect to the hemispheric specialization of linguistic and affective prosody processing, the results obtained from our Broca's patients would suggest more evidence for the functional hypothesis.

Generally speaking, based on the acoustic data, the findings of the current study when viewed together suggest that there are remarkably few differences between the formant patterns and values under sad and happy situations among the aphasic subjects. Broca's aphasics were able to signal emotional prosody despite the left hemisphere damage. The performance of Broca's aphasics exhibits relative spared sensitivity to the shape of the pitch contour in judging and distinguishing the linguistic prosodic meaning embedded in the utterances. Clearly, much work is required for investigating the pitch processing mechanism and how it is presented in the brain. This would enhance our ability to capture the nature of hemispheric dominance and the brain organization.

8. SUMMARY OF THE MAIN CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

8.1. Summary of the main findings and conclusions

Several results of the Palestinian Broca's aphasics compared to the normal speakers have been found. For example, concerning the articulation of the Palestinian Arabic vowels based on the acoustic data, there is a difference between the place of articulation of the long and short vowels. In this account, the results reveal that Broca's aphasics have problems in positioning the tongue in the correct position, demonstrated clearly by the deviant formant frequencies that they display compared to the normal speakers. This finding might point towards the fact that they suffer from articulatory limitations. Moreover, regarding the formant frequencies, Broca's aphasics revealed significant variability. They displayed higher averages for the first four-formants of the short and the long vowels than those of the normal speakers. In this account, the results indicate different formant patterns for the normal speakers and Broca's aphasics. For example, the normal speakers displayed higher F3 for the front high vowels [i:] and [i] than for the low vowels [a:] and [a], and the back vowel [u:]. The vowel [u] had the lowest average. Contrary to the normal speakers, Broca's aphasics revealed a higher F3 average for the low vowels [a] and [a:] than the front high vowels [i] and [i:], whereas the back vowels [u] and [u:] had the highest F3 average.

Moreover, it was noticed that there was a clear lowering of F2 in the short front vowel compared to its long cognate. In addition, with respect to the F2 values of the short vowels, it was obvious that the interaction between quality and vowel length was significant. Moreover, the F4 of the aphasic patients was higher than those of the normal speakers. In addition, the results indicate that Broca's aphasics exhibited higher F1 than the normal speakers, suggesting that vowel production by Broca's aphasics is associated with a wider vocal tract configuration.

The formant averages obtained from Broca's aphasics suggest that they are variably able to implement the acoustic-phonetic rules. Furthermore, the different values of the formants emphasize that the vocal resonators are distinguished by a continuous change in shape and area and tongue movement. In addition, the findings of the study indicate that the vowel formants of the normal Palestinian speakers are respectively close to those reported from other Arabic countries. However, it can be seen that the vowels [a] and [a:] have relatively lower values compared to those of other Arabic countries. Furthermore, the results display that the aphasic's vowel space area of F3 and F4 was significantly larger than the acoustic vowel space of F1 and F2, suggesting a strategy to make their speech clear and intelligible. It is thus very important to indicate that the magnitude of deviations between the first four formants in utterances produced by Broca's aphasics indicates that the first two formants apply to the vowel quality and F3 and F4 are related to the speaker.

Regarding vowel duration in Broca's aphasics, significant differences between their patterns and those of the normal speakers were found. In this account, the durational patterns of Broca's aphasics were highly variable. This variablity indicates impaired articulatory implementation at the phonetic-motoric level. This is associated with articulatory control and timing deficits, but with implementing the phonological knowledge between the long and short vowels. As a whole, the mean vowel duration for Broca's aphasics was longer than for the normal speakers, reflecting dysprosodic and durational abnormalities. Furthermore, the results indicate that vowel length in Arabic is phonologically significant. In addition, the analysis shows a significant influence of the consonant class on the preceding vowel. For example, the average vowel duration for the high vowel [i:] preceding both voiced and voiceless fricatives was the shortest among Broca's aphasics, and this was the same in the speech of the normal speakers. Furthermore, the findings exhibit that Broca's aphasics generally comply with the low vowel rule by increasing the duration of [a] and [a:] before the consonant classes under study. The findings show that Broca's aphasics displayed the most increase in the duration of the short vowel [a] before voiced fricatives. However, the normal speakers displayed such increase before voiceless stops. Based on the judgment of whether the vowel is long, longer, or the longest, different patterns between the performances of Broca's aphasics and the normal speakers can be found. For example, Broca's aphasics produced their shortest [u:] before [s], [d], [t] and [k], whereas the normal speakers demonstrated this before [z], [d], [t] and [b].

