PERCEPTION OF STRESS IN PATIENTS WITH CEREBRO-VASCULAR ACCIDENT

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Dedicated to

My Guru and Guide

(The great source of inspiration)

DECLARARION

*I declare that this thesis entitled "***Perception of Stress in Patients -with Cerebro-Vascular Accidents***" submitted herewith for the award of the Degree of Doctor of Philosophy (Speech and Hearing) to the "University of Mysore, Mysore, is the result of work carried out by me at the All India Institute of Speech and Hearing, Mysore, under the guidance of (Dr. S. Savithri, Ph.D., (Professor & Head, (Department of Speech-Language Sciences, A.I.I.S.H, Mysore. I further declare that the results of this work have not Seen previously submitted for any other degree.*

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Place: Mysore

Date: 10.08.2006

CERTIFICATE

*This is to certify that the thesis emitted "**Perception of Stress in Patients with CereSro-Vascular Accidents**" submitted by H.Rohini for the (Degree of (Doctor of Philosophy (Speech and Hearing) to the University of Mysore, Mysore, is the result of work done by her at the All India Institute of Speech and Hearing, Mysore, under my guidance.*

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"Gratitude is the hardest of all emotions to express
There is no word capable of conveying all that one feels
Until we reach a world where thoughts can be
Adequately expressed in words"

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"A teacher affects eternity, NNo one can tell where her influences stop"

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Abstract

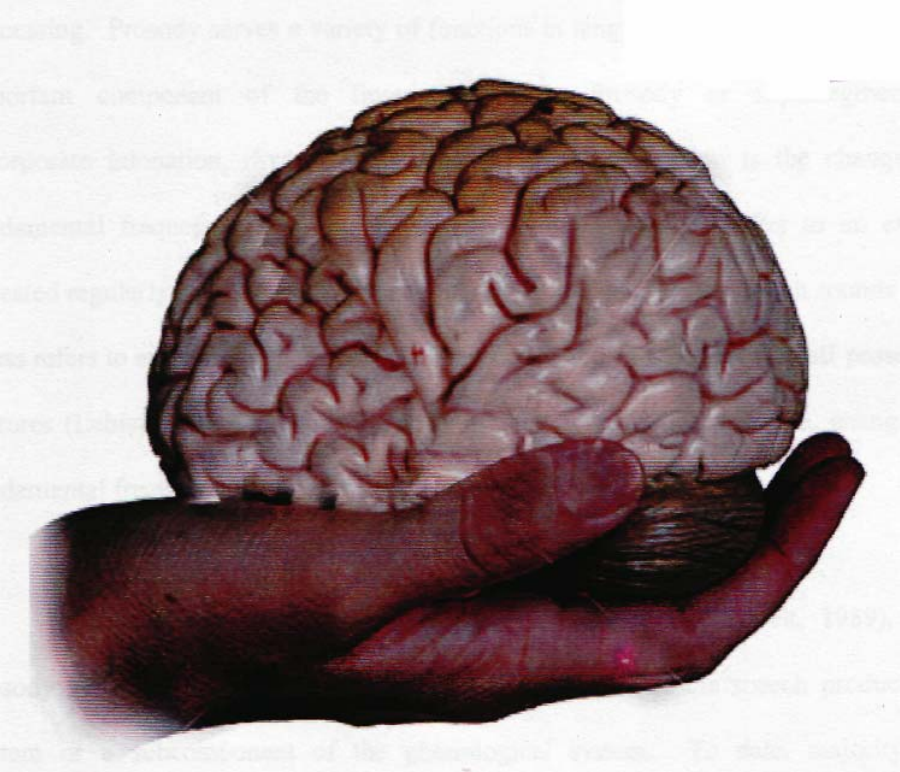
The study investigated perception of stress in subjects with cerebro-vascular accidents (CVA) and normal controls speaking Kannada. The study was designed to examine the effect of CVA, acoustic cue and age on the perception of stress. The following research questions were asked: (1) Are there differences between subjects with CVA and normal controls in perception of stress? (2) Are there differences between LHD and RED (CVA) subjects in perception of stress? (3) Are there differences between young and old CVA subjects in perception of stress? (4) Do LHD and RHD (CVA) subjects use different acoustic cues to perceive stress? and (5) Are there differences between single and multiple cue conditions? To answer these questions, independent manipulation of the cues available in the stimuli was performed. Specifically, three experiments were conducted. Experiment I dealt with acoustic analyses of Kannada words with and without stress, experiment II dealt with generation of synthetic phrases and experiment III dealt with discrimination of stress in individuals with CVA and in normal control subjects. Fifty normal controls and 59 subjects with CVA (27 with left hemisphere damage - LHD and 32 with right hemisphere damage - RHD) listened to phrase pairs altered in individual (frequency - F0, intensity - A0, and duration - D0) and multiple acoustic parameters of stress. They responded to the stimuli as 'same' or 'different' on a multiple forced choice response sheet.

Results of experiment I indicated that duration was the major cue of stress in Kannada. Results of experiment III indicated that subjects with CVA scored significantly poorer compared to normal controls. Subjects with LHD scored significantly higher on altered F0D0 and F0A0D0 conditions compared to subjects

with RHD. Young subjects scored significantly higher on altered FO condition and old subjects scored significantly higher on altered DO condition. Significantly better performance on altered FO (Young LHD and RHD), altered F0A0D0 (old LHD) and altered DO (old RHD) conditions was observed.

Chapter I

Introduction



"Four pounds and several thousand miles of interconnected nerve cells (about 100 billion) control every movement, thought, sensation, and emotion that comprises the human experience. 'Within the brain and spinal cord there are ten thousand distinct varieties of neurons, trillions of supportive cells, a few more trillion synoptic connections, a hundred known chemical regulating agents, miles of minuscule blood vessels, axons ranging from a few microns to well over a foot and a half in length, and untold mysteries of how—almost flawlessly—all these components work together". This is the amazing brain........

en,wikigpedia.org/wiki/human_ brain

The relation between brain and behaviour has attracted researchers for many years. By investigating this relationship, one can independently deduce models of neural organization and cognitive processing. In the search for neuroanatomical correlates of behaviour, a great deal of attention has been focused on language processing. Prosody serves a variety of functions in language processing and it is an important component of the linguistic system. Prosody or suprasegmentals incorporate intonation, rhythm, stress and quantity. Intonation is the change in fundamental frequency (F0) over a period of time. Rhythm refers to an event repeated regularly over a period of time, quantity is the duration of speech sounds and stress refers to extra energy. Stress has been called the most elusive of all prosodic features (Lehiste, 1970) signaled by at least three acoustic correlates i.e. change in fundamental frequency, amplitude and duration (Lieberman, 1960).

In most recent models of speech production (for e.g. Levelt, 1989), the prosody generator is considered as a distinct component of the speech production system or a subcomponent of the phonological system. To date, majority of neurolinguistic research in this area has focused in some detail on the neural basis of the segmental aspects of speech. But far less attention has been devoted to speech prosody. Thus, despite its importance in communication, the neural systems responsible for the production and comprehension of prosody remain largely unspecified.

Monrad-Krohn (1947) was the first to introduce the notion of prosody in verbal behavior of certain brain damaged individuals. He distinguished four different types 0f prosody: intrinsic prosody (refers to intonation contours that distinguish a declarative from an interrogative sentence), intellectual prosody (refers to the placement of stress, which gives a sentence its particular meaning), emotional prosody (conveys emotions), and inarticulate prosody (consists of grunts or sighs and conveys approval or hesitations). He also described three disorders of prosody - hyperprosodia, observed in manic states and in motor aphasia, dysprosodia, also called ataxic, characterized by a foreign pseudoa and was first observed in a patient recovering from Broca's aphasia, and aprosodia, an inability to produce variations in prosody observed in the case ofParkinsonian patients.

Stress, one aspect of prosody, is the perceived loudness of a syllable/word or greater muscular effort and comparatively greater force. In traditional phonetics, stress has been frequently divided in to dynamic or expiratory stress and musical or melodic stress. This assumption seems to have been based on a belief that stress and pitch are interdependent on each other. Phonemic or word level stress presupposes that the domain of stress is a word. The minimum size of the unit of stress placement is the syllable. However, stressed and unstressed words can be distinguished only within a larger utterance. Thus the minimal unit of contrastive stress placement is a sequence of two syllables. If the placement of stress on one of the syllables of utterance is not predictable by morphological, lexical or syntactical criteria, it is said that stress occupies independent position within the phonology of the language. This kind of linguistically significant stress is termed phonemic or free stress. In free stress, shifting the stress changes the word in to another meaningful word and not in to a non-word. On the other hand, in a number of languages, the place of stress on a certain syllable is fixed and is determined with reference to the word. The position of stress identifies the word as a phonological unit. Placing the stress on a different syllable changes the word in to a non-word. This is termed bound stress. In morphological stress the position of a word is fixed with regard to a given morpheme. When stress functions at a sentence level, it does not change the meaning of any lexical item; but it increases the relative prominence of one of the lexical items. There are three types of sentence stress. In primary or non-emphatic stress, the important syllable or word in a sentence is stressed and each sentence automatically has a primary stress. Contrastive stress occurs in a sequence of sentences with parallel constituents that are filled with different morphemes. Contrastive stress is used to distinguish a particular morpheme from other morpheme that may occur in the same position. On the other hand, emphatic stress is used to distinguish a sentence from its negation. Most studies on brain damaged have investigated production and perception/comprehension of lexical or emphatic stress.

Some of the continuing questions posing those interested in the neural substrates for the processing and controlling of prosody are (a) is the function (linguistic vs. emotion) lateralized or are the acoustic cues (FO vs. duration) lateralized? (b) given that the linguistic prosodic system is part of several grammatical components (phonological, lexical and syntactic), to what extent does a particular break down in the prosodic system effect these components?, and (c) are the comprehension and production of prosodic cues similarly affected by brain damage under the hemisphere control?

A great deal of attention has been recently directed to investigate the neural substrates of speech prosody. One of the hypothetical dichotomies that have been the object of research in prosody is that of emotional prosody (happy, angry, sad, surprise, sarcastic etc.) vs. linguistic prosody (statement, question, continuation, command, etc.). The left hemisphere has long been associated with linguistic processing and the right hemisphere with emotional information processing (Milner, 1962; Curry, 1967). Several theories concerning neuroanatomical regions active in prosodic processing have been proposed. The theory put forth by Van Lancker (1980) elaborates on the functional lateralization hypothesis (linguistic processing by left hemisphere and emotional processing by right hemisphere). In the past, several studies have been conducted on the production and perception of stress in brain damaged.

The first experiment on the comprehension of lexical stress in left hemisphere damaged (LHD) individuals (Blumstein & Goodglass, 1972) indicated several errors in Broca's and Werriicke's aphasia. In this study subjects listened to a series of words and selected one picture among the four pictures. A further study by Baum, Daniloff, Daniloff & Levis (1982) on comprehension of lexical stress in sentence by Broca's aphasics and age matched normal subjects indicated that Broca's aphasics made significantly more errors compared to normals. Behrens (1985) used dichotic listening technique in 15 normal subjects to identify stress placement in phonemic stress pairs (e.g. hotdog vs. hotdog) and demonstrated a significant right-ear (left hemisphere) advantage on this task. Filtering the same stimuli at 200 Hz for presentation or reducing the semantic content of the stimuli (e.g. hotdog) did not lead to a right-ear advantage. The results suggested that left hemisphere processes stress contrasts except when these cues are of minimal linguistic importance (as in the low-pass-filtered stimuli).

