NASAL CONSONANT AND VOWEL PRODUCTION IN INDIVIDUALS WITH BROCA'S APHASIA: AN ACOUSTIC STUDY

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CERTIFICATE

This is to certify that this dissertation entitled ***" Nasal Consonant and Vowel production in Individuals with Broca's Aphasia: An Acoustic study"*** is a bonafide work submitted in part fulfilment for the degree of Master of Science (Speech Language Pathology) of the student Registration No: 09SLP021. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore
June, 2011

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CERTIFICATE

This is to certify that the dissertation entitled ***"Nasal Consonant and Vowel production in Individuals with Broca's Aphasia: An Acoustic study"*** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

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DECLARATION

I hereby declare that this dissertation entitled ***"Nasal Consonant and Vowel production in Individuals with Broca's Aphasia: An Acoustic study"*** is the result of my own study under the guidance of Mr. R. Rajasudhakar, Lecturer in Speech Sciences, Department of Speech Language Sciences, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other university for the award of any diploma or degree.

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Introduction

Communication is the process by which individuals exchange information and convey ideas (Owens, 1990). It is an active process requiring a sender who formulates the message and a receiver who comprehends the message. In order for the communication to be effective, each partner should be alert to the needs of the other. Communication is very vital for the existence of society. The importance of communication extends from expressing basic needs of an individual to promoting a better quality of life.

Communication occurs mainly in two modes. Humans mainly communicate through speech, which is the verbal output of a language. Verbal communication is confined to humans, which requires the precise coordination of oral neuromuscular movements to produce sounds in a language and linguistic units. Whereas the other form of communication which is nonverbal; is common to both humans and animals. Nonverbal communication between humans takes place mainly in the form of gestures, body movements, eye contact and facial expressions etc.

Any condition that impairs the comprehension of language, or ability to speak, can interrupt the normal verbal form of communication which is referred to as a language disorder. It may involve the sound structure, grammar, meaning and the function of language in a communication.

The main cause for a language disorder in adults is as a result of cerebrovascular accident which leads to damage to the parts of brain which are mainly involved in language functions. The condition is referred to as aphasia which is characterized by difficulty in understanding or using language or both.

LaPointe (2005) defined ‘aphasia as an acquired communication disorder caused by brain damage that impairs a person’s ability to understand, produce and use language’. Other than comprehension and use of language, individuals with aphasia have cognitive deficits related to language such as reasoning, thinking etc. Broca’s aphasia, a type of aphasia occurs as a result of damage to the anterior regions of brain which is responsible for spoken output of language. The condition is characterized by difficulty expression of language, non-fluent speech with short utterances which lacks grammar.

Apart from language production deficits seen in individuals with Broca’s aphasia, these individuals have underlying deficits in speech production. But in most of the condition, these deficits are masked by the most prominent language deficits seen in these individuals (Kurowski, Hazen & Blumstein, 2003).

Speech production is a complex task which requires the coordinated functioning of various systems such as respiratory system to provide air supply, phonatory system acting on expiratory air to produce the voice, resonatory system which modifies the voice quality, articulatory system which is responsible for production of individual speech sounds of a language, sounds into words and sentences and finally the information from the central nervous system which coordinates these systems.

A number of speech disorders also co-exist in individuals with aphasia, especially in Broca's aphasia. The most common condition that co-occurs with Broca's aphasia is dysarthria, which occurs as a result of damage to the nerves that carry information from brain to respiratory, phonatory, resonatory and articulatory systems. As a result, there will be in weakness in the structures involved in these systems leading to impaired intelligibility of speech. A person with dysarthria will mispronounce every word with some phonemes affected more than others. But one of the key features of speech of an individual with dysarthria is consistency of the errors produced.

Another disorder that co-exists with Broca's aphasia is apraxia of speech. Unlike dysarthria, apraxia is not as a result of muscular weakness, slowness or incoordination. It is a disorder of motor planning characterized by prosodic alterations such as changes in speech stress, intonation and rhythm, may be associated with the articulatory disruption either as a primary part of the condition or in compensation for it (LaPointe, 1990).

According to Lapointe, dysarthria alone; coexisting with aphasia will not be severely debilitating because speech musculatures are bilaterally innervated and the aphasia- causing lesion only affects one side of the speech apparatus. But dysarthric component may interact with apraxia of speech in individuals with Broca's aphasia and the cumulative effect of even mild dysarthria and apraxia of speech can significantly impair intelligibility of speech.

Apart from motor execution deficits as a result of comorbid dysarthria and motor planning deficits due to apraxia, there is evidence that individuals with Broca's aphasia exhibit certain speech production deficits which are unique to the condition. The speech of individuals with Broca's aphasia is characterized by slow articulation, hesitant speech with extrinsic facial movements with frequent substitution of one phoneme with another, also referred to as cortical dysarthria (Bay, 1962).

Blumstein, Cooper, Goodglass, Statlender & Gottlieb (1980) reported that phonetic disintegrations of speech of these individuals are due to a deficit in articulatory timing of vocal fold vibration. Apart from this, they show deficits in coordination of various articulators (Itoh, Sasanuma, & Ushijima, 1979), errors in timing (Blumstein et al., 1980) and laryngeal control (Kurowski, Hazen, & Blumstein, 2003).

Need for the study

- Review of literature shows that most of the study done, investigating the speech production defects in individuals with Broca's aphasia were done on small sample size of 2-5 subjects.
- Most of the studies were done on foreign language speakers with aphasia and there is a scarcity of study in Indian context.

- A very few empirical data available in the literature on acoustic analysis of speech errors of Kannada speaking Broca's aphasic individuals.

Chapter II

Review of literature

The expressive language of individuals with aphasia contains both linguistic and non-linguistic deficits. The various linguistic deficits constitute loss of verbal fluency, word finding difficulty, disturbance in repetition, loss of grammar and syntax, paraphasic errors and difficulty in auditory comprehension; which varies according to the type of aphasia. Apart from these linguistic errors, the expressive language of individuals with aphasia commonly contains speech production errors such as difficulty in coordinating various articulators and deficits in laryngeal control.

The speech production deficits exhibited by person with aphasia are of two types-phonological errors and phonetic errors (Blumstein, Cooper, Goodglass, Statlender & Gottlieb, 1980). Phonological errors are characterized by substitution of phonemes of a particular language whereas the second type, phonetic errors represent articulatory distortions of a particular phonemic target.

The type of speech production deficit in an individual with aphasia, whether phonetic or a phonemic error depends on the type of aphasia. According to Goodglass and Kaplan (1972), phonemic errors are more produced by person with posterior fluent aphasia; meanwhile a person with anterior nonfluent aphasia produces deficits which are more phonetic in nature (Luria, 1966).

Even though speech production deficit is a common manifestation of individuals with aphasia, these deficits are more evident in individuals with Broca's aphasia. In 1973, Blumstein studied the phonological errors seen in anterior and posterior aphasia. He found a large number of similar features in the phonological patterns exhibited by both the groups and concluded that, the speech of an individual with anterior aphasia may compromise for both phonemic as well as phonetic disintegration. But this is not true every time because these individual often exhibit extreme phonetic distortion which is perceived by the listener in terms of a different phonetic category from the target. For example, the substitution of the sound [b] with [p] is the substitution of one phonemic category with other, but at the same time it can also be due to a timing error in laryngeal initiation.

So in individuals with anterior aphasia, a low-level timing error also co-exists. Investigations of the phonetic patterns of speech have shown that individuals with anterior aphasia shown errors of timing, articulatory coordination and laryngeal control (Kurowski, Blumstein, Palumbo, Waldstein, & Burton, 2007).