The findings demonstrate an influence of the voicing effect on vowel duration. However, it seems also that the effect of the voiced stops is different from the one of the voiced fricatives. As a result, this effect appears to operate significantly on the low short vowel [a] being longer than the other vowels in the normal speakers and Broca's aphasics as well. The durational patterns of Broca's aphasics shed light on the nature of their errors. This could be related to articulatory implementation deficits at the phonetic/motoric level including the articulatory control, simultaneously with preserved phonological distinction between the long and short vowels.

Concerning syllable duration, Broca's aphasics increase the duration of the syllable in trisyllabic words compared to the duration of the same root embedded in disyllabic or in isolated words. This pattern was completely different for the normal speakers, who decreased the duration of the same syllable in trisyllabic words. Moreover, the magnitude of word duration was relatively greater for Broca's aphasics than for the normal speakers, particularly in trisyllabic words. Furthermore, the findings indicate that Broca's aphasics display particular problems in the production of polysyllabic words due to the increase of the articulatory complexity, giving evidence for motor timing impairments. The comparisons indicate that Broca's aphasics produced significantly longer word durations than the normal speakers for both disyllabic and trisyllabic words. Contrary to the patterns of the normal speakers, Broca's aphasics demonstrated a greater degree of overall duration of the word as the number of syllables increased. However, it is true for Broca's aphasics and the normal speakers that they reduced the duration of the vowels in trisyllabic words, but the magnitude of reduction was smaller for the aphasics than for the normal speakers. In general, a tendency was noticed in the performance of Broca's aphasics that the average word duration increased as the number of syllables increased. Nevertheless, the average vowel duration and average word duration for Broca's aphasics are longer than those for the normal speakers.

The findings indicate that speech of Broca's aphasics is characterized by relative centralization of vowels, slowness and inaccuracy of the articulator movements resulting in increasing the vowel durations as the number of syllables increased. Regarding vowel reduction, the results indicate that Broca's aphasics display vowel duration reduction, but with a lower magnitude of reduction compared to the normal speakers. Importantly, this indicates that Broca's aphasics have this phonological encoding ability, suggesting that their durational impairments could be related to motoric and timing deficits rather than phonological ones.

Regarding the acoustic vowel space, Broca's aphasics display remarkably narrow and compressed vowel spaces compared to the normal speakers. The short vowels are somewhat centralized in relation to the long vowels. The long vowels, however, are extremely reduced. The compressed vowel space of Broca's aphasics suggests that they suffer from limitations in the musculature apparatus movement, affecting the tongue movement, displacement and direction of the movement. Furthermore, these findings lead to the conclusion that Broca's aphasics display significant problems in maintaining the maximal frequency range of the vowel distribution in the acoustic space.

Concerning the VOT patterns, the results indicate that the normal speakers comply with the universal rules by exhibiting, for instance, that velar stops have longer VOT and VOT is shortened before bilabial stops. Moreover, they revealed higher VOT values for voiceless stops than that for voiced stops. In contrast, Broca's aphasics revealed impaired VOTs by exhibiting overlapping between the places of articulations of the stop consonants under study. The normal speakers, on the contrary, were able to show full normal VOT distributions for voiced and voiceless stops. However, despite the VOT overlapping, Broca's aphasics were able to maintain some of the acoustic durational rules that are found across languages such as the further back the closure, the longer the VOT by exhibiting longer mean VOT for the velar stop [k].