Emmorey (1987) studied comprehension and production of linguistic stress contrast. She tried to see the association or dissociation that existed between acoustic cues and the lexical level. In her study, the ability to comprehend and produce the stress contrast between non-compounds and non-phrases (e.g. Green house Vs. Green house) was examined in seven non-fluent aphasics, seven fluent aphasics, seven right hemisphere damaged (RED) individuals, and 22 normal controls. Results indicated that RED group performed as well as normals. Further, the ability to produce stress constraints was tested with a sentence reading task and acoustic measurements revealed that no non-fluent aphasic used pitch to distinguish noun compounds from phrases, but used duration. All but one of the RHD individuals and all but one of the normals produced pitch and / or duration cues. These results suggest that linguistic prosody is processed by the left hemisphere and with brain damage the ability to produce pitch and duration cues may be dissociated at the lexical levels.

Baum (1998) investigated processing of phonemic and emphatic stress in brain damaged (LHD and RHD) and non-brain damaged (NBD). The results indicated that LHD were more severely impaired when deprived of FO information and RHD also exhibited deficits compared to NBD when not all acoustic cues were available in the stimuli. The results of the study in part support the claim that linguistic prosody is processed in the left hemisphere, whereas the right hemisphere controls emotional prosody. Walker, Tracy & Buzzard (2002) addressed the extent to which the processing of lexical stress differences would be lateralized to the left or right hemisphere by requiring listeners to determine the meanings and grammatical assignments of two-syllable words conveyed through stressed or unstressed syllables.

The results showed that L H D group demonstrated a significantly poorer performance than the control and R H D groups.

The results of the above studies support the functional lateralization hypothesis that left hemisphere controlled linguistic prosody and right hemisphere controlled emotional prosody (Van lancker, 1980). According to this hypothesis, the specialized role of the left hemisphere is revealed for processing prosodic structure that perform a linguistic function (e.g., conveying lexical stress differences), and the right hemisphere for processing nonlinguistic prosodic information (e.g., conveying emotion). This theory does not account for potential hemisphere differences in processing the acoustic characteristics of the prosodic structure at a perceptual level. Rather, it suggests that hemispheric specialization is determined at later stages of sentence processing where an in-depth analysis of the linguistic and nonlinguistic function is determined.

A second hypothesis that all aspects of prosody are processed in the right hemisphere and integrated across the corpus callosum with linguistic representation was put forth by Klouda, Robin, Graff & Cooper (1988). Six studies

that supported this hypothesis are as follows:

Weintraub, Mesulam, & Kramer (1981) studied stress production in right hemisphere damaged. They presented to a single listener, a model utterance followed by utterance of nine right hemisphere damaged and ten normal subjects. The stimuli included declarative and interrogative sentences and sentences with emphatic stress. The listener was asked to judge how similar the subjects' productions were to the model stimuli. Results indicated that right hemisphere damaged subjects utterances were consistently judged to be less adequate examples in relation to the model stimuli than those of the normal control group. Weintraub et al. (1981) concluded that right hemisphere damage yields a deficit in linguistic prosody as well as affective prosody. Weintraub et al. (1981) went one step ahead in concluding prematurely that whole of prosodic processing was managed by right hemisphere.

Grant & Dingwall (1985) evaluated comprehension of shifts in grammatical class as a function of the placement of lexical stress on RHD and LHD using discrimination task where subjects were asked to identify verb or noun based on stress placement on the first or second syllable. They found that RHD performed same as aphasics but performance was significantly less than that of NBD and thus they concluded that each hemisphere is involved to a varying degree depending on the type of linguistic prosody.

Klouda, Robin, Graff & Cooper (1988) presented a case report of a 39-year old woman who suffered an aneurismal hemorrhage damaging the anterior four-fifths of the corpus callosum. In their study they wanted to find evidence for impairment of both affective and linguistic prosodic feature following callosal disconnections and whether collosal connections are directly involved in prosodic processing. They performed computer aided acoustic analysis of FO contours and durational pattern on emotive and non emotive utterances at 4 weeks, 4 months and one year post surgery. The study provided strong evidence that the right hemisphere generally contribute to the processing of FO information and suggested that FO information processed in the right hemisphere is integrated with information processed in the left hemisphere speech centers via the corpus callosum.

Bryan (1989) examined the right hemisphere contribution to the processing of linguistic prosody by presenting a battery of 13 linguistic prosody tests that incorporated stimuli of various perceptual domains (phonemic/emphatic stress discrimination, identification of declarative vs. interrogative intonation). Results of her study indicated that individuals with RED were impaired on all 13 tasks of linguistic prosody relative to the NBD and on 8 tasks relative to the individuals with LHD. Further, individuals with LHD were significantly impaired relative to the NBD on 10 of the 13 tasks suggesting bilateral control for at least some aspects of linguistic prosody.

Bradvik, Dravins, Holtas, Rosen, Ryding, & Ingvar (1991) compared the performance of RHD and NBD on tasks of both linguistic and affective prosody (e.g. emphatic stress perception, identification of linguistic and emotional intonation). Authors noted inferior performance of their RHD individuals on both linguistic and emotional tasks and arrived at conclusion of essential role for the right hemisphere in the processing of both (linguistic and affective) prosody, irrespective of the domine over which prosodic cues were perceived.

Pell (1998a) studied for evidence of a bilateral substrate for emotional prosody comprehension considering LHDs, RHDs and age matched NBDs. In his study, subjects listened to common set of utterances over several conditions which manipulated the strength of particular acoustic parameters of stimuli and were to independently judge either the location of emphatic stress within the sentence or the emotional tone. Results indicated that although emphasis perception was uniquely disturbed in LHD, accuracy in recognizing emotional attributes of the same stimuli was significantly impaired in both RHD and LHD relative to age matched NBDs.

Van Lancker & Sidtis (1992) put forth a third hypothesis, the differential cue lateralization hypothesis, which stated that the hemispheric specialization is dictated by the acoustic characteristic of prosodic structure where a right hemisphere dominance exists in processing the frequency characteristics of the acoustic signal and the left hemisphere processes the temporal information contained within prosodic structures. The hypothesis was based on the results of their study which compared the performance of participants with LHD and RHD and non-brain damaged (NBD) individuals on an emotional prosody identification task. Results revealed that both groups (LHD and RHD) performed poorer than NBD and performance of both groups did not differ in terms of accuracy. However, a discriminant analysis showed that both group errors were based on different acoustic cues used. Individuals with LHD seemed to rely on FO variations and those with RHD seemed to base prosodic judgment on durational cues. Van Lancker & Sidtis (1992) concluded that mechanisms sub serving prosodic processing are bilaterally distributed with right hemisphere more specialized for processing FO and left hemisphere more specialized for processing temporal acoustic parameters. This hypothesis was supported by the results of the study by Zatorre, Evans, Meyer, & Giedde (1992) who conducted a Positron Emission Tomography (PET) study with non-brain-damaged individuals. In their study, they compared activation patterns in tasks requiring phonetic judgments and pitch judgments. The results demonstrated increased activity in Broca's area during phonetic judgments of CVC syllables; in contrast, there was right prefrontal activation during pitch judgments of the same CVC syllables suggesting that FO processing is associated with RH mechanisms.

Baum (1998) conducted an experiment to decipher the role of FO and duration in the perception of linguistic stress by individuals with brain damage and non-brain damage (NBD). The stimuli included a naturally stressed syllables and syllable in which the FO was neutralized and set of stimuli in which the duration cue was effectively neutralized. The results indicated that subjects with LED were impaired in perception even when full cue was provided, RHD were poorer than NBD but were better than LHD. For FO neutralized stimuli even NBD and RHD performed poorly. LED performed at chance factor. There was high individual variability in the results obtained. Baum (1998) concluded that neural substrates of prosody remain elusive, undoubtedly both hemispheres involve in the processing of prosody. Also, there is differential preference for temporal and spectral cues for processing stress in the brain damaged.

Two studies were conducted by Sarah (2000) and Sarah, Prakash & Savithri (2000) on the perception of word stress in Kannada speaking LHD individuals and normals, and individuals with RHD, LHD and normals, respectively. In these studies, the stimuli were 5 2-word phrases with adjective-noun combination. These phrases as spoken by a normal Kannada speaker with and without stress on the adjective were audio-recorded and acoustically analyzed to extract F0, intensity (every 10 ms), and word duration of the stressed and unstressed adjectives. Synthetic stimuli were generated in which a single acoustic parameter (FO/intensity/duration) of the stressed word was transposed to the counterpart unstressed word. Therefore, three types of synthetic phrases - one with FO cue, one with intensity cue, and one with duration cue - were generated. Each synthetic phrase was paired with it's original unstressed phrase to make phrase pairs. Subjects listened to the phrase pairs and responded on a binary response sheet indicating whether the two phrases in a pair were the same or different. The results indicated that individuals with LHD performed poorly on task involving temporal cue (duration) and those with RHD performed poorly on task involving FO cue. The results supported the differential lateralization hypothesis.

In an effort to replicate and extend the findings of Van Lancker & Sidtis (1992), Pell and Baum (1997b) conducted a similar analysis exploring the identification of both linguistic and affective prosody. The results of discriminant analysis failed to indicate that the patients with LHD and RHD were relying on different acoustic cue in making prosodic judgments. Thus, although intriguing, the hypothesis that individual acoustic cues to prosody are independently lateralized (Van Lancker & Sidtis, 1992) remain speculative.

Dichotic listening task, picture selection, production of stress contrast, FO and duration perception, identification and discrimination tasks have been used by various authors to study perception/comprehension of stress. Most of the studies, except that of Sarah (2000) and Sarah et. al. (2000), are in English.

Most authors agree that increments in F0, duration, intensity, and alterations in the vowel quality are the primary acoustic cues of stress. However, the relative importance of these cues varies from one language to another. While F0 is the major cue of stress in English (Bolinger, 1958; Lieberman, 1960), French (Rigault, 1962), Hungarian (Fonagy, 1966), and Kechi (Berinstein, 1970), duration is the major cue in languages including Swedish (Fant, 1958), Serbo-Croatian (Lehiste & Ivic, 1963), Estonian (Lehiste, 1968 a), Italian (Bertinetto, 1980), Tamil (Balasubramanian, 1981) and Kannada (Savithri, 1987, Rajupratap 1991, Savithri, 1999 a, b). Further, Kannada does not have phonemic or lexical stress but has a sentence stress. Stress is used to emphasize a word in a sentence.