Some of the research findings in the area of speech production deficits in Broca's aphasia are explained in the following sections. They are;

a) Errors in timing

Most common speech production error in anterior aphasics is the errors of timing. The conclusion has been drawn based on examination of voicing in the production of stop consonants and nasal consonants. Voicing in stop consonants is measured by spectrographic analysis of voice onset time. Voice onset time (VOT) is defined as the time duration between the release of burst of a stop consonant to the onset of glottal pulse (Blumstein et al., 1980). Voiced stop consonants would have a short lag VOT ranging from 0 to 25 msec whereas voiceless stop consonants have a long lag VOT ranging from approximately 30-80 msec.

In terms of VOT, a phonemic error or literal paraphasia can be defined as a substitution error in which VOT value of the target word falls within the VOT of opposite phonetic category. In contrast, a phonetic error would be characterized by VOT value for a particular target falls within or outside the normal range of VOT for the voiced and voiceless categories. Blumstein, Cooper, Zurif, and Caramazza (1977) reported that individuals with anterior aphasia can perceive the phonetic contrast between voiced and voiceless stops, even though these individuals produced both phonemic and phonetic error.

Blumstein et al (1980) suggested that, speech of individuals with Broca's aphasia has a large area of overlap between the voiced and voiceless categories when compared to Wernicke's and conduction aphasia in the production of stop consonants, suggestive of a deficit in temporal coordination of these articulatory gestures. The conclusion was based on the analysis of phonetic and phonemic deficits in the speech production of four Broca's, four Conduction, five Wernicke's aphasic individuals and an individual with dysarthria. Thirty monosyllabic real words containing initial stop consonant [p t k b d g] followed by the vowel [a] were used as stimuli. The target productions by the participants were measure for VOT using oscillography- a computer-controlled program.

The result also showed that Broca’s aphasics exhibited more severe speech production deficit than Conduction aphasics, whose deficits are more severe than individuals with Wernicke’s aphasia. Even though dysarthria can co-exist with anterior aphasia especially Broca’s aphasia, the comparison of VOT of Broca’s aphasic speech with that of dysarthria revealed that individual with dysarthria produced longer VOT of 150 msec for voiceless consonants where as individuals with Broca’s aphasia never produced voiceless consonants which were longer than 150 msec in VOT. The authors of the study concluded that timing errors seen in speech of individuals with Broca’s aphasia is unique and is not due to any co-morbid conditions existing with the disorder. But the drawback of the study was that it focused only on timing errors and no emphasis was given on other production deficits seen in these individuals.

Error in timing is also noticed in the production of nasal consonants in individuals with Broca’s aphasia. The deficits in Broca’s aphasia are more prominent while producing nasal consonants because spectral characteristics of nasal consonants are formed by the resonances of the pharyngeal, nasal and oral cavities. Production of a nasal consonant requires coordination of the following structures- lowering of the velum to open the velopharyngeal port, closing of the oral cavity for the sound to propagate through nasal cavity, followed by closure of velopharyngeal port along with release of oral closure into the next vowel. The propagation of sound through the nasal cavity results in the occurrence of nasal murmur prior to the release of the oral closure.

In the production of nasal consonants, the duration of murmur is an objective measured acoustic parameter which is an indicative of timing of the laryngeal mechanism. Kurowski et al., (2007) studied the nasal consonant production by five individuals with Broca's and two individuals with Wernicke's aphasia. The aim of the study was to investigate the acoustic patterns of nasal consonants and the accompanying lesion sites. The study also aimed to find out, whether individuals with Broca's aphasia show articulatory implementation deficits in nasal consonant production and the factor or combination of factors that are impaired in the production of nasal consonants such as timing, articulatory coordination and laryngeal control. The participants were within the age range of 54 to 68 years with a mean age of 61.5 years. Each participant produced real word mono syllables beginning with a nasal consonant [m,n], followed by one of the vowel [i, e, a, o, u]. The recorded responses were analyzed using a software editor – BLISS. They measured various parameters such as nasal murmur duration, local and global amplitude change within the nasal murmur. The authors found that, in individuals with Broca's aphasia, the murmur duration for nasal consonants is shorter and tightly clustered than in normal speaking individuals which indicated the presence of abnormal laryngeal excitation in these individuals. Apart from this, these individuals showed impairments in the value of maximum local amplitude difference. But the study was done in English language, where the target stimuli (CV) were embedded in English monosyllabic words and ths study had a smaller sample size of 5 subjects.

b) Deficits in articulatory implementation

The speech of individuals with anterior brain damage is characterized by the presence of errors in sound structure. Speech errors of individuals with anterior aphasia consists of substitution error in which one phoneme is substituted for another or the order of the phoneme is transposed. This can be the result of an impairment in phonological selection or planning and an impairment in articulatory implementation (Blumstein et al., 1980).

Investigation of phonetic pattern of speech has shown that individuals with Broca's aphasia have impaired articulatory coordination, which manifested as errors in the production of speech sounds which require coordinated movements of two articulators at a time.

Shankweiler and Harris (1966) reported that individuals with Broca's aphasia show particular difficulty with clusters. The frequent occurrence of errors of voicing and nasalization and the integrity of the vowels are indicative of disturbance of coordinated sequencing of several articulators. The authors arrived at a conclusion based on study of phonetic disintegration of five individuals who were diagnosed as having Broca's aphasia. The study aimed at analyzing the speech of these individuals at the phonological level. For the same purpose, two hundred real word monosyllables were used as stimuli and the production of various phonemes and clusters were analyzed.

It was found that the fricatives, affricates and some consonant clusters were the most misarticulated sounds by the participants. It was noted that there was no sharply localized defects of articulators in any of the participants and also the participants were able to correctly produce lingual consonants correctly which indicated a difficulty in coordination of various articulators in individuals with Broca's aphasia. But the major shortcoming of the study was that, the participants were having wide spread lesion and not confined to anterior portion of left hemisphere, even though they were diagnosed as having Broca's aphasia. Also, it has to be noted that the stimuli used were monosyllabic words, which can provide less information while assessing task such as articulatory coordination.

For example, during the production of nasal consonants, the articulatory coordination deficits will be manifested as variability in velar gestures affecting velum height and slope of velar lowering (Itoh, Sasanuma, & Ushijima, 1979; Itoh, Sasanuma, Hirose, Yoshioka, & Ushijima, 1980), premature occlusion of the velar port (Ziegler & Cramon, 1985) and inappropriate velar lowering and a high degree of velar movement variation (Katz, Machetanz, Orth, & Schonle, 1990).

Articulatory coordination is highly essential during the production of a nasal consonant which is followed by a vowel. Because during the production of nasal consonant, there should be coordination of independent articulators namely closure of oral cavity along with opening of velopharyngeal port for the nasal murmur production followed by rising of velopharyngeal port and the release of the oral cavity closure into the following vowel.

A comparison of amplitude of the last two pulses of nasal murmur with the first two pulses of following vowel will provide information about the articulatory coordination in both normal speaking individuals and individuals with aphasia. Abnormal patterns implicate difficulty in coordination of velum movement prior to the release of oral closure.

According to Kurowski et al., (2007), in individuals with Broca's aphasia, the amplitude changes at the release of the nasal consonant is weaker when compared to normal speaking individuals and those having Wernicke's aphasia. This can be attributed to the velum being too open at the release of nasal murmur or closing too slowly at the release of oral constriction. The consequence is that there is a loss of energy through the oral cavity, thus weakening the amplitude change at the point of nasal release. But the conclusions arrived were based on the findings from limited number of subjects with Broca's aphasia.

c)Deficits in laryngeal control

Other than timing and coordination deficits in aphasics, studies also documented that the aphasic individual also manifest impairment in laryngeal control. In order to produce a sustained laryngeal excitation; several articulatory mechanisms are required such as adequate adduction of the vocal folds and modification of supralaryngeal cavity like lowering the larynx and expanding the pharyngeal volume (Stevens, 1998). A failure to adduct the vocal fold or expansion of laryngeal volume would result in reduced amplitude of glottal excitation and inability to sustain phonation.