The findings indicate that Broca's aphasics were unable to maintain the normal voicing distinction for the Arabic stop consonants. Furthermore, a relation between the nature of errors and the overlapping between places of articulation of the stop consonants was found. In this respect, they exhibited phonemic errors for [t], whereas the errors were phonetic for [d] rather than phonemic. Nevertheless, the performance of Broca's aphasics on alveolar stops generally reveals no preference for phonetic or phonemic errors. However, they exhibit only phonetic errors in producing velar stops. Taking the results as a whole, Broca's aphasics tend to produce phonetic errors more than phonemic ones. Furthermore, the findings indicate that the articulatory errors in Broca's aphasics do not seem to reflect a general global weakness of the articulator's musculature. Rather, the articulatory disabilities appear to be best characterized as affecting two independent articulators. The deficits displayed by Broca's aphasics are presumably due to a deficit regarding timing and speech motor control in terms of integration of movements of the articulatory system.

With respect to the fricative sounds, Broca's aphasics in this study were able to maintain the phonetic distinction between voiced and voiceless fricatives. However, the acoustic analysis reveals significant differences and similarities between the performances of Broca's aphasics and the normal speakers. For example, Broca's aphasics displayed longer durations for the voiceless fricatives than for the voiced fricatives as the normal speakers displayed. On the other hand, the sound [ʃ] achieved the longest duration among the normal speakers, whereas the sound [χ] was the longest fricative for Broca's aphasics. While the normal speakers produced the emphatic fricative sound [sˤ] longer than its non-emphatic counterpart [s], Broca's aphasics opposed this pattern. Furthermore, the findings demonstrate that the sound [s] has achieved the highest frequency from the fricative sounds under study by the normal speakers, while [z] has the highest frequency by the aphasics. Moreover, it is true for the normal speakers and Broca's aphasics that the fricative [z] was the shortest sound from those under study. The analysis also reveals an effect of the place of articulation on the frequency values. In this regard, for example, it was found that the frequency average lowered as the place of articulation moved back, a feature which was noticed for the normal speakers and Broca's aphasics.

Regarding the energy distribution, the results show that it was generally flat in the case of Broca's aphasics indicating weak amplitude values. The normal speakers exhibited higher frequency and intensity for voiceless fricatives than for their corresponding voiced fricatives, as shown in the fricatives [s] and [z]. In contrast, Broca's aphasics were not compliant with this result. Substitutions and distortions were found to be the predominant errors. Importantly, the findings indicate that the target phoneme and the substituted one rarely differed by more than one distinctive feature and the place of articulation is the most involved. In this account, the errors were categorized as one place-distance errors. Consequently, the target phoneme in most of the cases was substituted by phonemes having the same place of articulation.

The results clearly show that fricatives having a back place of articulation were mostly affected. The fricative [ʃ] was the most difficult for Broca's aphasics to be produced precisely. Despite the fact that Broca's aphasics exhibited voicing disorders in the stop consonants, it was noticed that they did not demonstrate such a deficit in voiced fricative sounds. This would suggest that this problem does not indicate a disability in selecting the distinctive features of the sounds, but a sloppiness of the motor execution.

Furthermore, consonant deletion was found to mainly affect complex clusters. De-emphasis of the emphatic [sˤ] was clearly noticed in Broca's aphasics, indicating the loss of the secondary articulation. In addition, Broca's aphasics displayed long frication for the fricative sounds compared to the normal speakers. At the same time, they showed a capability to maintain duration differences between voiced and voiceless fricatives by displaying shorter duration for voiced fricatives than for voiceless fricatives. Regarding the affricate sound [dʒ], Broca's aphasics exhibited articulatory difficulty in its production. Thus, they tended to reduce this complexity by replacing it with the unpredictable variant [g]. However, this substitution is considered a legal one in Egyptian Arabic. The results indicate that the complexity of speech production in phonetic context can result in severe articulatory impairments in Broca's aphasics.