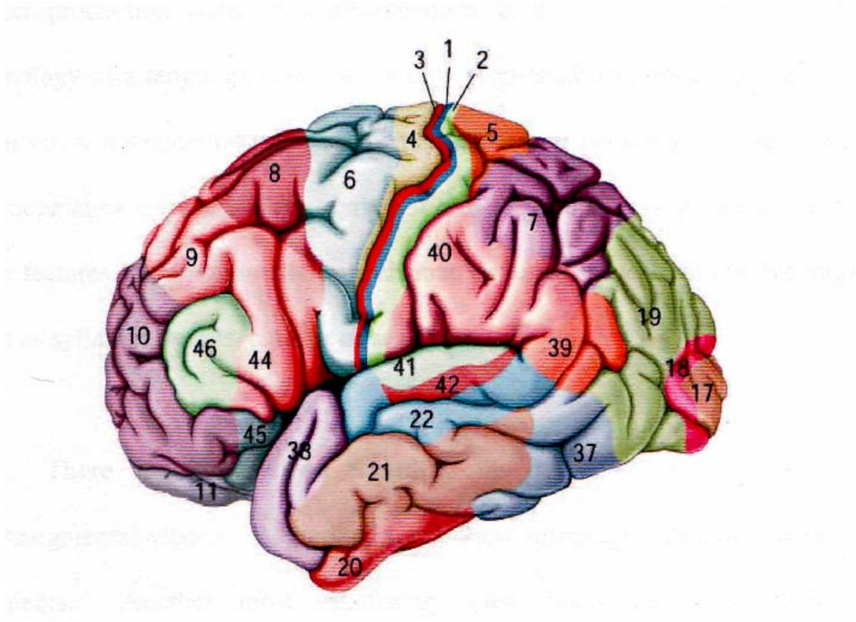
Though investigation of prosodic elements has been conducted in different languages, the area of prosodic perception has received little attention at the national and international levels. The existing contradictory evidences on stress perception in brain damaged and the language dependency of stress perception provoked the present study. The objective of the present study was to investigate perception of stress in subjects with cerbro-vascular accidents (CVA) speaking Kannada and normal controls [Kannada is a Dravidian language spoken by 20,000,000 persons in Kamataka, a state of south India (H. M. Nayak, 1967, http://www.in.gov.in/population/india.htm); Kannada is a Dravidian language spoken by 20,000,000 persons in Kamataka, a state of south India - http://www.in.gov.in/population/india.htm]. If the left hemisphere is specialized in processing temporal acoustic parameters (duration), it should be better reflected in left hemisphere damaged individuals speaking Kannada. Studies in language like Kannada, where duration is a major cue for stress, would be interesting in that the role of left hemisphere in processing temporal cue would be better emphasized compared to a language like English where the major cue for stress is F0.

Thus the study was designed to examine the effect of CVA, acoustic cue and age on the perception of stress. The following research questions were asked: (1) Are there differences between subjects with CVA and normal controls in perception of stress? (2) Are there differences between LHD and RHD (CVA) subjects in perception of stress? (3) Are there differences between young and old CVA subjects in perception of stress? (4) Do LHD and RHD (CVA) subjects use different acoustic cues to perceive stress? and (e) Are there differences between single and multiple cue conditions?

To answer these questions, independent manipulation of the cues available in the stimuli was performed. Specifically, three experiments were conducted. Experiment I dealt with acoustic analyses of Kannada words with and without stress, experiment II dealt with generation of synthetic phrases and experiment III dealt with evaluation of perception of stress in individuals with CVA and in normal control subjects. The results of the study have theoretical and clinical implications. Research on prosodic perception will add information about the neroanatomical regions active in prosodic processing, and the specific role of hemispheres in prosodic processing which will be helpful in providing effective diagnostic and rehabilitative methods to individuals with brain damage (CVA).

Chapter II

Review of Literature



"The brain-the master control for the entire body and the starting point for virtually alt behavior-is probably one of the most complex and challenging topics for anyone to study. Its myriad neurons, dozens of chemical messengers, and infinite interconnections provide the fascination that attracts neuroscientists to study it."

www.innerbody.com/tutorial2/tutorial.html

Suprasegmentals, also called prosodies are properties of speech that have a domain larger than a single element and include intonation, stress, rhythm, and juncture. Prosody serves a variety of functions in language processing, from the conveyance of the speaker's emotions to the phonemic use of tone to differentiate lexical items in certain languages. In some models of speech production (Garret 1980, Levelt, 1989), the prosody generator is considered a distinct component of the speech production system or a subcomponent of the phonological system. Learning phonology of a language involves not only segmental inventories and rules affecting them but non-segmental (suprasegmental) aspects of phonology as well. Segmental characteristics involve the description of size of phonemes or phonetic segments and their features. Suprasegmentals are characteristics of speech that involve larger units, such as syllables, words, phrases or sentences.

There are two views regarding the relation between segmental and suprasegmental aspects. According to one view suprasegmentals are added on to the segments. Another most satisfactory view holds that both segments and suprasegmentals blend and mutually influence each other. The suprasegmental information in speech can be described by basic physical quantities of amplitude, duration, and fundamental frequency of voice. The suprasegmental features include stress, intonation, juncture and rhythm. Stress refers to accentuation or emphasis, laid on syllable or word. Intonation refers to variations in pitch as a function of time. Juncture refers to the boundaries between the phonological units, signaled by segmental modifications and rhythm to the pattern of movement in speech.

Stress, one of the suprasegmental features, has been considered the most elusive one for a long time. Stress can be defined either from the listener's point of view or from a speaker's point of view. From the listener's point of view it can be defined as perceived loudness of a syllable/word. From the speakers point of view it can be defined in terms of greater muscular effort and comparatively greater force. Speakers and listeners benefit from the use and interpretation of stress. Speakers emphasize salient aspects of a message to enhance the probability of listener comprehension. Listeners attend to the salient stressed segments of an auditory message, which in turn facilitates listener's comprehension of the entire stress bearing utterance (Lehiste, 1970).

English and other Germanic languages make far more use of differences in stress than do most of the languages of the world. In many languages, the position of the stress is fixed in relation to the word. Czech words nearly always have stress on the first syllable, irrespective of the number of syllables in the word. In Polish and Swahili, the stress is usually on the penultimate syllable. Variations in the use of stress cause different languages to have different rhythms. Earlier, languages were classified as syllable-timed languages (French) in which syllables tend to recur at regular intervals of time and stress-timed languages (English, German) in which stresses were said to be the dominating feature of the rhythmic timing. Ladefbged (2001) stated that a better typology of rhythmic differences among languages would be to divide languages into those that have variable word stress (English, German), those that have fixed word stress (Czech, Polish and Swahili), and those that have fixed phrase stress (French).

The present study examined the perception of stress in patients with cerebro-vascular accidents (CVA - left hemisphere and right hemisphere damaged). Therefore, the review will be dealt under the following headings:

(a) Definition of stress
(b) Types of stress
(c) Functions of stress
(d) Cues of stress
(e) Measurement of stress
(f) Perception ofstress in normal individuals
(g) Perception of stress in brain damaged

(a) Definition of stress

There are two major views in defining stress, the physiological and the psychological. The most common among the two is a physiological definition. Only occasionally does one get the required blend of two views in the work of an individual scholar. From the speaker's point of view, stress may be defined in terms of greater effort that enters into the production of a stressed syllable as compared to unstressed syllable (Lehiste, 1970). From the listener's point of view Bloomfield (1933) claimed that stressed syllables are louder than unstressed syllables. Thus stress indicates both articulatory or motor feature of speech and also perceived sound feature by a listener denoting both the transmission and reception of speech.

Sweet (1878) defines stress as the comparative force with which the separate syllables of a sound group are pronounced. He has considered the extra physical effort in the production of stress. According to Abercrombie (1923) stress is a force of breath impulse and Classe (1936) states that stress is an impulse which expresses itself in the first place by an increase of pressure in the speech mechanism and approximately coincides with the point of greater pressure. According to Heffner (1949) it is referable to kinesthetic sensation of muscle and pressure changes. Trager & Smith (1951) opined that stress is assumed to be manifested by loudness, each level being louder than the next lower level. Jones (1956) defined a strongly stressed syllable as one that the speaker consciously utters with greater effort than the other neighbouring syllables in a word or sentence. According to Fonagy (1966), stress is the greater speaking effort. All these authors consider force, pressure, effort or loudness in the production of stressed syllables/words.

A second type of definition considers the listeners view point. Bolinger (1958) defines stress as the perceived prominence imposed within utterances. It may function linguistically at syllable, word or sentence level. Stress is a feature perceived by the listener, which involves complex interactions of suprasegmental elements. Gatenby (1975) says stress is the property that endows sequential syllables with differentiating grades of acoustic prominence.

(b) Types of stress

In traditional phonetics, stress has been frequently divided into dynamic or expiratory stress and musical or melodic stress. This assumption seems to have been based on a belief that stress and pitch are independent of each other. Saran (1907) was an early critic of the traditional distinction between the dynamic and musical stress. He insisted that the analysis of stress must proceed from the standpoint of the hearer. Later Schmitt (1924) criticized the distinction between dynamic and musical stress. According to him, the expiratory differences normally go together with melodic differences, and therefore, a sharp distinction between the two types is unwarranted.

Two types of stress described in the literature include lexical stress and emphatic stress.Lexical stress is used to distinguish two words with the same phonemic structure (e.g., "redcoat", a British soldier, versus "red coat", a piece of clothing). Emphatic stress is used to convey a different idea depending on the word's position in the sentence (e.g., in the sentence "John drives the car" it is surprising that John is the driver, whereas in "John drives the car" it is the fact that he actually drives the car which is emphasized). Emphatic stress corresponds to what Monrad-Krohn (1947) called intellectual prosody

Based on the size of the units stress can be divided into word level or phonemic stress and sentence level stress. Phonemic stress or word level stress presupposes that the domain of stress is a word, and the definition of a word does not depend on a criterion involving stress. The minimum size of the unit of stress placement is the syllable and is concerned with the prominence relationships between the syllables of a word. However, stressed and unstressed monosyllabic words can be distinguished only within a larger utterance. Thus, the minimal unit of a contrastive stress placement is a sequence of two syllables. If the placement of stress on one of the syllables of utterance is not predictable by morphological, lexical or syntactic criteria, it is said that stress occupies an independent position within the phonology of the language. This kind of linguistically significant stress is termed phonemic or free stress. In free stress shifting the stress changes the word into another meaningful word and not into a non-word (Lehiste, 1970).

On the other hand, in a number of languages, the place of stress on a certain syllable is fixed and is determined with reference to the word. The position of stress identifies the word as a phonological unit. Placing the stress on a different syllable changes the word in to a non-word. This is termed bound stress. In languages with such bound stress, there is no opposition between stressed and unstressed syllables within word-level phonology (Lehiste, 1970). Jakobson (1931) talked about an intermediate type between phonemic stress and bound stress called morphological stress The position of stress is fixed with regard to a given morpheme but not with regard to word boundaries in languages with morphological stress. This type of morphological stress may differentiate between compound words but not between individual morphemes. Weinreich (1954) defined one more type of stress called constructive stress. This type of stress serves to combine a sequence of morphemes into a stress construction in which the morphemes stand in a fixed stress relationship to each other.

When stress functions at a sentence level, it does not change the meaning of any lexical item but it increases the relative prominence of one of the lexical items. Bierwisch (1966) differentiates three types of sentence level stress as follows:

Primarystress (non-emohatic): Each sentence automatically has a primary stress. Here, in a sentence, the important syllable or word is stressed.

Contrastive stress: This occurs in a sequence of sentences with parallel constitutes that are filled with different morphemes. Contrastive stress is used to distinguish a particular morpheme from other morpheme that may occur in the same position.

Emphatic stress: This is used to distinguish a sentence from its negation. Occasionally it may be indistinguishable from contrastive stress. But there are some languages in which the two are different.

(c) Functions of stress

Prosodic features including intonation, rhythm and stress fulfill important functions in speech perception and production. Perceptually prosodic information assists the listener in segmenting the flow of speech by contouring words. Syntactically it aids in differentiating different sentence types through different patterns. Lexically it helps in differentiating grammatical categories, such as verbs and nouns and pragmatically contrastive stress helps to distinguish between topic and content (Chafe, 1970).

Linguistic stress, a feature of speech perceived by the listener, involves complex interactions of suprasegmental elements. According to Bolinger (1972), distribution of stressed elements in speech functions for semantic and emotional highlighting by drawing the listener's attention to them. Bates (1976) stated that it is also used to distinguish new and old information in discourse. The new information is generally stressed compared to the old information. Linguistic stress functions to set off elements which carry a heavier information load and on which the speaker tries to place special focus (Baltaxe, 1984). On a whole stress can either be used to give special emphasis to a word or to contrast a word from the other.