Voicing in fricative consonants is a good measure of laryngeal excitation which also provides information about timing of the articulators. During the production of a voiced fricative there will be active vibration of the vocal folds. So the distinction between voiced and voiceless fricatives has been made based on the presence or absence of laryngeal excitation throughout the duration of fricative noise. Studies have shown that presence of at least 30ms of glottal excitation at the beginning or end of frication noise can be considered as voiced (Pirello, Blumstein & Kurowski, 1997).

Apart from presence of glottal excitation, voiced and voiceless fricatives are differentiated based on certain other parameters such as the duration of fricative noise (Crystal & House, 1988), the pattern and extent of fundamental frequency transition into the following vowel (Stevens, Blumstein, Glicksman, Burton & Kurowski, 1992) and the presence or absence of glottal excitation (Kurowski, Hazen, & Blumstein, 2003).

The insufficiency in laryngeal excitation can be manifested as reduction in overall spectral energy of the consonants also. In individuals with Broca’s aphasia, there is a weak energy throughout the frequency spectrum of a fricative noise (Harmes, Daniloff, Hoffman, Lewis, Kramer & Absher, 1984). The laryngeal control deficit also emerge in the production of stop consonants where individuals with Broca's aphasia show, weaker high frequency energy for these sounds (Shinn & Blumstein, 1983).

Laryngeal deficits also have an effect on prosody which is manifested as overall restrictions in fundamental frequency and greater variability in fundamental frequency (Cooper, Soares, Nicol, Michelow, & Goloskie, 1984; Harmes et al., 1984; Kent & Rosenbek, 1983; Ryalls, 1982). Individuals with Broca's aphasia have shown reduced proficiency in implementing lexical tone (Gandour et al., 1986).

It is noted that difficulty in producing fricative and affricate sounds is a common feature shared between phonetic disintegration in individuals with Broca's aphasia and other disorders of articulation. The reason is that, fricative sounds require the use of more muscles and closer control of the amount and timing of movements than other consonants such as stops (Shankweiler et al., 1966, Sarno, 1972).

Kurowski et al, (2003) examined the acoustic properties of voicing in fricatives in three individuals with Broca's aphasia. The study aimed at examining the production of voicing in fricative consonants in both citation form and in phonetic context by individuals with Broca's aphasia. The study was carried out on two males and one female, who were in the age 65 years, 55 years and 54 years respectively. The stimuli used consisted of consonant-vowel syllables beginning with the fricatives [s, z] followed by one of the vowels [I, e, a, o, u]. The participants produced the target words both in isolation and in sentence form- following a voiceless velar stop consonant and following a voiced velar stop consonant. The target stimuli produced by the participants were acoustically analyzed using a software waveform editor and the parameters such as presence of glottal excitation, the patterns of glottal excitation in the fricative noise interval and the duration of fricative noise were measured.

It has been found that the production of voiced and voiceless fricatives showed more overlap in the amplitude of glottal excitation. The result suggested that individuals with Broca's aphasia do not have sufficient laryngeal control to distinguish voiced from voiceless fricative. Another finding was that, in individuals with Broca's aphasia, the amplitude of glottal excitation were lower when compared to normal speaking individuals. This is indicative of a failure to appropriately adduct the vocal folds for laryngeal excitation or due to inability to expand the volume of the vocal tract resulting in reduction in amplitude of glottal excitation and inability to sustain glottal excitation. But all the three participants were able to maintain appropriate fricative duration differences between the voiced and voiceless fricatives. The authors concluded that the locus of the speech production is not at the higher stages of speech production involving phoneme selection or planning, but in laryngeal control too. One of the downside of the study is that the authors analyzed perceptually correct utterances only. That is, individuals with Broca's aphasia may also produce phonemic paraphasias involving the voicing distinction which were not considered for acoustical analysis. Another shortcoming is that the study was limited to a smaller sample size of three participants.

Another measure of laryngeal control is the local and global amplitude change for the nasal consonant. Local amplitude measure the variation in amplitude across the murmur pulses. Global amplitude change provides information about the overall amplitude change across the nasal murmur. Individuals with aphasia shown impairment in the value of maximum local amplitude difference (Kurowski et al, 2007). This pattern of deficit is indicative of a deficit in laryngeal control in these individuals.

Production of nasal consonants requires coordinated movement of various articulators involved whereas vowels are produced with an open vocal tract with limited movement of articulators. Various research findings support that speech production deficits in individuals with Broca's aphasia will manifest during the production of vowel also. A few deficits are explained below.

Vowel production in aphasia

Vowel formants are the spectral peaks of the sound spectrum of the voice (Fant, 1960). Formant frequencies are different from the fundamental frequency of the individual and occur due to resonance of the human vocal tract. It is often measured as an amplitude peak in the frequency spectrum of the sound using a spectrogram. When compared to other events in spectrogram such as VOT which requires coordination of laryngeal and supralaryngeal structures, vowel formants are measured from the steady state portion of vowel. That is, VOT has more temporal components which require the appropriate timing of two articulators whereas vowel formants are more stable acoustic events.

Even though formants are relatively stable events, they are greatly influenced by the characteristics of the supralaryngeal tract. Also, age of the individual has an influence on the variability of formant frequencies (Eguchi & Hirsch, 1969). The variability of formant frequency of children is almost twice as large as those found in adults. This is due to children being unable to sufficiently adjust their vocal tract configurations like adult manner (Oller & MacNeilage, 1983). When compared to elder children, younger children demonstrate greater variability in second formant frequency (F_2) production. The inability to maintain a stable formant frequency on repeated trials is indicative of lack of precise control of vowel production in children. Investigations done of vowel production by individuals with aphasia revealed that these individuals show less precise control for vowel production. Also, individuals with aphasia show greater instability of the second formant frequency which is indicative of poor precise control of supralaryngeal tract which is similar to that seen in children.

In normal speaking individuals, vowels are produced without much articulatory contacts and are produced with open vocal tract. But spectrographic analysis of speech of individuals with aphasia shown that there is more variation in the formant frequencies of vowels produced by these individuals (Keller, 1975). Similarly, it has been noticed that the vowels produced by a person with dysarthria shows less variation in formant frequency production. Whereas the formant variations in normal speaking individual's speech falls in between that of individuals with aphasia and those with dysarthria Even though Individuals with aphasia maintain good supralaryngeal control than individuals with dysarthria, which is responsible for formant frequency characteristics, these individuals exhibit greater variation compared to control.

Ryalls (1981; 1986) reported that, even though formant frequency variations for vowels are more in individuals with both Broca's and Wernicke's aphasia when compared to normal speakers and individuals with dysarthria (Keller, 1975), individuals with Broca's aphasia shows greater variability in vowel duration than normal speakers. The conclusion arrived based on the acoustical analysis of vowel production by five individuals with Broca's aphasia, seven Wernicke's aphasia and one individual with Wernicke's aphasia. The study aimed at investigating the intra-individual variability in vowel production in repeated productions. The stimuli used consisted of monosyllabic words with vowels in medial position. The target responses produced were recorded and were analyzed for vowel duration and formant frequencies following normalization of formant means. It was found that the individuals with Broca's aphasia showed greater average standard deviation than those with Wernicke's aphasia, whose average standard deviations were greater than that of normal speakers. The study concluded that aphasic patients maintain good control of acoustic features, but these individuals are more variable as a group.

Other than variability in formant frequencies, individuals with Broca's aphasia also have prolonged vowel duration when compared to normal speaking individuals (Shankweiler, Harris & Taylor, 1968).The researchers arrived at a conclusion based on the electromyographic study done on five individuals with Broca's aphasia. The authors found out that the vowel duration was longer than the normal speaking individuals. The similar findings are reported in younger children who presented longer than average segment duration as well as greater duration variability (Kent & Forner, 1980).