With regard to the emphatic sounds, as exhibited by the normal speakers, F2 is lowered while F3 is raised representing a significant feature for distinguishing emphatic sounds in Arabic. F2 lowering was not clearly noticeable by Broca's aphasics. Furthermore, Broca's aphasics exhibited overlapping between the F2 locus for [t] and [tˤ]. The data from the normal speakers suggests that the second and third formants of the vowels are influenced by the place of articulation of the emphatic stop consonant under study [tˤ]. A narrower distance between the F1 and F2 in the emphatic environment [tˤ] than its non-emphatic cognate [t] was observed in the normal speakers affecting the formant's movement and transition. However, Broca's aphasics displayed a wide distance between the first two formants.

From an acoustic point of view, the results obtained from the normal speakers demonstrate that the tongue position and the place of articulation of the stop consonant influence the transitions of the second and third formants. Broca's aphasics displayed an extreme lengthening of the VOT indicating a long duration for the release phase. This suggests that Broca's aphasics suffer from motoric difficulties and slowness in the transition from one articulatory shape to another. In fact, the results emphasize that, based on the acoustic data, Broca's aphasics due to motoric limitations by moving the tongue in the right direction have produced the consonant [tˤ] in the same region of [t]. Therefore, Broca's aphasics de-emphasized the emphatic sounds, reflecting a disability in implementing the secondary articulation. This leads one to conclude that they were unable to keep the acoustic-articulatory boundaries between the two sounds resulting in this categorical overlapping. Furthermore, the deficits in the production of the empathic sounds which involve primary and secondary articulation give evidence to the fact that Broca's aphasics were unable to execute speech movements that require integration of different types of information by the brain. Consequently, this affects the synergy of the muscle commands and movements that are coded in order to place the speech articulators appropriately.

They also demonstrated a remarkable frication noise during the phase preceding the closure. The formant's movement of F2 for the vowels after [t] by the normal speakers was generally flat. Broca's aphasics were inconsistent with this pattern. In addition, the results display that the emphatic sounds are generally characterized by a concentration of energy in low frequencies and spreading over a wide frequency bandwidth. Furthermore, the frequency values of F2 and F3 for the vowels in alveolar context are increased if the following vowel is a front vowel [i] and decreased if it is a back one [u]. This suggests that the further back the vowel is, the bigger the differences between F2 and F3 values. Variable and inconsistent patterns were observed in Broca's aphasics. The shape of the transition is determined by the place of the locus to the frequency of the adjacent vowel in the sequence.

With respect to anticipatory coarticulation, the patterns which emerged from Broca's aphasics were quite different from those of the normal speakers. That is, for example, they particularly displayed a lack of formant frequency lowering in the environment of [bu] as compared to the normal speakers, who experienced a lowering in the formant frequency. In this account, the results obtained from the coarticulation patterns of Broca's aphasics suggest that they demonstrated inefficient and imprecise timing of the articulatory movements of the adjacent segments. This implies spatiotemporal deficits in the speech production process. In this regard, their anticipatory errors could be related to a deficit in the laryngeal abduction-adduction mechanism. In addition, the results would lead to conclude that Broca's aphasics display deficits in the interarticulatory organization of consonantal sequences, reflecting impairments in the dynamic transitions between adjacent segments in a particular context.

Furthermore, the coarticulatory deficits would suggest that Broca's aphasics produced sounds independent of their phonetic context, reflecting impairments in transitioning from one speech sound to the next. In light of the discussion in the present study, the results indicate that the coarticulatory impairment in Broca's aphasics might be a motor sequencing deficit that requires a precise coordination between independent articulators. As a result, from the results of this study it is evident that the coarticulatoty deficits in subjects with Broca's aphasia could be associated with impairments in the phasing of movements and the spatial configurations of articulatory movements. In this account, the results would give evidence for the neurolinguistic role of Broca's area in speech planning in addition to other brain structures such as the supplementary motor area.