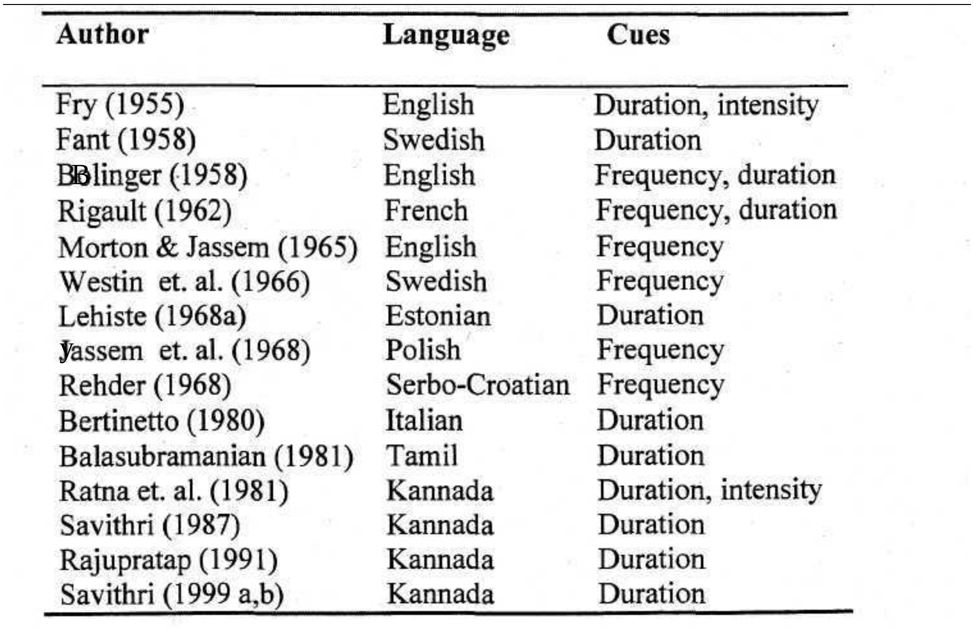
Stress also has a major function in indicating the syntatic relationship between words or parts of word. English has many such noun-verb oppositions. For example, in the pair "an overflow", "to overflow", noun has stress on the first syllable where as verb has on the last syllable. Thus, the syntactic function of the word is indicated by the placement of stress. A similar kind of opposition is also seen in cases where two word phrases form a compound noun like "a wa'lk out", "to wa'lk ou't", "a pu't-on", "to pu't o'n". Here placement of stress is noticed only on the first element of the noun whereas in case of verbs stress is placed on both the elements.

A syntactic function of stress lies in distinguishing between a compound noun (a ho4dog) and an adjective followed by a noun as in the phrase "a h'ot do'g". Compound nouns have a single stress on the first element, and the adjectival phrases have stress on both elements. However, in languages like English, it is possible to predict the location of stress in majority of words provided sufficiently complex sets of rules are formulated.

(d) Cues of stress

Perceptually stress is cued by increased pitch, increased loudness, longer duration and change in vowel quality. Fonagy (1958) says that stress is not definable in acoustic terms and the listener simply uses the various cues as a basis for judging the degree of force employed by the speakers. Cooper & Mayor (1960) say that stress is a product of a number of variables whose interaction is not precisely known. Fisher-Jorgenson (1967) opines that none of these cues are necessary and sufficient. A number of acoustic cues correspond to a simple physiological difference and to one final feature of stress. A problem in interpreting the physiological and acoustic correlates of stress is the ambiguous role of intensity in the perception of stress. The reason for lack of more direct relationship between intensity and stress is that output intensity changes with the articulatory configuration of the vocal tract. Subglottal pressure is also one of the physiological factors that control the rate of vocal fold vibration. Thus, stress is intimately connected with frequency. Unless vocal fold tension is adjusted, increased subglottal pressure results automatically in an increased rate of vocal fold vibration. Thus, in many languages, higher F0 serves as a strong cue for the presence of stress. While increased respiratory effort and increased vocal fold vibration serves as physiological cause for increased intensity and FO, respectively in a stressed element, no such cause is apparent for third most frequently cued parameter of stress - increased duration. There are many languages in which a stressed syllable is longer than an unstressed one. Thus, duration seems to be a language-determined phenomenon.

The relative importance of FO, intensity and duration in perception of stress has been studied experimentally in several languages including English (Fry, 1955, 1958; Bolinger, 1958; Morton & Jassem, 1965), Polish (Jassem, Morten & SteGen-Botog, 1968), French (Rigault, 1962), Swedish (Westin, Buddenhagen & Obrecht, 1966), Serbo-Croatian (Rehder, 1968), Tamil (Balasubramanyan, 1981), and Kannada (Savithri, 1987; Raju Pratap, 1991; Savithri, 199 a, b). Table 1 shows a summary of prominent acoustic cue of stress in various languages.



Author	Language	Cues
Fry (1955)	English	Duration, intensity
Fant (1958)	Swedish	Duration
Bolinger (1958)	English	Frequency, duration
Rigault (1962)	French	Frequency, duration
Morton & Jassem (1965)	English	Frequency
Westin et. al. (1966)	Swedish	Frequency
Lehiste (1968a)	Estonian	Duration
Jassem et. al. (1968)	Polish	Frequency
Rehder (1968)	Serbo-Croatian	Frequency
Bertinetto (1980)	Italian	Duration
Balasubramanian (1981)	Tamil	Duration
Ratna et. al. (1981)	Kannada	Duration, intensity
Savithri (1987)	Kannada	Duration
Rajupratap (1991)	Kannada	Duration
Savithri (1999 a,b)	Kannada	Duration

Table 1: Acoustic cues of stress in different languages.

As reported, in languages like English, Polish, and French, pitch prominence is the primary cue for stress. But in languages like Swedish, Estonian, Italian, Tamil, and Kannada, syllable lengthening is the primary cue for stress. This may be because of the marked durational differences between long and short vowels in these languages. The ratio between the duration of short (lax) and long (tense) vowel is around 1:1.54 in English (Klatt, 1976). However, the ratio is 1:2 in Kannada (Savithri, 1987). It can be assumed that the differentiation of temporal parameters should be more distinct in a language like Kannada. Though difference of opinions exists, all authors agree that increments in FO, duration, intensity and alterations in the vowel quality are the primary acoustic cues of stress.

(e) Measurement of stress

Mechanical and computer based methods have been used in the past to locate stress. Lieberman (1960) presented a flow chart that represented a program for mechanically recognizing the stressed syllables in stress pairs. With the help of the flow chart he attempted to locate stressed syllables in pairs of syllables from acoustic cues alone. Figure 1 shows the flow chart. The FO criterion at the top of the flow chart corresponds to the traditional notion of pith-prominence. The first step of this program is to recognize the syllable that has the higher FO, which is indicated by positive arrow in the figure. If the amplitude is also high for the syllable recognized then that syllable is considered as stressed. On the other hand, if the peak amplitude is lower as indicated by the negative arrow, the integral of the amplitude with respect to time over the entire syllable is noted. If this is found to be positive and the pitch difference and amplitude ratio between the stressed and unstressed syllables fall into permissible area, then again the syllable is considered as stressed. Similarly, many such paths can be followed so that all arrive either at stressed or unstressed judgement. Lieberman in his study compared the judgement made based on this mechanical scheme and the one based on perceptual stress judgments and found that both judgements were in agreement with each other by 99.2% of the time.

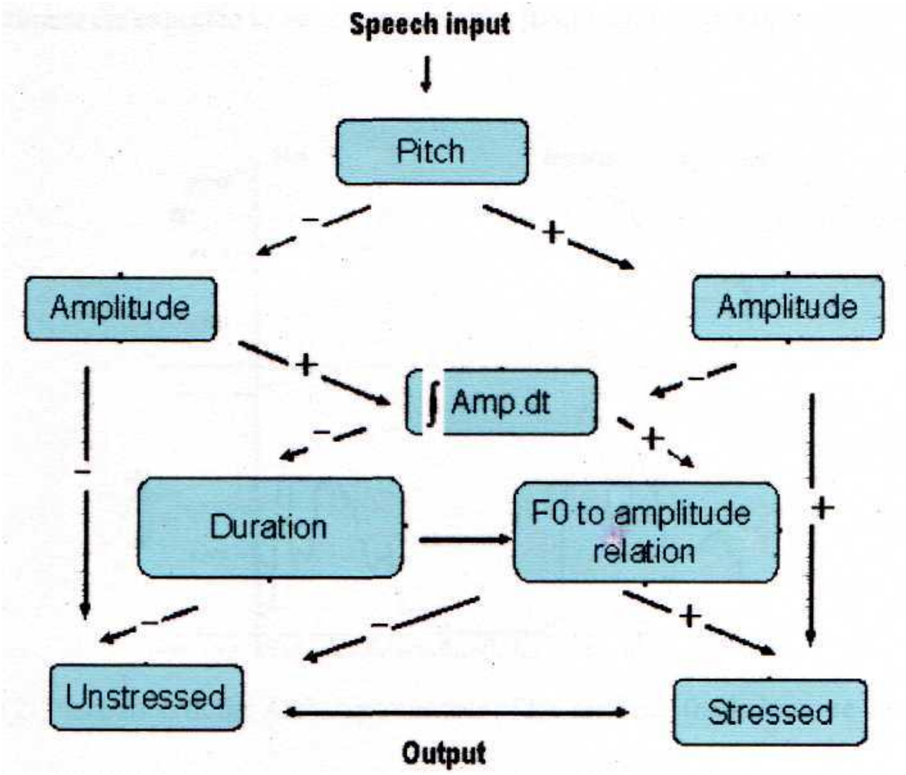


Figure 1: Program for mechanical recognition of stressed syllable (Lieberman, 1960).

Lea, Medress & Skinner (1975) devised a strategy for computer understanding of speech. It uses prosodic features to break up continuous speech into sentences and phrases and locates stressed syllables in those phrases. The algorithm for locating stressed syllables (from F0 contours and high energy syllable nuclei) correctly located the nuclei of over 85% of all those syllables perceived as stressed by a panel of listeners. The authors termed the contours as 'archetype'. Figure 2 illustrates how the acoustic correlates of rising F0 and large energy integral are used in an algorithm for locating the stressed syllables within constituents of sentences. A stressed "Head" to the constituent is associated with a portion of speech which is high in energy with rising F0 and bounded by substantial (5 dB or more) dips in energy. Other stressed syllables in the constituent are expected to be accompanied by local increases in F0.

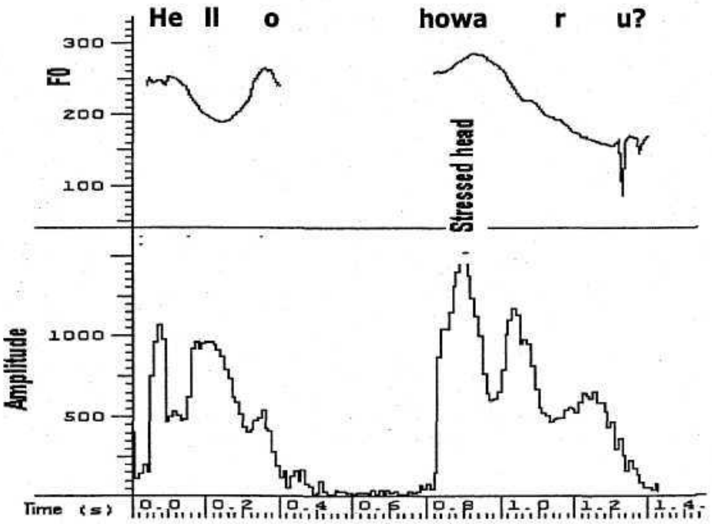


Figure 2: Illustration of the Archetype contour of the sentence [hello how are you?].