Need for the study

- Equivocal findings were reported in the literature about the articulatory implementation deficits in individual with Broca's aphasia. That is many researchers reported that the speech of these individuals shown timing and coordination errors, but a few findings were not supporting it.
- The speech errors exhibited by aphasics are timing, coordination and laryngeal control. This arise the question of, Do individuals with Broca's aphasia show single speech error or a combination of errors, which needs to be addressed.
- Review of literature shows most of the studies were done on smaller population consisted of 2-5 subjects.
- There is a very few empirical data available in the literature on acoustical analysis of speech errors of Kannada speaking aphasics.
- From the above points, there is a need to study the acoustic pattern of speech production (nasal consonants and vowels) errors in individuals with Broca's aphasia.

Aim of the study

To explore the timing, laryngeal control and articulatory coordination deficits in individuals with Broca's aphasia

The objectives of the study,

- To investigate the timing errors by measuring the nasal murmur duration in individuals with Broca's aphasia.
- To measure the laryngeal control deficit by quantifying the local amplitude change (amplitude change across murmur pulses) and global amplitude change (amplitude difference between the first and last pitch period of murmur) throughout nasal murmur.
- To investigate the articulatory coordination deficit by measuring the amplitude change at the point of release of nasal consonant into the following vowel.
- To compare the vowel duration between individuals with Broca's aphasia and normal speaking individual.
- To analyze the acoustic vowel space characteristics between individuals with Broca's aphasia and normal speaking individuals by measuring the first and second formant frequencies.

Chapter III

Method

Participants:

Two groups of participants were taken for the study; Group-I consisted of twelve individuals with Broca's aphasia in the age range of 23-62 years with a mean age of 43 years and group-II consisted of age and gender matched twelve neurologically normal individuals.

Subject selection criteria for group I:

- Subjects should have diagnosed as Broca's aphasia based on Western aphasia battery (WAB) (Kertesz, 1982) assessment tool, which was supported by neuro-diagnostic tests such as computerized tomography scan or magnetic resonance imaging.
- Subjects should have normal functioning prior to the cerebro-vascular accident (CVA) of left hemisphere.
- Subjects should have adequate physical fitness at the time of testing.
- Subjects should be right handed individuals
- Subjects should have Kannada as their mother tongue (native language).
- Individuals with right hemisphere damage were excluded from the study.

Subject selection criteria for group-II:

- Subjects should be right handed individuals
- Subjects should be native speakers of Kannada

- None of the individuals reported any history of speech, language, hearing and other neurological deficits.

Stimulus material:

The stimulus material consisted of six consonant-vowel (CV) bisyllabic words in Kannada, beginning with nasals [m] and [n] followed by long vowels [a:], [i:] and [u:]. The total number of words used were six in number and they were /ma:vu/, /mi:nu/, /mu:gu/, /na:nu/, /ni:Ru/ and /nu:lu/ (2 nasals x 3 long vowels). Care was taken to place the target sounds in the bisyllabic words in the initial syllable position. Each of the target words were printed on a card of 8 x 12cm size.

Procedure:

The subjects were made to sit comfortably in a quiet room and were asked to read orthographically presented stimuli for 3 times at a comfortable pitch, loudness and rate. The participants who unable to read correctly; were asked to repeat the target word/stimuli thrice after the examiner. The total number of tokens produced by participants was 18 (6 words x 3 trials). The target stimuli produced by the participants were audio recorded using a digital voice recorder (Olympus audio recorder, WS-100 model, Japan). The recorded responses were transferred into a computer memory and were analyzed using a waveform editor software – Brown lab interactive speech systems (BLISS) (Mertus, 2002). The first and second formant frequencies of the long vowels were measured using PRAAT software (Boersma & Wernick, 2005).

Analyses:

Two experienced speech language pathologists (SLPs) judged the accuracy of the target sounds produced by individuals with Broca's aphasia and words which correctly and accurately produced were subjected to acoustical analysis. Responses of distorted production of the final syllable were considered for analysis whereas responses with incorrect production of nasal consonants were excluded. The acoustical parameters measured from the target words were;

1) nasal murmur duration (*timing measure*)

2) local and global amplitude change measure (*laryngeal control measure*)

3) amplitude change at the point of release of nasal murmur into the following vowel (*articulatory coordination measure*)

4) vowel duration

5) first and second formant frequencies.

The explanations for the acoustic parameters are as follows;

1) Nasal murmur duration (timing measure)

Nasal murmur duration is measured from onset of murmur (L0) to the point of release of oral cavity closure (R0). It is measured in millisecond. Figure 1 shows the murmur duration measurement for /ma/ syllable.

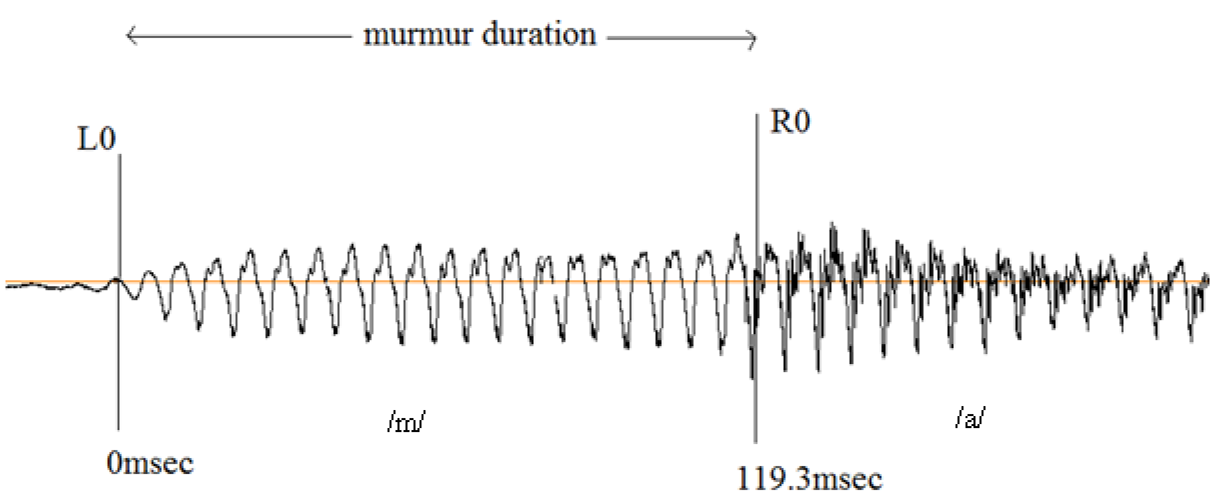

Figure 3.1: Murmur duration measurement for /ma/ syllable.

2) **Local and global amplitude change (Laryngeal control measure)**

a) **Local amplitude change measure**

It measures the variation in amplitude across the murmur pulses. It provides information about variation in excitation of laryngeal source.

- In order to measure local amplitude change, the entire murmur duration is divided into 3 segments namely initial, medial and final. In each segment of the murmur, consider 2 glottal pulses and measure the amplitude of the first harmonic. Totally amplitude of 6 points across the nasal murmur is measured. Figure 2 displays the local amplitude change measurement.
- In order to measure the first harmonic of the 6 points, the cursor is placed on each of the 6 pulse periods corresponding to initial, medial and final portions of the murmur and a Discrete Fourier Transform (DFT) analysis is employed to locate the first harmonic and measured its amplitude.
- In the same way, a DFT analysis is done for vowel by placing the cursor on the 3rd pitch pulse of the vowel to locate its first harmonic and its amplitude is measured. The initial two pulses of the vowel might fall in the onset state of vowel and might have weaker amplitude compared to the 3rd pitch pulse. Hence the 3rd pitch pulse of the vowel is considered for normalization.
- Normalization of vowel amplitude is done by subtracting the amplitude of the 3rd pitch pulse of vowel from amplitude measured at each of the 6 points in the nasal murmur.

- The scores obtained from 6 points are compared to find out the change over the course of the murmur and it is measured as the first harmonic difference (local) between each of the 6 data points corresponding to consecutive pulse periods of the murmur. The obtained six values which is representative of amplitude change across the murmur pulse period are averaged for local amplitude change.