Furthermore, Broca's aphasics displayed remarkable initiation problems at the utterance or single sound levels. The results indicate that context-sensitivity and lexical frequency would have an effect on the coarticulation patterns of Broca's aphasics. In this account, the results display that Broca's aphasics display lexical processing deficits distinguished by a general reduction in lexical activation. They were able to store intact lexical concepts while having a deficit in accessing these representations and performing imprecise cognitive judgments like analytical isolation. In addition, the results obtained from Broca's aphasics indicate that the motor complexity might have a negative impact on the spatiotemporal parameters of the articulator movement. The current results of the coarticulation patterns obtained form Broca's aphasics are inconsistent with different studies such as the one made by Katz. Furthermore, the findings would suggest that a distinction between motor program and motor planning that might operate separately in the speech production process should be established in order to understand the temporal control of speech which is exerted during the motor stages of speech production. The fact that duration of the articulator is a temporal parameter, which is considered an important component of the motor planning stage, would emphasize that Broca's aphasics displayed timing motor planning deficits. In this account, the findings suggest that the articulatory errors of Broca's aphasics are related to deficits in mapping between the acoustic, phonetic, orosensory and timed motor frames that are necessary for precise articulation.

Furthermore, the results indicate that speech of Broca's aphasics is characterized by hesitations, initiation difficulties and long pauses, emphasizing motor planning deficits. This is likely to be responsible for the arrangement of the segments that should be implemented concurrently and sequentially. In fact, initiation difficulties address the issue of control of speech movement and the muscle command representations by Broca's aphasics, since this control requires a complex integration and an interaction of different types of information controlled by the brain such as auditory, sensory and motor integration. Furthermore, the findings emphasize that methods of speech therapy should focus on the integration level between sounds while establishing a hierarchy complexity. In addition, the findings demonstrate that Broca's aphasics were able to detect their errors indicating a relative preservation of monitoring of speech production. Their attempts to get closer to the target sound would indicate that they use a system that enabled them to compare the impaired sound with the target one. On the other hand, the results display that latencies and pauses could be related to lexical activation mechanisms in Broca's aphasics, indicating that they show deficits in the activation levels of lexical entries. This depends on the extent of matching between the input segment and the target representation.

Furthermore, the findings show that, based on the acoustic analysis, Broca's aphasics demonstrate constraints in the degrees of freedom of movements reflecting deficits in the integration of movements of several articulators temporally and spatially in order to produce a particular segment, thus leading to coarticulation deviations. The problems as exhibited by Broca's aphasics lie at the phonetic level in terms of outputting selected sounds rather than selection problems.

The findings display that the variability of Broca's aphasics implies that they do not display a global loss in the articulatory system. Their problem seems rather to be in some parts of the articulatory subsystem. The findings indicate that motor equivalence should be recognized as an aspect of speech production of Broca's aphasics. Based on the patterns of Broca's aphasics, it seems likely that the role of economy as the only reason for coarticulation is not enough to interpret this phenomenon.

The findings indicate that final falling pitch for WH-questions was clearly seen by Broca's aphasics. Furthermore, declarative sentences have the lowest amplitude by the normal speakers and Broca's aphasics as well. However, as a general trend, Broca's aphasics showed higher amplitude values than the normal speakers. Interestingly, the findings indicate that Broca's aphasics were able to signal the intonational contrast at least in short sentences. In addition, it was apparent that Broca's aphasics displayed differences in F0 variation including F0 peak and shape. In declarative statements, patterns emerged from Broca's aphasics indicate that they displayed sentence terminal F0 fall contour similar to the pattern observed by the normal speakers. Regarding F0 declination, it was noticed that Broca's aphasics displayed the prosodic acoustic parameter as seen in the normal group.

Furthermore, the findings demonstrate that Broca's aphasics were unable to exhibit phrase-final lengthening compared to the normal speakers. In this account, they produced words in initial positions longer than those in final positions compared to the normal speakers. This emphasizes that their impairments related to speech planning and timing deficits, since phrase-final lengthening refers to speech planning. Furthermore, the results found an effect of vowel quality on F0, duration and intensity. For example, the low vowel [a] was characterized by lower F0, higher amplitude and longer duration. In general, the intonational patterns of Broca's aphasics indicate that some of the prosodic aspects are preserved, while other patterns are inconsistent with those of the normal speakers. Long segment duration, slow speaking rate, long pauses and frequent hesitations are also shown in Broca's aphasics. Moreover, the current study indicates that Broca's aphasics exhibit relatively spared rising and falling intonation patterns and their intonation is found to be changeable in conversational speech.