Thus, there are different opinions about locating stress. Some locate it by F0 / intensity / duration prominence, and some by both F0 and intensity prominence.

(f) Perception of stress in normal subjects

Literature on perception of stress is scarce and rare. However, based on the available data, it is noticed that the acoustic cues like FO, amplitude and duration play a very significant role in the perception of stress. A number of factors seem to influence the judgment of stress and of them most often listeners rely on differences in length, loudness, pitch of syllables, sound qualities occurring in the syllables and the kinesthetic memories associated with his/her own production of the syllables he/she is receiving.

These factors form a complex in which, no one is independent of the others. Thus, a stress judgment may be influenced by the length of the syllable and particularly by the length of the vowel that it contains but not independent of the vowel quality. For example, in the English word [mo:bid], the first syllable is perceived as stress partly because the first vowel is long. This vowel is, however, long in opposition to the first vowel of [mo:biditi] and not in contrast with the second /i/. For, in the latter word, the first vowel is still long in contrast with the second although the stress is now perceived to be on the second syllable.

Certain quality differences in English have particular significance in stress judgments. The substitution of the neutral vowel / a /, for some other vowel, the reduction of a diphthong to a pure vowel, or the centralization of a vowel are all powerful cues in the judgment of stress. Some features of consonant quality, such as the strength of friction or aspiration and the sharpness of onset of the consonant sound may act in a similar way.

Fry (1955) studied the effect of intensity and duration on the perception of stress. In his study he produced test words like o'bject, di'gest, pe'rmit using Haskins laboratories pattern playback synthesizer (Cooper, Liberman, & Borst, 1951). He varied the duration and intensity of both syllables in these words in a systematic fashion. Then listening test was performed on 100 subjects. Subjects were instructed to indicate the syllable stressed. Results indicated that listeners perceived vowel as strongly stressed when the vowel was long and of high intensity. In contrast, they perceived it as weakly stressed when it was short and of low intensity. When they studied the effects of duration and intensity separately, duration was found to be a more prominent cue. Increase in duration ratio and keeping the intensity constant led to increase in the noun judgements (identification of the first syllable as stressed) by 70% of subjects. However, the change in the whole range of intensity produced an increase of 29% in the number of "noun" judgments. This is one of the first studies on perception of stress. As the acoustic parameters changed included duration and intensity, no conclusive statement regarding F0 as a cue to stress was drawn.

In a second experiment, Fry (1958) explored the role of fundamental frequency variations in determining stress judgments. The word-pair 'subject' was synthesized by changing the F0 in step at the junction between the first and the second syllable. The synthesized speech was intended to sound like that of a male speaker and the selected reference frequency of 97 Hz gave this effect successfully. The frequency steps included F0 values of 5, 10, 15, 20, 30, 40, 60 and 90 Hz. Forty-one listeners heard a series of sense-groups, each containing two syllables, and made a judgment about the stress pattern. The results indicated that change in F0 differed from change of duration and intensity in that it tends to produce an all-or-none effect, that is to say that magnitude of the frequency change seems to be relatively unimportant while the fact that a frequency change has taken place is all-important. That is, it was the change in frequency that was important and not the magnitude of the change to judge a syllable as stressed.

Bolinger (1958) studied the phonetic and linguistic nature of stress by performing a series of experiments using both natural and artificial speech. Based on the results of his study he concluded pitch prominence as a primary cue of stress followed by duration. However, he rejected the notion of intensity playing a crucial role in the perception of stress. Rigault (1962) systematically varied F0, intensity and duration in a synthesized word 'papa' and the phrase 'Qu'est-ce que vous faites? The test tape was presented to French listeners. Results revealed that frequency was the most important physical correlate of perceived stress compared to duration and intensity.

In a third experiment, Fry (1965) attempted to explore the role of vowel quality in stress judgments obtained from English listener's versions of the word pairs 'object' and 'contract', 'subject' and 'digest'. These were synthesized with a systematic variation of the frequency of the first and second formants in the first syllable of 'object' and 'subject'. Variation in vowel duration ratio was introduced in the same stimuli in order to provide a means of estimating the weight to be assigned to the changes in the formant structure. The fundamental frequency of the periodic sounds was kept constant at 120 Hz throughout. The overall intensity of syllable was regulated so that the maximum intensity in the two syllable of a test word was equal and a constant difference of 6 dB between fbrmant 1 and fbrmant 2 was maintained throughout. The stimuli were made into a listening test in which each stimulus occurred once. Stress judgments were obtained from 100 subjects who were all young speakers of southern English. The results suggested that fbrmant structure cue for stress may be less effective than the intensity cue.

Morton & Jassem (1965) using parametric speech synthesizer produced synthetic nonsense syllables /sisi/, /səsə/ and /sasa/. The stimuli were constructed in such a way that same vowels were placed in both syllables thereby avoiding the problem of different intrinsic intensities. F0, intensity and duration were systematically varied and presented to English listeners. Results indicated that change in F0 led to greater effect than either intensity or duration. It was further found that raised F0 was more efficient than a lowered one in perceiving stress.

Westin, Buddenhagen, & Obrecht (1966) explored the relative importance of F0, duration and intensity in Southern Swedish. They produced combinations of two versions of 'halsa pa' using tape-slicing techniques. In the stimulus, the first and last syllable had F0 of either 122 or 144 Hz, duration of either 195 or 300 ms, either high or low intensity with the difference of 6 dB. Listening tests were administered to Swedish speakers in Lund. Results indicated F0 as a primary cue for identification. Further, it was observed that F0 of the first syllable was the major cue compared to that of cues of pitch, quantity, and intensity on the final syllable. However, they could not establish, which among quantity and intensity was, the most important one.

Acoustic cues of stress depend on the language. Evidence for this comes from the study of Jassem, Morton & Steffen-Batog (1968) who used the same stimuli as that of Morton & Jassem with Polish listeners. Results indicated both similarities and differences among the English and Polish group. Variation in F0 was the most striking similarity seen between the groups whereas variations in duration were more effective with Polish than with English listeners. Intensity was found to be effective only when the difference was above 6dB. F0 has been found to be a better cue in Serbo-Croatian accents. Rehder (1968) studied the relative importance of F0 and intensity as distinctive components of Serbo-Croatian accents. F0 and intensity were manipulated using a vocoder. He selected minimal accentual pairs as spoken by a native speaker which were processed and re-recorded under the following conditions: (a) F0 unchanged, intensity leveled; (b) intensity unchanged, F0 monotonized at 155 Hz; (c) both parameters leveled at the same time. Results of listening tests indicated that F0 provided relatively stronger cues for the presence of stress than intensity.

However, duration is found to be the prominent cue of stress in Italian. In a study by Bertinetto (1980) a total of 64 stimuli were constructed by means of a formant synthesizer, according to a pre-established pattern. Special care was devoted to the determination of duration, intensity and F0 values, which had to be assigned in turn (through a systematic permutation) to both syllables of the disyllabic word chosen for the test. This consisted in the phonemic sequence /papa/, which can give rise to two meaningful words in the Italian language, according to the position of prominence. The stimuli were presented in random order to two groups of listeners. The main set was composed of 52 Italian speakers from the northwest, whereas the second (control) group consisted of nine subjects from the north-east. Test responses, analyzed in relation to the various parametric values present in each stimulus, consistently pointed to duration as the most effective prominent cue.

Laterality effect in the identification of stress has been reported by Behrens (1985). His study consisted of two experiments. In the first experiment he used stress contrasting real-word minimal pairs (e.g. hotdog vs. hotdog). These items possessed both phonetic and semantic information. To determine the extent to which this phonetic and semantic information affected ear scores, they removed the phonetic, and consequently semantic, content of the stimuli by passing the same tapes through a low-pass (200 Hz) filter in the second experiment. Third experiment consisted of nonsense words differing only in stress placement. In this, phonetic information alone was replaced. Experiment 1 was carried out to determine possible laterality effects of stress identification, using minimal stress stimulus pairs presented dichotically. Fifteen graduate and undergraduate students, age ranging from 19-31 participated in the experiment. Test materials consisted of 21 pairs of compound nouns (e.g. whitecaps) and corresponding noun phrases (white caps) which differed only in the stress placement. The compound noun had primary stress on the first syllable while noun phrase had it on the second syllable. Subjects were first presented with the binaural pretest, which consisted of 84 stimuli, each utterance appearing twice, half with first-syllable stress, half with second-syllable stress. This was followed by presentation of dichotic tape, which consisted of stimulus pairs with each token appearing twice, each time with a different competing stimulus. These were presented once in each ear with each utterance appearing four times. Subjects were first presented with the binaural pretest. They were asked to listen to each utterance and to decide whether stress occurred on the first or second syllable. They were also asked to mark '1' or '2' on an answer sheet, accordingly. A laterally index was computed to measure ear performance using the formula number correct right ear-number correct left ear / Total number correct. A positive score indicated a right ear advantage, and a negative score indicated left ear advantage. Subjects showed a significant right-ear (left hemisphere) advantage in identifying stress dichotically, suggesting a left hemisphere processing component.

In the second experiment, filtering the same stimuli at 200 Hz for presentation or reducing the semantic content of the stimuli (e.g. hotdog) did not lead to a right-ear advantage. The results suggested that left hemisphere processes stress contrasts except when these cues are of minimal linguistic import (as in the low-pass-filtered stimuli). In the third experiment, nonsense words were created from the original 42 real word preserving phonetic information but lacking semantic content. This was done by switching the initial consonant or consonant cluster of the syllables of each stimulus (e.g. 'blue print' became 'prue blint'). Results indicated no ear asymmetry. Overall the results of the study suggested that as the linguistic significance of the stimuli is reduced, thereby lessening the linguistic function of stress, there is a less dominant involvement of the left hemisphere in stress processing.

William's (1985) experiments on synthesized Welsh minimal stress pairs found strong effects of duration on listener's stress judgments, but inconsistent effects of F0. In Kannada, duration is found to be the major cue of stress. Four studies have been conducted in Kannada. Savithri (1987) studied some acoustical and perceptual correlates of stress in Kannada. She considered 11 three-word meaningful Kannada sentences. The placement of stressed word was varied in each sentence to make four types of sentences - sentence with no word stressed, sentence with stress on first word, sentence with stress on second word and sentence with stress on third word. A total of 39 sentences formed the test material. Four Kannada speaking adults (two males and two females) spoke these sentences. The sentences were recorded and 30 subjects listened to them carefully and identified the stressed word. Further, they also indicated the perceptual cues used by them to identify the stressed word. Only those words, which were identified as stressed by 80 % or more subjects, were subjected to acoustic analysis. F0, intensity, duration, Fl and F2 (vowel) of the stressed words were compared with those of the words in unstressed utterances. Acoustic analyses revealed duration as the main parameter and perceptual analyses revealed duration and intensity increments as major cues to stress. Raju Pratap (1991) investigated perceptual correlates of stress in Kannada language. Twenty-seven Kannada clauses and 10 Kannada sentences as spoken by a native Kannada female speaker stressing the target word was audio recorded. This was audio presented to 10 native Kannada speakers (five males and five females) one at a time who were instructed to write down the words that they perceived as stressed. Further, they were also instructed to indicate the perceptual cues of stress. Results of the perceptual test indicated that a total of eight cues were identified by Kannada speakers - increased word duration, shortening of stressed word, prolongation of the stressed word, extra-effort in production, pause-before or after stressed word, raising and falling intonation in stressed word, and articulation. It was found that durational changes and loudness were the major cues for the perception of stress in Kannada.