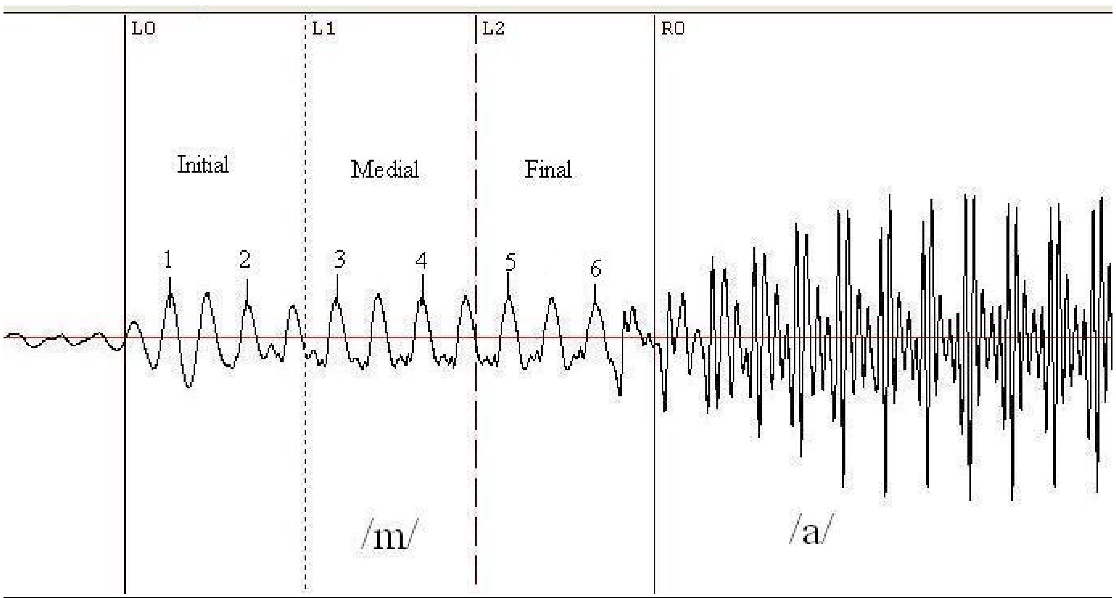

Figure 3.2: Local amplitude change measurement.

b) Global amplitude change measure

It provides information about the overall amplitude change across the nasal murmur. It is measured by subtracting the normalized amplitude value of first pulse period of murmur from the last pulse period of the murmur (i.e. amplitude of 6^{th} pulse period- amplitude of the 1^{st} pulse period).

3) Articulatory coordination measure

The amplitude of last two pulses of nasal murmur and first two pitch period of vowel are measured by DFT analysis. Then the local amplitude measure of last two pulses of nasal murmur are averaged and subtracted with the average of first two pitch period of vowel to find out the energy or amplitude difference at the point of release of nasal murmur into the following vowel. Figure 3.3 shows the measurement of amplitude/energy difference at nasal consonant release.

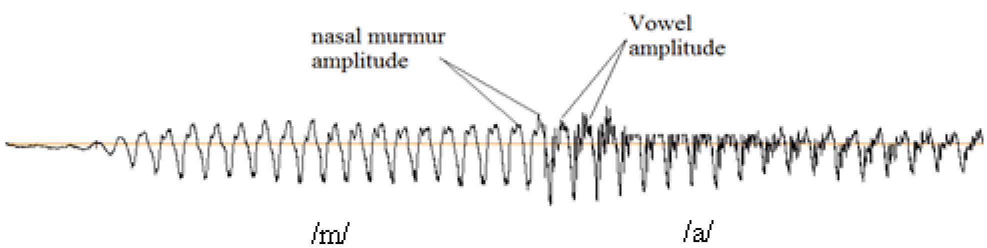

Figure 3.3: Amplitude/energy difference at nasal consonant release.

4) Vowel duration

Duration of long vowel of the initial syllable is measured from the onset of vocal excitation (voiced pitch pulse) at the release of the nasal consonant (L1) to the termination of voiced excitation (L2). It is measured in milliseconds. Figure 3.4 shows the vowel duration measurement for /ma/ syllable.

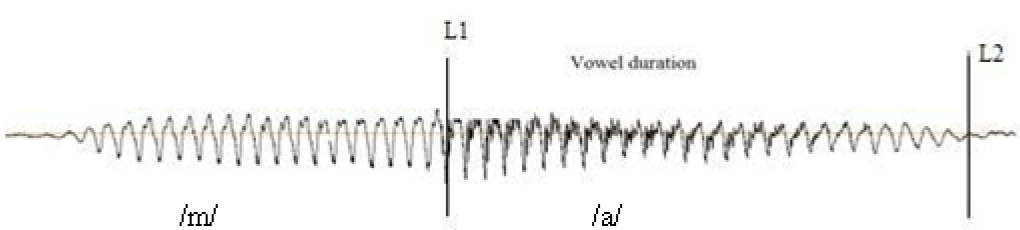

Figure 3.4: Vowel duration of /ma/ syllable.

5) Acoustic vowel space characteristics analysis

The first (F_1) and second (F_2) formant frequencies were measured using PRATT software by placing the cursor in the steady state portion of the long vowels |a:|, |i:| and |u:| in the target words. The obtained values for each vowel were averaged for 3 trials. The values were plotted in XY-plane with second formant frequency on X-axis and first formant frequency on Y-axis to obtain the acoustic vowel space.

Statistical analysis

The obtained data were tabulated and subjected to statistical measures. Statistical Program for the Social Sciences (SPSS) software (version 18.0) package was used for statistical analysis. Descriptive statistics and independent t-test was used to compare between the two groups.The statistical analysis was carried out in 2 stages

Stage-1

A descriptive statistics was done to obtain the mean (M) and standard deviation (SD) for both the groups for the mentioned acoustic parameters. A comparison between the groups was done based on the mean and standard deviation obtained to find out whether there is any difference between the groups.

Stage-2

Statistical test, Independent t-test was used to find the significant difference between individuals with aphasia and normal speaking individuals for the acoustic parameters measured: nasal murmur duration, local and global amplitude change, amplitude change at the point of release of murmur into the vowel and vowel duration.

Chapter-IV

Results and Discussion

The study was aimed at exploring the timing, laryngeal control and articulatory coordination deficits in individuals with Broca's aphasia in comparison with age and gender matched normal speaking controls.

Twelve Broca's aphasic individuals compared with age and gender matched normal controls on bisyllabic words in Kannada beginning with nasal consonants. The acoustic parameters were measured and compared between the two groups.

The following statistical procedures were carried out for group comparison:

1. Descriptive statistics was done to obtain the mean and standard deviation for both individuals with Broca's aphasia and normal speaking individuals across the variables such as nasal murmur duration, vowel duration, local amplitude change, global amplitude change, amplitude difference at nasal consonant release (articulatory coordination) and first and second formant frequencies of the vowel.
2. An independent t-test was employed to compare significant difference between the groups.

These results are discussed on the following headings;

1. Comparison of nasal murmur duration between the groups

The results indicated that, the overall mean nasal murmur duration was longer in individuals with Broca's aphasia (84.16) when compared to normal speaking individuals (60.96). Table 4.1 shows the mean and standard deviation of nasal murmur duration across the groups.

Table 4.1*: Mean and standard deviation for nasal murmur for group I and group II*

Parameter	**Individuals with Broca's aphasia (Group I)**		**Normal speakers (Group II)**	
	Mean (msec)	**SD**	**Mean (msec)**	**SD**
Nasal Murmur duration	84.16	26.11	60.96	12.16

Apart from high mean value, individuals with Broca's aphasia had larger standard deviation (26.11) for murmur duration when compared to normal speaking individuals (12.16) which indicates higher variability in the murmur duration production in individuals with Broca's aphasia. Results of independent t-test revealed that there is significant difference between group I and group II on nasal murmur duration at 0.05 level. That is, in individuals with Broca's aphasia, it was found that the nasal murmur duration was significantly longer; when compared to normal speaking individuals. Figure 4.1 shows the mean nasal murmur duration between the groups.