Despite the left hemisphere damage, Broca's aphasics were able to signal emotional prosody in terms of sadness, happiness and anger. Furthermore, their utterances were distinguished under these emotional situations by different acoustic cues. For example, sadness was distinguished by low mean F0, high deviation between maximum and minimum F0, low amplitude, low voice intensity, high mean F1, wide bandwidth of F1, high mean F3, low mean F4, flatness shape of LPC, concentration of energy at low frequencies, falling F0 contours, slow speech rate, long vowel duration and quite slackening articulation. In addition, the results indicate that the fundamental frequency range of Broca's aphasics is higher than that of the normal speakers. With respect to the hemispheric specialization of linguistic and emotional prosody processing, the results obtained from Broca's aphasics would suggest more evidence for the functional hypothesis. Furthermore, the differences between F1 and F2 for the vowels produced by Broca's aphasics were not significant when they were produced under happy and sad situations, whereas significant differences were seen between F3 and F4.

8.2. Suggestions and recommendations for further research

This study of Palestinian Broca's aphasics is intended as a contribution to current efforts to broaden the understanding of aphasia and its correlates and features in Arabic aphasics. Further research of the performance of Palestinian aphasics is needed to shed more light on different issues. In general, this study is considered to be a survey of the prominent features of Palestinian aphasics. However, research on aphasia in Palestine is still a virgin field, demanding more research on the behaviour of the aphasics, either linguistically or clinically.

It is also essential to establish a database for aphasia and other language disorders in Palestine concerning the degree of the problem, screening tests and establishing rehabilitation centres. The results of this study could help to launch further research in order to establish or develop assessment methods essential for clinical use. It is worthy to note that the use of diagnostic tests developed in other countries could create several difficulties in the interpretation of results, and consequently influence the therapy process because of cultural, demographic, ethnic and linguistic differences.

The need for speech clinical tests for the Palestinian aphasics is enhanced by the large scope and degree of this problem in the community. In fact, many tests used in diagnosis or assessment have been adapted from English into Arabic. To the researcher's knowledge, there are hardly any valid and reliable tests on aphasia diagnosis and assessment that have been developed in the Palestinian territories. Therefore, most of the speech pathologists in Palestine used the Boston Diagnostic Aphasia Examination (BDAE) for evaluation and diagnosis. Despite the fact that this test is highly scientifically constructed, when conducting such a test on the Palestinian patients misleading interpretations might appear regarding different issues. For example, are the reference values for American English speakers consistent with those for Palestinian aphasics so that they can be taken as reference values for our patients? Or how could the demographic variables influence the performance in the BDAE that responds to other social groups? Moreover, Goodglass and Kaplan have standardized the BDAE-2 using 242 male patients treated at the Boston Veterans Administration (VA) Medical Centre between 1976 and 1982. Here arises the question of whether this standardisation sample is only representative of aphasic patients in the United States. Thus, it is cautionable to generalize the results beyond this population.

Moreover, these norms were obtained from subjects identified only by their sex and found only in a single institution. Furthermore, they do not represent different socio-linguistic backgrounds. Likewise, other factors come into play such as the educational level of the population that could have a significant influence on the performance of subjects in such tests. For instance, in the Oral Spelling, Written Confrontation Naming and Sentences to Dictation subtests, we would expect Palestinian subjects to display different norms than those established for American English speakers. Norms for the Comprehension of Sentences and Paragraphs task, which require a certain reading ability, or in the Word Discrimination subtests, which include semantic categories based on knowledge related to experiences frequently acquired at school, like geometric shapes and details of body parts, should be reconsidered during the interpretations based on the scores and the norms they show. Consequently, this emphasizes the fact that the content of a language test should respond to the linguistic knowledge of the targeted community or group as well as the necessity for developing tests responding to the socio-linguistic profile of the Palestinians, specifically in the material and the pictures used to assess the patients.