Savithri (1999 a) investigated the importance of vowel duration as a cue for word stress in Kannada. Five two-word phrases as uttered with and without stress on the first word by a native Kannada female speaker aged 25 years were recorded. The duration of the vowel in the stressed word was decreased in steps of three pitch pulses till it matched the duration of the vowel in the counterpart unstressed word. The edited words were iterated thrice and audio presented to 10 Kannada speaking normal subjects. Subjects identified a phrase as having a stressed or unstressed word. The responses were tabulated and percent response was calculated. Vowel duration was found to be an important cue of stress in Kannada. In a second study, Savithri (1999 b) investigated the relative importance of F0, intensity and duration in signaling word stress. Five two-word phrases uttered by a 25-year-old native female Kannada speaker with and without emphasis on the first word were recorded. F0, intensity and duration of the stressed and the unstressed words were measured. Three experiments were done in which F0, intensity and duration of the unstressed words were edited to match that of the counterpart stressed words. A total of 63 tokens along with the original phrases with unstressed word were audio recorded and this formed the test material. Ten female subjects were audio-presented with the material and were instructed to indicate when they perceived stress on the first word of each token. Results indicated that the increments in duration were a major cue of stress in Kannada followed by increments in F0 and intensity.

Measurements of segmentally matched stressed and unstressed syllables in Arabic by de Jong & Zawaydeh (1999) revealed duration and FO as correlates of stress in Arabic. In Spanish, stress is perceived if cued by FO and duration or by FO and amplitude, but not by any one cue alone (Llisterri, Machuca, de La Mota, Riera, & Rios, 2003); syllable weight and lexical analogy also affect stress perception (Face, 2000, 2003). In Thai, a tone language, stress is signaled effectively by duration alone (Potisuk, Candour, & Harper, 1996).

Above studies have used words, phrases or sentences as stimuli. These stimuli are synthetic, tape-spliced, vocoder synthetic, and natural. The results of these studies indicate that the perception of stress by normal subjects depends on the primary acoustic features like F0, duration and intensity. However, the prominent cue varies from one language to another. While in languages like English, where the durational difference between short and long vowels is not clear, increment in F0 signals stress. But, in languages like Kannada, where durational differences are predominant, lengthened vowels signal stress.

(g) Perception of stress in brain damaged

Monrad-Krohn in 1947 introduced the notion of prosody in verbal behavior of certain brain damaged individuals. He distinguished four different types of prosody: intrinsic prosody (refers to intonation contours that distinguish a declarative from an interrogative sentence), intellectual prosody (refers to the placement of stress, which gives a sentence its particular meaning), emotional prosody (conveys emotions), and inarticulate prosody (consists of grunts or sighs and conveys approval or hesitations). He also described three disorders of prosody- hyperprosodia, an excessive or exaggerated prosody observed in manic states and in motor aphasia, dysorosodia, also called ataxic, is a distorted prosody which was first observed in a patient recovering from Broca's aphasia, and aprossodia, that referred to an attenuation or lack of normal prosody observed in the case of Parkinsonian patients.

Theories of receptive prosodic lateralization have concentrated on affective prosody, but the discussion may benefit from a review of the linguistic functions of prosodic cues as well. Prosodic features expressed over various domains signal differences in the illocutionary intent of an utterance (e.g. whether information is stated or requested), highlight items of relative importance in a spoken message (emphasis), or disambiguate the meaning of words with similar segmental structure (phonemic stress). Several investigators have explored the neural basis for comprehension of locally defined linguistic-prosodic features such as phonemic or emphatic stress.

Blumstein & Goodglass (1972) conducted one of the first experiments on the comprehension of lexical stress in left hemisphere damaged (LHD) individuals. Seventeen aphasic patients and 13 normal controls served as subjects for the study. Out of 17 aphasics, nine were fluent aphasics comprising of conduction, Wemicke's and anomic aphasias and remaining eight comprised of Broca's aphasics. Test materials used for the study comprised of 25 picture cards. Of these, 20 required a decision between compound noun (re'dcoat) and a noun phrase consisting of an adjective plus noun (red coat) comprising of minimal pair differing in stress. Five required a decision between a pictured verb (convict) and its corresponding identically spelled noun, differing only in stress. Each of the pairs was represented on a card illustrating the two contrasting words and two other pictures having reasonable relationship to the stimulus word. Subjects were made to listen to each word and select one, out of four pictures, corresponding to the word. In the example of red coa't, the correct picture would be that of a British soldier of the 18th century, the other pictures would be of a red coat and two distracters (i.e, a red cap and a porter dressed in red). Results revealed that both stress and random errors were of greater magnitude in the aphasic than the normal group for every category of stimulus. Both aphasics and normals made fewer errors in recognizing nouns than in recognizing their oppositely stressed adjective-noun phrases or their oppositely stressed verbs. The total number of errors was significantly greater for aphasics as a group than normals. However, the number of stress-determined errors was not significantly different either between aphasic subgroups or between normals and aphasics. The relatively high percentage of errors made by normals as well as aphasics may reflect in part the artificiality of this task, in part the difficulty of making these discriminations on words spoken out of context. In normal conversation, the listeners may depend much more on context than on stress perception. The two groups were distinguished by the percentage of random errors with more errors in aphasics. Thus, the most remarkable finding in this study was the stability, on the face of aphasia, of the recognition of stress and the application of the grammatical rules to which stress applies. No significant differences were found between the two aphasics groups. Part of these results may be due to the fact that the posterior aphasics included both conduction and anomic aphasics who clinically have relatively good comprehension, as do the anterior aphasics. Thus, the only subjects with relatively impaired comprehension are the Wernicke's aphasics. Nonetheless, the results suggest that regardless of clinical type of aphasia, stress contrasts are preserved.

A similar study in German (Weniger, 1978) revealed that errors due to poor comprehension of the placement of lexical stress were more frequent in aphasics than in normals. It should be noted, however, that the task was more difficult than the one used by Blumstien & Goodglass (1972), since twice as many pictures were used (eight pictures).

Weintraub, Mesulam, & Kramer (1981) focused their attention on emphatic stress and intonation based modality in a discrimination task. They considered 9 RHD patients and 10 normal subjects for their study. The subjects were asked to determine whether two sentences were identical. The sentences differed (1) by the emphatic stress, which was either on the first word or on the last word (e.g., "Steve drives the car" versus "Steve drives the car"), or (2) by the intonation contour associated with a given modality, which was either declarative or interrogative (e.g., "Margo plays the piano" versus "Margo plays the piano?). They found that RHD made significantly more stress-placement errors than normal subjects. The results of Weintraub et. al's (1981) study suggests that several different types of linguistic prosody (lexical stress, emphatic stress, and accentuation of the intonation contour) were the source of the difficulties of the RHD patients. They further predicted that a similar deficit subsequent to left hemisphere damage would be unlikely to emerge and therefore the right hemisphere is dominant for prosodic production in general. This conclusion drawn by the authors based on the task used raises certain criticism due to absence of LHD control group. However, it should be noted that with a similar number of stimuli, the scores of RHD was almost identical (75%) to the results reported by Emmorey (1984).

A further study by Baum, Daniloff, Daniloff & Lewis (1982) examined the comprehension of lexical stress in sentences such as "She is home sick" and "She is homesick" in a group of eight Broca's aphasics and age matched normal subjects. Results indicated that Broca's aphasics made significantly more errors compared to normals in comprehending sentences that were disambiguated by stress change and even more so as their aphasia increased in severity contradicting the results of Blumstein & Goodglass. Similar to Blumstein & Goodglass's picture pointing task, Baum et. al.'s study had patients identify stress that best fit sentences. Point to be noted here is that the Broca's aphasics had difficulty with the contrasting stress, which signals the boundary between two morphemes (e.g., 'It's a great day" Vs "It's a grade A"). The authors concluded that Broca's aphasics have deficit in processing and perceiving variations in the acoustic information that signals stress.

Emmorey (1984) used the same procedure as that of Blumstien & Goodglass (1972) but also included right hemisphere damaged (RHD) patients. She compared the performance of 15 aphasics, 7 RHD patients, and 22 normal subjects. The success rate of the RHD (76%) was similar to that of the normal subjects (87%) and significantly better than that of the aphasics, whether they were fluent (55%) or nonfluent (62%).

The results of these studies seem to suggest, not withstanding the limitations concerning the Blumstein and Goodglass (1972) study, that LHD do experience difficulties in understanding the acoustic cues involved in lexical stress. Therefore, the integrity of the right hemisphere is not sufficient to ensure normal performance on these tasks. A comparison of performance of patients with RED and LHD (Emmorey, 1964) suggests a necessary contribution of the left hemisphere.

It has been observed that emphatic stress plays a role in auditory comprehension. Pashek & Brookshire (1982) studied the effects of rate of speech and linguistic stress on auditory paragraph comprehension of aphasic individuals. In their experiment, they used 12 expository paragraphs that had been equated for length, lexical and syntactic complexity, reading level, number of sentences (eight), and number of words per paragraph (93 to 96). Three paragraphs were recorded at a normal rate with one main fact in each of the eight sentences per paragraph produced with exaggerated stress. Also, three paragraphs were recorded at a normal rate with normal stress patterns. Aphasic subjects then listened to each paragraphs in both conditions and then answered 16 Yes / No questions about the main facts in each paragraphs. Results revealed that subjects with aphasia demonstrated better auditory comprehension when paragraphs were presented with exaggerated stress rather than normal stress patterns. The study compared the auditory comprehension of stress in different paragraphs. Stress in each paragraph was different and the results also did not indicate any test-retest reliability.

Ambiguity regarding the benefit of stress for aphasic listeners led Kimelman & McNeil (1987) to replicate an investigation by Pashek & Brookshire

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and emphatic stress on the auditory comprehension performance of nine aphasics and five normal adults in the age range of 56-70 years. They randomly selected and re-recorded four of the paragraphs developed by Pashek & Brookshire. Each paragraph was recorded once using normal stress and again using emphatic stress as spoken by a male native English speaker. Each paragraph was presented twice.

paragraph was recorded once using normal stress and again using emphatic stress

questions about the eight target facts in each paragraph. This procedure allowed for direct comparison of performance across conditions on the same paragraph rather than on different paragraphs as in the original study. The number of facts correctly identified was tabulated for each paragraph. Difference scores were then determined by subtracting each subject's total score in the normal stress condition from his total score in the emphatic stress condition. T tests were conducted on the difference scores for each subject group. The study confirmed that aphasic's comprehension of spoken paragraph length narratives was significantly better when target words were emphatically stressed than when they were normally stressed. In addition, no significant learning effect was observed over two repetitions of each paragraph. The results suggest that emphatic stress plays an

stressed. In addition, no significant learning effect was observed over two

emphatic stress could not be attributed solely to changes incumbent upon the

important role in auditory comprehension. However, the observed effect of

emphatic stress could not be attributed solely to changes incumbent upon the

stress bearing word. The benefit accrued from the presence of stress in an utterance may be due to factors that occur simultaneously with the stressed word (local), nonlocal factors, or a combination of both local and nonlocal factors. Locally there are changes in a stressed word's intensity, duration and fundamental frequency. The presence of these acoustic changes may attract attention, filling the listener that something important is occurring at that point in the message, simply by being physically different from previous words. The influence of stress on auditory comprehension may also be attributed to acoustic changes occurring on segments of an utterance that occur prior to the word receiving stress. Such nonlocal changes have been documented (Cooper, Soares, Ham, & Damon, 1983), and research on normal subjects has revealed nonlocal influences on the speed of processing stressed targets (Cutler, 1976). The nonlocal acoustic changes may act by alerting the listener to the presence of an upcoming stressed word. Alerting signals have been shown to improve performance on a variety of tasks for both normal (Neisser, 1967) and aphasic subjects (Loverso & Prescott, 1981). Because words that are stressed usually carry a high level of meaning, fare knowledge can allow the allocation of additional attention to the processing of the word, resulting in improved auditory comprehension. Also, while the positive effect of emphatic stress on aphasic auditory comprehension appears to be a reliable finding, the difference in absolute magnitude of the effect is small and has little immediate clinical utility.