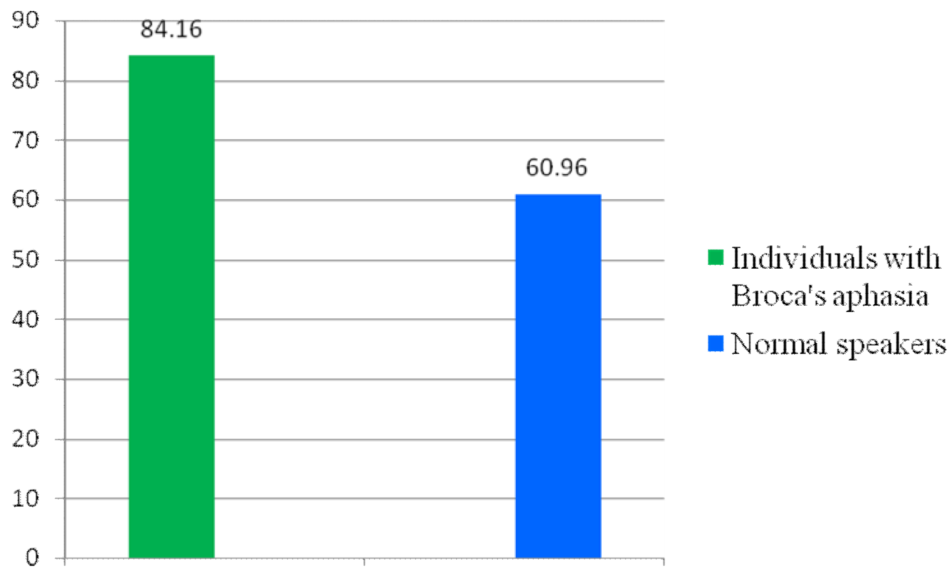

Figure 4.1: Mean nasal murmur duration for group I and group II

The above findings is in consonance with Kurowski et al's (2007) study, who reported that individuals with Broca's aphasia had longer murmur durations than age-matched normal speakers and had larger standard than normal controls. Also, the present findings support the findings of Blumstein et al., (1980) who reported that the individuals with Broca's aphasia exhibited VOT overlap for voiced and voiceless stop consonants.

Hence, the present findings (larger murmur duration in Broca's aphasia) suggesting a temporal (timing) deficits in the articulatory gestures in these individuals.

2. Comparison of local amplitude change of nasal murmur between the groups

The amplitude change within the nasal murmur pulses for both the groups were compared. Results of the descriptive statistical analysis revealed that the mean and standard deviation values for both the groups, are tabulated in table 4.2.

Table 4.2: *Mean and standard deviation for local amplitude change across the group*

Parameter	**Individuals with Broca's aphasia (Group I)**		**Normal speakers (Group II)**	
	Mean (msec)	**SD**	**Mean (msec)**	**SD**
Local amplitude change	1.05	0.47	0.97	0.57

It was noted from the Table 4.2 that the local amplitude change across murmur was higher in individuals with Broca's aphasia (1.05); compared to that of normal speaking individuals (0.97). Figure 4.2 shows the mean local amplitude change for group I and group II. Results of independent t-test revealed that the difference in local amplitude change between group I and group II was not statistically significant.

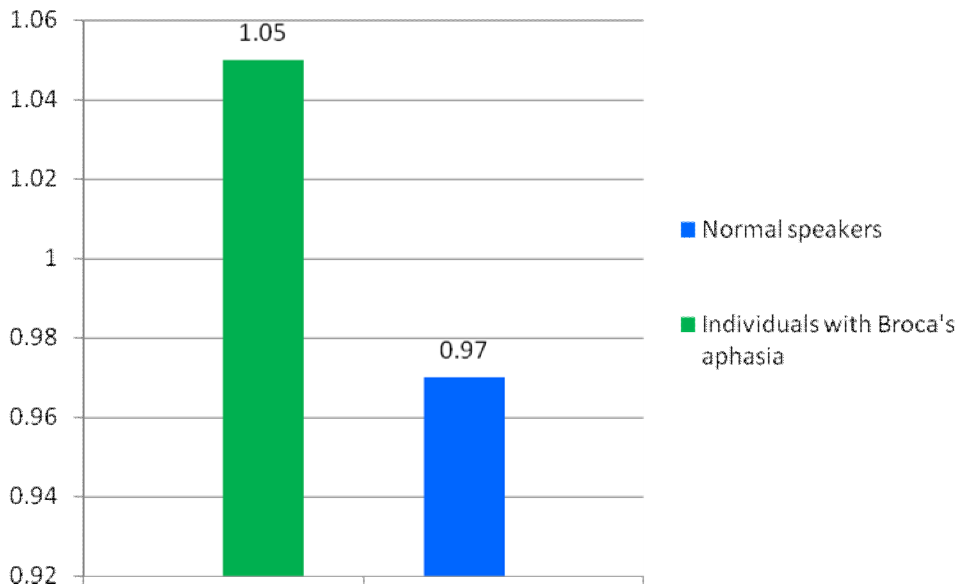

Figure 4.2: Mean local amplitude change for group I and group II

Though there is no statistically significant difference between the groups, the results of the present study indicated that the individuals with Broca's aphasia had higher mean value for local amplitude change which is in consonance with the findings of Kurowski et al.'s (2007) study, who reported that these individuals had high mean values when compared to individuals with Wernicke's aphasia and normal speaking individuals. Kurowski et al., (2007) reported that among the three groups studied- Broca's aphasia, Wernicke's aphasia and normal speakers, individuals with Wernicke's aphasia and normal speakers showed less local amplitude change when compared to individuals with Broca's aphasia.

Also, the findings of the present study are in consonance with Kurowski et al (2003) study who reported that individuals with Broca's aphasia shown less distinct voiced/voiceless separation and weaker amplitude of glottal excitation for the voiced fricatives. Also, it has been noted that these individuals shows changes in the spectral characteristics of stop consonants (Shinn & Blumstein, 1983) and fricative consonants in utterances which are supportive of the present findings. That is, the local amplitude change of the nasal murmur reflects the laryngeal control. So the impaired (higher value) local amplitude change over the murmur in individuals with Broca's aphasia supports the findings of Shinn et al., (1983); and Kurowski et al.,(2003) which is suggesting of laryngeal control deficits in these individuals.

3. **Comparison of global amplitude change of nasal consonants between the groups**

The difference between normalized amplitude of first and last murmur pulse were calculated, to obtain the global amplitude change in the nasal consonant and the obtained values were compared across the groups. Table 4.3 shows the mean and standard deviation of global amplitude change for both the groups

Table 4.3*: Mean and SD for global amplitude change between the groups*

Parameter	**Individuals with Broca's aphasia (Group I)**		**Normal speakers (Group II)**	
	Mean (msec)	**SD**	**Mean (msec)**	**SD**
Global amplitude change	5.65	2.58	4.32	1.71

It was found that mean and standard deviation of global amplitude change for individuals with Broca's aphasia was high (5.64 and 2.56, respectively) compared to the normal speaking individuals (4.32 and 1.71, respectively).

The mean and standard deviation values of global amplitude change was higher for the long vowels in individuals with Broca's aphasia, a comparison across the group using independent-t test revealed that the differences were not statistically significant.

The above results indicated that individuals with Broca's aphasia have high mean and standard deviation for global amplitude change. This finding is in consonance with

Kurowski et al.'s (2007) study, who reported that, the individuals with Broca's aphasia had larger mean global amplitude change, compared to normal speaking individuals.

There is evidence from the literature that, individuals with Broca's aphasia shown prosodic impairments like restrictions in fundamental frequency (Cooper et al., 1984) and less proficiency in correctly implementing lexical tone (Gandour et al., 1992) in their speech. Prosodic impairments and poor in lexical tone production are due to the deficits in laryngeal control in individuals with Broca's aphasia. Similarly, higher values in the local and global amplitude change across the nasal murmur in the present study suggests laryngeal control deficits in individuals with Broca's aphasia.