The adapted or translated tests did not take into account the differences between English and Arabic. For example, diglossia is considered one of the major characteristics of Arabic. This term indicates that this language has two levels: an oral level, manifesting itself in dialects, and a literary level. Speech and language pathologists should be aware of the dialectal features when conducting their assessments.

Another feature characterizing those tests is that they did not meet the specific features of Palestinian Arabic at the phonological or phonetic level. This partially includes the vowel and consonant system like the pharyngeal and the emphatic consonants, voicing patterns and other features. Therefore, developing a test made to fit responds to Palestinian Arabic aphasics would lead to avoiding undesirable factors affecting the evaluation process.

The lack of relevant normative data on several employed language assessment measures is considered a main difficulty. As a result, it is not easy to accept the idea that assessment tools developed in other countries are a valid measure for other countries. Therefore, it is very important to obtain normative data on language assessing tools. Those measures and norms should take into consideration several variables like the educational level, dialect, socioeconomic background, familiarity, age, gender, word frequency and context. For example, using Boston Naming Test [390](BNT) by our speech pathologist could also result in misdiagnosis, since no normative data on healthy Palestinian speakers are available. Also, the word frequency and familiarity of the picture they used for the Palestinian subjects are not clear. Some of those pictures are socially dependent. A picture familiarity in one community may not be familiar in other societies. Moreover, the pictures which were used to elicit the stimuli in different cases did not belong to the environment of subjects. In light of these notions, the results of this study could contribute to establish tests responding to the specific features that are unique to the Palestinian Arabic aphasics.

[390] Cf. Kaplan, E., Goodglass, H., & Weintraub, S. (1983): Boston Naming Test.

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10. APPENDICES

10.1. Test words for vowel duration and formant values

kataba	wrote
sabʕa	seven
ba:b	door
ʕu:d	come back
ʃuba:k	window
ʃaʕrak	your hair
kam	how much
taχit	bed
θala:θ	three
arbaʕa	four
zudʒa:dʒ	glass
si:d	grandfather
ħasan	good
χubz	bread
tu:b	shame on you!
ru:s	heads
du:b	shame
ʔisʕu:djih	Sudia Arabia
duka:n	grocery
dʒo:z	pair
mɑbsu:tˤ	fine
rumma:n	pomegranate
ti:n	figs
ruz	rice
ʕu:m	swim
tuffa:ħ	apple
dʒami:l	beautiful
ʃu:f	see
biglib	make up side down
sala:m	hello
biħlib	milking
kala:m	talk
ʕasˤfu:r	bird
saʕi:d	happy
ʕi:d	festival
bi:d	hit
min	from

sitti	my grandmother
binit	girl
ʔilχali:l	Hebron
bis	cat
χami:s	Thursday
ʔarbiʕah	Wednesday
bilʕabu:	playing
dʒami:ʕ	all
bɛ:dˤɑ	one egg
bɛ:t	house
ʔana	I am
zɛ:t	oil
hɛ:k	it is so!
ʔisbɛ:ʕah	name of a girl
lɛ:ʃ	why
kɛ:f	how
bisawi	doing
sˤo:t	sound
ʃo:k	acanthus
tama:m	exactly
mo:z	banana
χo:χ	peach
madʒðu:b	attracted
ʕala	on
tˤɑ:lib	student
ʕumri:	my age
walad	boy
batˤi:χ	water melon
sajja:rah	car
ʃantih	bag
sir	go
bir	favour
bi:r	well
du:r	houses
do:r	turn
su:q	market
suq	drive
mazbu:tˤ	exact
ʃimma:m	cantelope
kabi:r	big
χa:lti	my aunt
ra:ħ	went

qitˤ:ɑr	train
aula:d	boys
baʕmal	working
madrasɛh	school
binti	my daughter
ʔistanna	wait
bando:rah	tomato
kaʕkɛh	biscuit
mara	woman
muba:ra:	game
ʔitfarradʒit	watched