There are several issues of interest in the investigation of the neurological substrate for the processing and control of prosody. First, is the function (linguistic vs emotional) lateralized or are the acoustic cues (pitch vs timing) lateralized? Second, given that the linguistic prosodic system is part of several grammatical components (phonological, lexical, and syntactic) to what extent does a particular breakdown in the prosodic system affect these components? Finally, are the comprehension and production of prosodic cues similarly affected by brain damage and under the same hemispheric control? In an attempt to answer these questions, Emmorey (1987) studied comprehension and production of stress contrast (linguistic stress). Seventeen noun compound / adjective noun pairs and 3 noun / verb pairs used by Blumstein & Goodglass (1972) formed the material. Eight non-fluent aphasics, seven fluent aphasics, seven right hemisphere damaged (RED) individuals, and 22 normal controls participated in the study. The subjects were presented with two practice items and were told to listen to how the words were said and to point to the correct picture. In the production task the subjects were asked to name the noun compounds and adjective noun sequences in the picture. Results indicated that nonfluent and fluent aphasics performed significantly worse than normal controls on the comprehension task and the RED group performed as well as normals. There was no significant difference between the performance of nonfluent and fluent aphasics. Further acoustic measurements revealed that no non-fluent aphasic used pitch to distinguish noun compounds from phrases, but two of them used duration. All but one of the RHD individuals and all but one of the normals used pitch and / or duration cues. Emmorey (1987) interpreted her findings as indicative of a functional organization for prosodic lateralization, with an additional important determinant being the size or domain of the unit planned. The results indicated that comprehension of lexical / phrasal stress contrasts was preserved with damage to the right hemisphere but impaired with damage to the left hemisphere. The fact that the right hemisphere damaged patients did not perform significantly different from normal controls conflicts with the Weintraub et. al's (1981) results, which showed a difference between these groups using a subset of the same materials. However, since Weintraub et. al's (1981) used only 10 of Blumstein & Goodglass's 25 stimuli, the particular subset of items chosen may account for the different results. The results also differ from the original Blumstein & Goodglass results, which showed no difference between aphasics and normals. But, in Blumstein & Goodglass's study the aphasics made more errors than the normal controls. The results support the hypothesis that the functions of prosody (emotional or linguistic) determine the laterally of processing. Prosody itself is not controlled by one hemisphere, and when prosodic parameters signal linguistic structure, they are processed by the left hemisphere. The ability to utilize different components of the prosodic system can be dissociated with brain damage - duration being more resilient than pitch to left hemisphere damage.

Behrens (1988) conducted acoustic and perceptual analysis of lexical stress pairs and pairs of sentences with emphatic stress contrasts produced by RHD and normal control subjects. Duration, amplitude and F0 measures were computed for stressed and unstressed syllables elicited in a scenario-completion paradigm. Results of the acoustic analysis revealed that the RHD subjects used fewer of the cues to lexical and emphatic stress than did normals, but they were able to signal stress, as determined by perceptual identification scores. Behrens concluded that the right hemisphere is probably not dominant for linguistic prosody at word level.

Kimelman (1991) determined the influence of stressed word prosody on auditory comprehension by listeners with aphasia. Four paragraphs each with eight sentences taken from Kimelman & McNeil (1987, 1989) were used for the study. Target words were selected for each of the eight sentences, and each paragraph was recorded twice by a Native American male speaker. Paragraph length narratives were computer edited to yield two conditions. In one condition, both the target words and the surrounding context were periodically neutral. In the second condition, target words were stressed and the surrounding contexts were prosodically neutral. The paragraph length stimuli were presented to 10 aphasic listeners in different random order. After listening to each paragraph the subjects were instructed to answer 16 yes/no questions verbally and/or gesturally. Two questions were asked about each of the 8 target words in each paragraph. Analysis revealed that for aphasic listeners, target word stress alone does not contribute significantly to the auditory comprehension of those target words in paragraph length stimuli. This suggests that improved auditory comprehension of paragraph-length stimuli, when target words are stressed, may be due almost to contextual influences. Also, it was apparent that some aphasic listeners can use stress to facilitate their auditory comprehension. The evidence suggests that the role of stress in aphasic auditory comprehension is similar to that of reduced rate; it facilitates comprehension for some of the people some of the time.

Independent manipulation of acoustic cues may determine whether patients with LHD and RHD relay on different acoustic parameters. To test this, Baum (1998) attempted to neutralize the F0 or duration cues in phonemic and

emphatic stress stimuli to ascertain the effects of such manipulations on identification accuracy. Three groups of participants were included in the experiment: 12 LHD and aphasia, 10 RED, and 10 age-matched non-brain-damaged individuals. Two sets of base stimuli were created: phonemic or lexical stress pairs (i.e., pairs of utterances that are phonologically identical and differ in stress placement) and emphatic or contrastive stress pairs (i.e., pairs of utterances that differ in terms of which content word receives primary focus or emphasis). For the phonemic stress stimuli, 12 two-syllable utterances that formed either a compound noun or noun phrase, depending on which syllable was stressed, were used. Similarly, for the emphatic stress stimuli, 12 short (4-5-word) NP V NP utterances that could receive contrastive stress on the initial or final noun were created. For each version of the phonemic stress pairs, a color drawing depicting the meaning of the stimulus was prepared. For the emphatic stress pairs, utterances were printed in orthographic form with either the first or last noun highlighted. From this set of naturally produced base stimuli, two additional stimulus sets were derived. In one, F0 cues to stress were neutralized, whereas in the other duration cues were effectively neutralized. Participants were tested with stimuli in each of 6 subjects (phonemic stress - full cue; phonemic stress - duration equivalent; phonemic stress - F0 equivalent; emphatic stress - full cue; emphatic stress - duration equivalent; emphatic stress - F0 equivalent). Stimuli were presented via computers over headphones. Simultaneous with presentation of the auditory signal, a choice of two pictures depicting contrasting stress (for the phonemic stress subsets) or two orthographic stimuli with contrasting highlighted nouns (for the emphatic stress subsets) were presented. Responses were recorded by the examiner. Percent correct stress identification was computed for each individual. Results demonstrated that aphasics with LHD exhibit an impaired ability to make phonemic stress judgments, even when stimuli contain the full complement of acoustic cues to stress. Because their performance on full-cue stimuli does not differ from chance, altering the stimuli by neutralizing temporal or F0 cues does not further diminish their performance. Individuals with RHD also exhibited a deficit relative to normal participants in identifying phonemic stress contrasts. On the full-cue stimuli, their performance significantly exceeded that of the patients with LHD and was significantly better than chance. When either F0 or duration was neutralized, the patients with RHD performed at chance level. It is important to note that, for stimuli in which F0 cues were unavailable, KBD control participants also could not identify phonemic stress contrasts with better than-chance accuracy, suggesting a heavy reliance on F0 information in making such judgements. The results of the above study in part support the claim that linguistic prosody is processed in the left hemisphere, whereas the right hemisphere controls emotional prosody. A comment concerning individual variability in performance is also warranted. Within both the RHD and LHD group, there were individual participants who performed well above the group average, in some instances approximating normal performance. Although, no measured clinical characteristics differentiated these individuals from the rest of the group, there are several factors that could have influenced performance. Perhaps most obvious among the contributing factors are differences in site and extent of lesion. Some previous investigations have reported marked differences in prosodic processing, depending on lesion site (Ross, 1981, among others). A related factor is severity of deficit and accompanying neuralgic symptoms, such as visual or behavioral neglect. It has been suggested that the presence of such associated deficits may reflect a more severe impairment and thus be indicative of poor performance in prosodic perception tasks (Pell & Baum, 1997a). Finally, it is noteworthy that, even among the normal control group, some inter individual variability was found in performance and in the relative reliance on durational or fundamental frequency cues to stress. In order to make claims about impaired performance, it is therefore important to examine individual performance as well as group trends in analyzing the perception of prosody.

Whether additional discourse processing of nonreflexive pronouns affects Broca's aphasic's comprehension of contrastive stress in isolated sentences is a further question of study. Avrutin, Lubarsky & Greene (1999) took eight patients with Broca's Aphasia and five control subjects in age ranging from 45 to 81 years. The stimuli consisted of 52 isolated sentences. Thirteen sentences were of the form "First John [verb hit] s Bill and then MARY [verb hit] s him" (vocal stress indicated by capitalized letters). These kind of sentences had pronoun stressed and were referred to as stressed condition sentences (SC). These were matched with 13 sentences of the form "First John [verb (hit)] s Bill and then Mary [verb (hit)] s him". These kinds of sentences had pronoun spoken without stress and were referred to as unstressed condition sentences (US). The remaining 26 sentences in which none of the words were stressed beyond the normal patterns served as controlled sentences. Prior to the test, the subjects were shown pictures of John, Bill, and Mary, introducing each character and asking them to identify the characters on their own. The subjects were instructed that they would be listening to sentences containing two parts. They were shown the picture illustrating the action described in the first part of the sentence and then asked to point to one of the three pictures that best illustrated the scenario described in the second part of the sentence. All sentences were presented orally in random order and repeated once upon the request. Results showed a significant discrepancy between the normals and Broca's aphasics in both SC and UC sentences; the aphasic group was not significantly above chance on either. The results suggested a disruption in Broca's aphasics ability to comprehend stress during sentences requiring the establishment of pronoun reference. According to authors of this study, this disruption is due to simultaneous discourse processing of pronouns that generally poses problems for agrammatic subjects.

In order to test this hypothesis they conducted a second experiment in which discourse-related operations were eliminated. Thus, none of the sentences contained elements requiring discourse-level processing. The aim of the second experiment was to test Broca's aphasic's comprehension of contrastive stress in sentences invoking morphosyntactic rather than discourse-related linguistic operations. The same subjects participated in the second experiment. The target stimuli consisted of 40 isolated sentences such as the form "show me an X" (hotdog vs hot dog). This included 10 combinations of minimal pairs with respect to stress and 20 control sentences. In 10 of the sentences, X was a compound noun (CN) and these were matched with 10 sentences in which X was a noun phrase. The remaining 20 sentences were controls (CS). All sentences were presented orally in random order and repeated once upon request. For each sentence, the subjects were asked to point one of the three pictures corresponding to the correct meaning of X. Results indicated that Broca's aphasic group improved significantly in their comprehension of sentences involving compound nouns, while their comprehension of sentences containing adjectival phrases remained at chance. So, authors concluded that Broca's aphasics, though not insensitive to the stress patterns of sentences containing discourse-related operations, have difficulty in implementing an intact knowledge of contrastive stress to assist their establishment of reference for pronouns. When they are presented with sentences invoking morphosyntactic without additional discourse processing, Broca's aphasics showed an enhanced ability to apply their knowledge of stress towards interpretation and comprehension of sentences. These results offer into the nature of language impairment in Broca's aphasia, supporting a processing account model of linguistic deficit.