4. Comparison of amplitude difference at nasal consonant release (articulatory coordination) between the groups

The amplitude difference between the last two murmur pulses of the nasals and the first two pitch pulses of vowel in individuals with Broca's aphasia and normal speakers were measured and compared. The mean and standard deviation values of amplitude change at the point of release of nasal murmur into the following vowel (articulatory coordination) for both the groups are given in the table 4.4. Results of independent t-test revealed that there is no significant difference between the two groups in terms of amplitude difference at nasal consonant release.

Table 4.4: *Mean amplitude difference and standard deviation for group I and group II*

Parameter	**Individuals with Broca's aphasia (Group I)**		**Normal speakers (Group II)**	
	Mean	**SD**	**Mean**	**SD**
Amplitude difference at nasal consonant release	1.86	0.67	1.67	0.67

The above findings do not support of Kurowski et al.'s (2007) study, who reported that individuals with Broca's aphasia have low band energy changes. In the present study, higher value of amplitude difference at nasal consonant release in individuals with Broca's aphasia can be attributed to the delayed lowering of velum or inappropriate velar lowering. Due to the delayed velar occlusion, there might be presence of higher nasal energy to the following vowel which resulted in higher value of amplitude difference at nasal consonant release. The present findings support the findings of Ziegler & Cramon (1985) and Katz, Machetanz, Orth, & Schonle (1990)

who also found higher degree of velar movement variations. Hence, the higher amplitude difference at nasal consonant release suggesting the articulatory coordination deficits in individuals with Broca's aphasia.

5. **Comparison of vowel duration between individuals with Broca's aphasia and normal speaking individual**.

The mean and standard deviation of the long vowel produced by both the groups were measured and was compared across the group. The results showed that the mean vowel duration and standard deviation were high for individuals with Broca's aphasia than normal speaking in

dividuals; Table 4.5 summarizes the mean and standard deviation of vowel duration in both the groups. Figure 4.3 shows the mean vowel duration between the groups.

Table 4.5: *Mean vowel duration of the vowel for the groups I and II*

Parameter	**Individuals with Broca's aphasia (Group I)**		**Normal speakers (Group II)**	
	Mean (msec)	**SD**	**Mean (msec)**	**SD**
Vowel duration	237.43	48.56	204.74	36.75

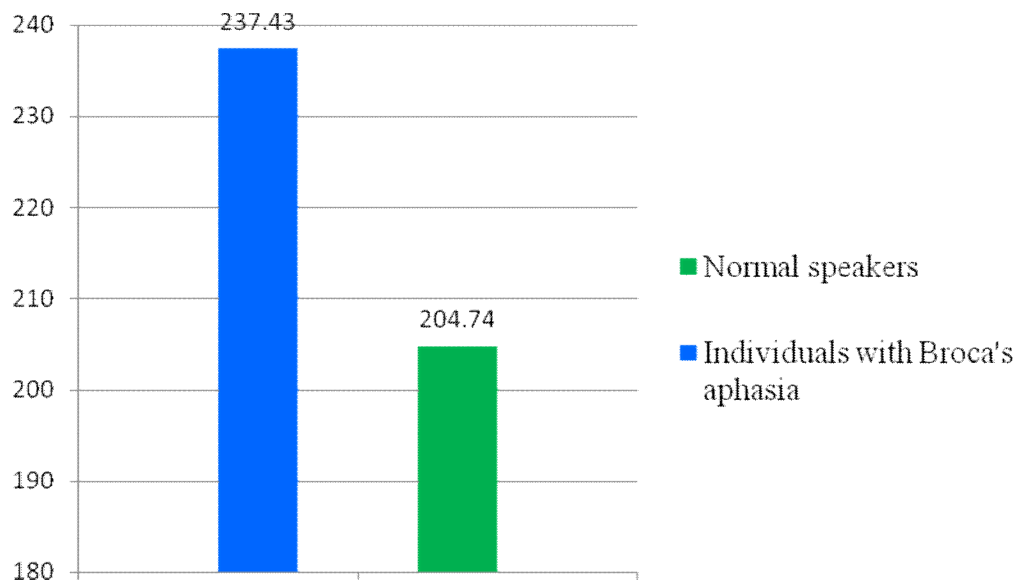

Figure 4.3: Mean vowel duration value for group I and group II

In order to find whether the obtained differences were statistically significant, independent-t test was administered. The results shown that the longer vowel duration in individuals with Broca's aphasia was not statistically significant ($t=1.859$, $p>0.05$)

In individuals with Broca's aphasia, the presence of higher mean and standard deviation of vowel duration can be attributed to longer transition time of the vowel into the following consonant (phoneme).

Ryalls (1981) found significantly longer vowel durations in individuals with Broca's aphasia when compared to normal speakers. Shankweiler et al., (1968) based on his study on five individuals with Broca's aphasia arrived at the same findings as Ryalls (1981). Hence, the present findings supports the findings of Shankweiler et al., (1968) and Ryalls (1981).

6. **Comparison of Acoustic Vowel Space in individuals with Broca's aphasia and normal speaking individuals**

The first and second formant frequencies (F_1 and F_2) were measured for long vowels (first syllable) in the target words using PRAAT software [10]. F_1 and F_2 of 3 trials of vowels /a:/, /i:/ and /u:/ were averaged separately and compared between individuals with Broca's aphasia and normal speaking adults. The F_1 anf F_2 values obtained are given in the Table 4.6. The first and second formant frequency of vowels /i: and /u:/ were high in individuals with Broca's aphasia when compared to normal speaking individuals. Whereas for the vowel /a:/, the first and second formant frequencies were low in individuals with Broca's aphasia than normal controls.

Table 4.6: *Mean F_1 and F_2 of the vowels /a:/, /i:/ and /u:/*

Vowel	**First formant frequency**		**Second formant frequency**	
	Individuals with Broca's aphasia (Group I)	Normal speaking individual (Group II)	Individuals with Broca's aphasia (Group I)	Normal speakers (Group II)
/a:/	726.47 Hz	758.45 Hz	1274.88 Hz	1338.50 Hz
/i:/	405.49 Hz	392.73 Hz	2242.00 Hz	2176.00 Hz
/u:/	479.11 Hz	413.87 Hz	1279.67 Hz	805.13 Hz

A graph was drawn with second formant frequency values on x-axis and first formant frequency values on y-axis to obtain the acoustic vowel space for both the groups as given in Figure 4.5.

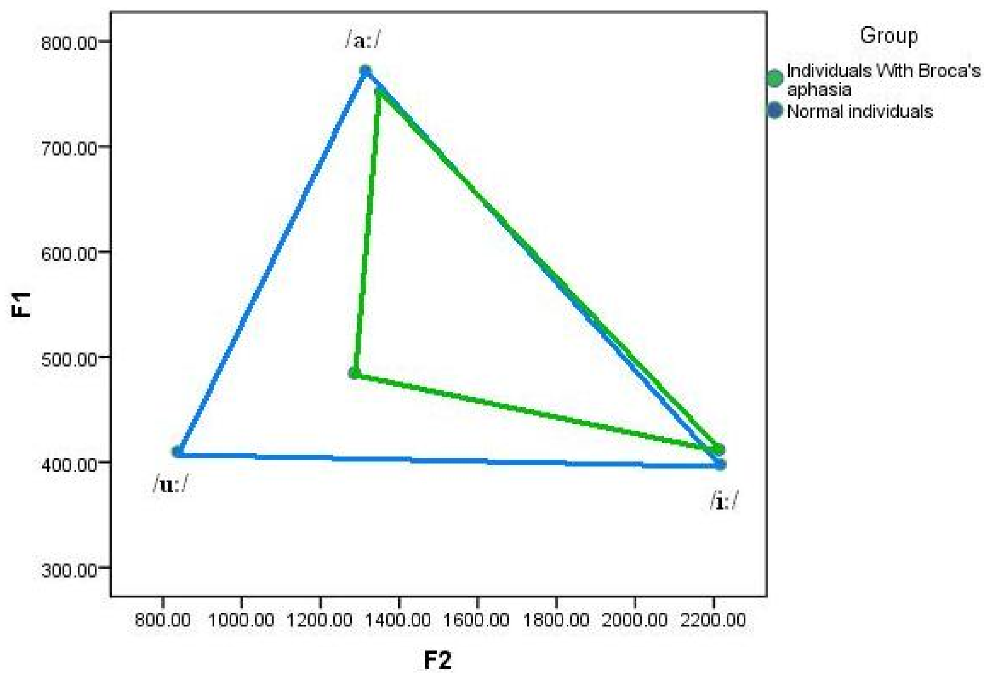

Figure 4.5: Acoustic vowel space in individuals with Broca's aphasia and normal speakers