10.2. Test words for VOT analysis

baʕd	after
bagarah	cow
bas	enough
kanab	furniture
kaf	hand
baru:ħ	I go
bando:rah	tomato
bata:biʕ	I follow
baʕdi	after me
dara:him	money
taχit	bed
daʕ	pushing
daʃʃartu	I left him
kari:m	generous
dalaʕ	pampering
tasbaħ	swimming
gaʕdat	sat down
taħit	under
daba:bih	tank
kasaru	he broke it
badri	i know
galam	pencil
galli	he told me
gafasˤ	cage
targu:mja	name
tasi:r	walking
gala:jih	pan
dalɛtu	described
kalb	dog

kaʕkih	cake
karaz	cherry
taftaħ	open
gaffarat	finished
gaħħa	coughing
tafri:ɣ	discharge

10.3. Test words for fricative sounds

ħasan	good
χaraz	bugles
sali:m	healthy
χalf	back
χami:s	Thursday
samakih	one fish
saʕda:n	monkey
samu:	they named him
saħabu	pulled him
sajja:rah	car
ʃaʕar	hair
sami:ħ	name of a person
ʃamsijjih	umbrella
ʃukur	thanks
ʃimma:m	cantelope
ʃaku:ʃih	hummer
ʃuba:k	window
sitih	six
zatu:n	olives
zudʒa:dʒ	glass
χali:li	from Hebron
zaʕal	anger
zalamih	man
sˤɑdi:qi:	my friend
χamsi:n	fifty
zahar	cauliflower
sˤɑʒb	difficult
safi:na	ship
χaru:f	lamb
sˤura	picture

zara:fa	giraffe
χatim	stamp
zirr	button
safar	traveling
χuðha	take it
sˤala:	pray
sˤɑħin	plate
ʃatˤtˤɑ	hot pepper
ʃidd	pull
ʃaħin	truck
sˤɑbir	patience
χadʒu:l	shy
sˤɑndal	shoe
χubz	bread
zija:ra	visit
sallamtu	I gave him
sabʕa	seven
sitih	six
ʃara:b	soup
χalasˤ	enough
zahga:n	bored
sˤɑlɛ:t	prayed
ʃanti	bag
ʃaba:b	boys
χamsi	five
sabit	Saturday
ʃaʕar	hair
saʕudjih	Saudi Arabia
ʃuɣil	work
sˤɑħi:ħ	correct
suʕa:d	name of a woman
sukkar	sugar
ʃuftha	I saw it
samak	fish
sˤuħbi	friendship
ʃamis	sun
ʃurtˤi	police man
sˤiʕib	difficult
zahrah	cauliflower
χadd	cheek

10.4. Test words for the emphatic sounds

tˤɑjja:ra	airplane
tˤɑjjib	okay
tˤɑbi:χ	food
tˤɑri:g	way
tˤifli	small baby
tˤɑl	come
tˤundʒra	pot
tˤɑχχu:	they shot him
tˤɑrbu:ʃu	his turban
tˤiʕim	delicious
tˤulla:b	students
tˤɑħi:n	flour
tˤɑgih	hat
tˤɑnnaʃ	ignored
tˤubi	ball
tˤultu	pick up
tˤuju:r	birds
tˤɑbarija:	Tiberias
tamir	date
tisbaħ	swimming
timʃi	walking
tuffa:ħ	apple
tiħit	under
tuɣassil	wash
talbis	wearing
tumaʃʃitˤ	comb
tisgi:	watering
taʕba:n	tired
tisʕa	nine
targu:mja	name of a place
tisħabha	pull it
tal	hill

Eidesstattliche Erklärung

Hiermit erkläre ich, daß ich die Dissertation selbständig, ohne fremde Hilfe und mit keinen anderen als den darin angegebenen Hilfsmitteln angefertigt habe und das die wörtlichen oder dem Inhalt nach aus fremden Arbeiten entnommenen Stellen, Zeichnungen, Skizzen, bildlichen Darstellungen und dergleichen als solche genau kenntlich gemacht worden sind.

Mainz, den.. Unterschrift