From the above figure, it is noted that, the acoustic vowel space was relatively narrow and smaller in individuals with Broca's aphasia, when compared to normal speaking individuals. The acoustic vowel space in individuals with Broca's aphasia is shifted anteriorly and upwards towards the right quadrant because of the high first and second formant frequency of the vowel /u:/. First formant frequency (F_1) of vowel /u:/ is influenced by height of the tongue. High F_1 value for /u:/ in individuals with aphasia shows less elevation of tongue (tongue height) while production of the vowel. Also, a high F2 value for /u:/ in individuals with aphasia indicates increased tongue advancement when compared to normal speaking individuals. The results of the acoustic vowel space reveals reduced, restricted and narrow space in individuals with Broca's aphasia suggesting reduced movement of the articulators during the production of vowels.

Chapter V
Summary and Conclusions

The aim of the present study was to explore the timing, laryngeal control and articulatory coordination deficits present in individuals diagnosed as having Broca's aphasia. The objectives of the study were to investigate timing errors by measuring the nasal murmur duration, to measure the local amplitude change by quantifying the local amplitude change and global amplitude change throughout the nasal murmur, to measure the duration of vowel and to compare it with that of normal speakers and to analyze the acoustic vowel space characteristics between individuals with Broca's aphasia and normal speaking individuals by measuring the first and second formant frequencies.

Twelve individuals who were diagnosed as having Broca's aphasia and twelve age and gender matched neurologically normal individuals participated in the study. The stimuli used were bisyllabic words beginning with nasal consonants [m,n] followed by long vowels [a:,i:,u:] were used. The target stimuli produced by both the groups were recorded and were analyzed for nasal murmur duration, local and global amplitude change across the nasal murmur, articulatory coordination by measuring the amplitude difference between the average of last two pulses of nasal murmur and first two pulses of the following vowel, vowel duration, first and second formant frequencies of the vowel and acoustic vowel space was drawn.

The obtained data was treated statistically (Descriptive statistics and independent t-test) to compare between individuals with Broca's aphasia and the normal speakers.

The salient findings of the study after analysis were:

Nasal murmur duration (measure of timing)

- Individuals with Broca's aphasia have longer nasal murmur duration when compared to age and gender matched normal speakers.
- Longer duration of nasal murmur indicates errors in timing present in these individuals.

Local amplitude change (laryngeal excitation measure)

- Individuals with Broca's aphasia have high mean values for local amplitude change when compared to normal speakers.
- High mean value for local amplitude change is indicative of variation in laryngeal excitation during the production of nasal murmur.

Global amplitude change (laryngeal excitation)

- A high global amplitude change value in individuals with Broca's aphasia is indicative of difficulty in maintaining the laryngeal excitation throughout the nasal murmur.
- In individuals with Broca's aphasia, the presence of high local and global amplitude change suggestive of laryngeal control deficits i.e. they have difficulties in sustaining normal amplitude of glottal excitations.

Amplitude difference at nasal consonant release (Articulatory coordination)

- Individuals with Broca’s aphasia have high mean values of amplitude difference at nasal consonant release when compared to normal speakers.
- The results indicates that individuals with Broca’s aphasia have underlying deficits in coordinating various articulators required for the production of nasal consonants such as lips, tongue and velum.

Vowel duration measure

- High mean and standard deviation of vowel duration was measured in individuals with Broca’s aphasia.
- But there was no significant difference between individuals with Broca’s aphasia and normal speakers in terms of vowel duration.

Acoustic vowel space

- Acoustic vowel space in individuals with Broca’s aphasia was shifted anteriorly and upwards towards the right quadrant
- High first and second formant values for vowel /u:/ in individuals with Broca’s aphasia, indicative of less tongue elevation and increased tongue advancement during the production of vowel.
- The acoustic vowel space was relatively narrow and smaller in individuals with Broca’s aphasia indicative of reduced movement of articulatory gestures during the vowel production.

Conclusions of the study

The study reveals several points of interest,

- The present study concluded that the individuals with Broca's aphasia found to have three speech articulatory implementation errors like timing errors, artculatory coordination errors and laryngeal control errors which co-exists in these individuals.
- The measured acoustical parameters like nasal murmur duration, local and global amplitude change, amplitude difference at nasal consonant release, vowel duration and formant frequencies (first and second) has shown higher values in individuals with Broca's aphasia.
- Except nasal murmur duration, other acoustic parameters did not show significant difference between the groups suggesting timing deficits is the most prominent speech error.
- Vowel duration was found to be more in individuals with Broca's aphasia suggesting these individuals sustain vowel for longer duration and delayed phoneme transition.
- Individuals with Broca's aphasia found to have smaller, narrow acoustical vowel space which reflects the higher first and second formant frequencies of /i:/ and /u:/ vowel. The higher formant frequencies suggest reduced tongue height and increased tongue advancement in the articulatory gestures of individuals with Broca's aphasia. However, physiological observation are needed to further support the above view

- The measured parameters were not found to be statistically significant between the groups may be because of many subjects in aphasic group are attendees of speech of speech therapy sessions and the number of speech therapy sessions as a variable was not considered.
- As the measured acoustic parameters had high mean values in individuals with Broca's aphasia as like the standard deviations. Compared to normal controls, individuals with Broca's aphasia had higher value of standard deviation which indicates wider variability of the measured parameters.
- It is an easy method to study the articulatory implementation errors (non-invasive method).

Limitations of the study

- The conclusions of the study are derived based on findings on a population size of 12 subjects.
- Variables such as the site of lesion, extent of lesion and severity of the condition were not controlled.
- The post-onset aphasia period was not considered as a variable.
- The study included Kannada speaking individuals with Broca's aphasia and normal controls. Generalization of the findings cannot be possible in other Indian languages.
- Three out of twelve participants in the study fell in the geriatric age group. It is not clear that age also had any influence on dependent variables of the study, which has to be investigated further.

Implications of the study

- The results of the present study will help the speech clinician to understand the deficits in timing, laryngeal control and articulatory coordination present in individuals with Broca's aphasia
- The results of the study can be taken as baseline before the introduction of the therapy and to compare the efficacy of the therapy.
- The results of the present study also guide the SLPs to plan accordingly in the intervention of programs whether to focus on single speech deficit (timing or laryngeal control or articulatory coordination) or combination of errors.
- The study provides baseline for further studies in speech output deficit in individuals with Broca's aphasia.
- It adds information to the existing literature.

Future research directions

- Studies can be done by considering various place of articulation of nasal consonants (bilabials, retroflex/alveolar) on the dependent variables i.e. nasal murmur, local and global amplitude change, vowel duration, amplitude difference at the nasal consonant release and acoustic vowel space.
- Studies can be planned to explore the effect of vowels (high, low and mid vowels) on the selected acoustic parameters.
- Studies can be done by considering more sample size and also, consider female participants in the future study.
- The speech deficits of individuals with Broca's aphasia can be studied by considering the various stimulus materials like trisyllable and polysyllable.

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