Different theories have been proposed to provide plausible explanations of the conflicting findings regarding hemispheric specialization in processing prosodic structures. In order to examine the functional lateralization theory, Walker, Trager & Buzzard (2002) conducted four experiments that altered the linguistic and nonlinguistic functions across a range of prosodic structures. They addressed the extent to which the processing of lexical stress differences would be lateralized to the left or right hemisphere through four experiments that altered the linguistic and nonlinguistic functions across a range of prosodic structures. Three groups of subjects participated in each of the four experiments: 8 LHD, 8 RHD and 8 control subjects. The first experiment addressed the extent to which the processing of lexical stress differences would be lateralized to the left or right hemisphere by requiring listeners to determine the meanings and grammatical assignments of two-syllable words conveyed through stressed or unstressed syllables. In another linguistic condition, the second experiment placed demands on syntactic parsing operations by requiring listeners to parse syntactically ambiguous sentences, which were disambiguated through the perception of prosodic boundaries located at syntactic junctures. A third linguistic condition required listeners to determine the categorical assignment of a speaker's intention of making a statement or asking a question conveyed through the prosodic structures. The fourth experiment was designed to determine hemisphere lateralization in processing nonlinguistic prosodic structures. In this experiment, listeners were required to determine the emotional state of a speaker conveyed through the prosodic structures in sentences that contained semantic information, which was either congruent or incongruent with the emotional content of the prosodic structures.

The results of experiment 1 in which subjects were asked to identify lexical stress differences indicated that control group (total = 127/136, 93 %, M = 15.8, SD= 0.64) and RHD group (total = 116/136, 85 %, M = 14.5, SD = 1.7) performed better than LHD group (total = 90/136, 66 %, M = 11.2, SD = 2.6). The results from this experiment supported the functional lateralization theory as the lexical stress placement in two-syllable words performs a linguistic function of conveying either noun or verb grammatical categories. Further, the pattern of errors too supported functional lateralization theory with the control and RHD groups having made fewer errors than the LHD group. The results of experiment 2 involving syntactic parsing identification again indicated better performance of control (total = 147/160, 91 %, M = 18, SD = 1.18) and RHD group (total = 135/160, 84 %, M = 16.8, SD = 0.83) compared to LHD group (total = 102/160, 63 % , M = 12.7, SD = 3.19). This again supported functional lateralization theory as prosodic structures that influence syntactic parsing decision performs a errors compared to LHD group. Third experiment involving questions and statements identification too indicated better performance of control (total = 149/160, 99 %, M = 19.8, SD = 0.35) and RHD group (total = 149/160, 93 %, M = 18.65, SD = 1.68) in comparison with LHD group (total = 113/160, 70 %, M = 14.12, SD = 3.48) supporting functional lateralization theory. Experiment 4 involving emotional identification revealed better performance of control (total = 159/160, 99 %, M = 19.85, SD = 0.35) and LHD group (total = 143/160, 89 %, M = 17.87, SD = 3.64) compared to RHD group (total = 108/160, 67 %, M = 13.5, SD = 2.87). This again supported the functional lateralization theory with LHD group performing better than RHD group in processing prosodic structures that perform a nonlinguistic function of conveying emotion.

Because the LHD group had a poorer performance than the other two groups in the linguistic experiments, inferences can be drawn which implicate the left hemisphere in processing prosodic structures that play a linguistic function. Similarly, based on the poorer performance of the RHD group than the other two groups on the nonlinguistic experiments, inferences can be drawn which implicate the right hemisphere in processing prosodic structures that play a nonlinguistic function of conveying emotion. Some of the limitation of the study is that a few of the subjects would have benefited from more than two practice items as their responses reflected a learning effect on initial items. Pictorial ambiguities of some of the stimulus items contributed to the difficulty a few of the subjects had in formulating responses, in spite of the piloting procedures utilized during the stimuli development and visuo-spatial screening procedures that were administered prior to the execution of the experiments. Utilizing more concrete stimuli that are easy to depict may have eliminated potential ambiguities. Lastly, the experiments were impacted by individual subject variations in response strategies, a problem inherent in all research using human subjects.

The results of the above studies support the functional lateralization hypothesis that left hemisphere controls linguistic prosody and right hemisphere controls emotional prosody (Van Lancker, 1980). According to this theory, the specialized role of the left hemisphere is revealed for processing prosodic structure that performs a linguistic function (e.g., conveying lexical stress differences), and the right hemisphere for processing nonlinguistic prosodic information (e.g., conveying emotion). This theory does not account for potential hemisphere differences in processing the acoustic characteristics of the prosodic structure at a perceptual level. Rather, it suggests that hemispheric specialization is determined at later stages of sentence processing where an in-depth analysis of the linguistic and nonlinguistic function is determined.

The most straightforward of the hypothesis contends that all aspects of prosody are processed in the right hemisphere and intergrated with linguistic information via callosal connections (Klouda et. al., 1988). The hypothesis that callosal connections are directly involved in prosodic processing would be better supported by evidence of impairment to both affective and linguistic prosodic features following callosal disconnection. Weintraub et. al. (1981) in a study on phonemic stress contrasts in RHD patients concluded that right hemisphere damage yields a deficit in linguistic prosody as well as affective prosody. The impairment of the RHD appears to concern the actual perceptual decoding of prosody, independently of its linguistic function. This hypothesis is all the more plausible since these subjects also had difficulties discriminating emotional prosody. Another argument to support this hypothesis would be the observation of a positive correlation between scores for emotional or linguistic prosody and a deficit on an auditory discrimination test. Weintraub et. al. (1981) further predicted that a similar deficit subsequent to left hemisphere damage would be unlikely to emerge and therefore the right hemisphere is dominant for prosodic production in general. The task upon which these conclusions are based is open to a great deal of criticism, rendering the data suspect. Listener judgments may be quite subjective and those of a single listener are even more prone to bias. Moreover, the absence of a LED control group raises questions about the validity of the claims of right hemisphere dominance for both affective and linguistic prosodic production. The results of the Weintraub et. al. (1981) study suggests that several different types of linguistic prosody (e.g., lexical stress, emphatic stress, and accentuation of the intonation contour) were at the source of the difficulties of the RHD. However, it is not known if these difficulties were of the same nature or if they were correlated to one another.

The model proposed by Grant & Dingwall (1985) adds interesting perspectives, at least with respect to the English language. First, it postulates that lexical stress is linked to a given linguistic segment, whereas intonation-based modality is more independent and concerns the sentence as whole. The hypothesis advanced by these authors is that the left hemisphere is all the more involved as prosody is related to a given segment (stress), whereas the right hemisphere is all the more involved as prosody occurs over a longer period of time (and therefore involves a greater number of segments). Grant & Dingwall used discrimination task to evaluate the comprehension of shifts in grammatical class as a function of the placement of lexical stress. They considered 9 RHD, 9 LHD and 9 non-brain-damaged as subjects and each subject was asked to identify verb or noun, based on stress placement on the first or second syllable. Thus the word "import" in English could be either a noun or a verb, depending on whether the stress is placed on the first or second syllable. They found that RHD performed same as aphasics. However, the performance was significantly less than that of non-brain-damaged (NBD). In a second task, the subjects were required to discriminate between the intonation-based modality of two sentences. RHD made significantly more errors than aphasics, whether or not the sentences were filtered, and the performance of both of these groups was significantly worse than that of NBD. In summary, RHD obtained lower scores than normals for both types of linguistic prosody and obtained lower scores than aphasics only for prosody marking intonation-based modality. Thus the authors concluded that each hemisphere is involved to a varying degree depending on the type of linguistic prosody. The Grant & Dingwall (1985) model requires more study, but it should be recognized that it is compatible with the results of previously mentioned studies.

Klouda et. al. (1988) presented a case report of 39-year old woman who suffered an aneurismal hemorrhage damaging the anterior four-fifths of the corpus callosum. In their study they wanted to find evidence for impairment of both affective and linguistic prosodic feature following callosal disconnections and whether callosal connections are directly involved in prosodic processing. Patient's prosody was tested longitudinally at 4 weeks, 4 months, and 1 year after surgery. They administered two production tests during each test period. The first test intended to assess the patient's ability to modulate prosody in order to signal emotional and the linguistic contrast between interrogative and declarative sentences. Base stimuli for this test included four sentences that were affectively neutral and plausibly rendered with different affective tones. The patient was instructed to read each sentence with a happy, sad, angry, neutral, and questioning tone of voice. Totally there were 20 items that were presented randomly at each test period. The second test assessed the patient's ability to utilize prosody to signal emphatic stress placed on the initial or final words of a sentence. The subject was asked to read sentences in which the location of stress was systematically varied. The second test included 18 test items that were presented randomly at each test period. Subject's utterance for both tests were recorded and computer aided acoustic analysis was performed on emotive and non-emotive utterances at 4 weeks, 4 months and one year post surgery. F0 and durational measures were taken for each set of utterances. F0 measure included peak F0 values for each key word and durational measures included word duration, pause, sentence duration, voice onset time, vowel duration, second formant frequency, transition duration, fricative duration and closure duration. Results of affective prosody analysis indicated acoustic evidence of the loss of affective F0 distinctions immediately following callosal disconnection, with improvement as a function of time. Linguistic patterns characteristic of emphatic stress and question forms were found to some degree at all test periods, but again improved with time. Suprasegmental durational analysis revealed intact affective and linguistic durational distinctions one month following callosal damage, suggesting that interhemispheric connections may not be necessary for proper programming of these durational features. However, a decrease in durational distinctions for the second and third testing sessions is attributed to the signs of depression shown by the patient during the same time period. In general, the results of this study provided acoustic evidence that interhemispheric connections via the corpus callosum are important for proper F0 programming, especially emotive distinctions. Further, the study provided strong evidence that the right hemisphere generally contribute to the processing of F0 information and suggested that F0 information processed in the right hemisphere is integrated with information processed in the left hemisphere speech centers via the corpus callosum.

The fact that durational measures were relatively intact in this patient suggests that, unlike F0, duration may be processed primarily in the left hemisphere. This conclusion is consistent with the results of several studies of speech perception in normal and brain damaged subjects (Blumstein & Cooper, 1974; Berlin & Me Neil, 1976; Gregory, 1982; Sidtis, 1984). Further, it can be noted that although the patient exhibited F0 deficits initially, she showed considerable improvement with respect to both affective and linguistic F0 distinctions as a function of time (post surgery). These improvements in speech production were accompanied by improvements in the perceptual judgment of her intended tone by normal listeners. Such improvement may imply that, while the right hemisphere generally contributes to F0 programming, following callosal damage the left hemisphere can later perform such programming.

Bryan (1989) examined the right hemisphere contribution to the processing of linguistic prosody by (a) comparing the performance of RHD to both normal and LHD subjects, (b) examining discrimination and production in the same subjects, (c) examining several aspects of prosody involving lexical and sentence processing, (d) examining prosodic production in a number of different tasks e.g. repetition, naming and elicited speech, and (e) by ensuring that aphasia and dysarthria do not account for any right hemisphere disorder. Groups of 30 RHD, 30 LHD and age and gender matched 30 NBD control subjects were assessed on a battery of 13 linguistic prosody tests that incorporated stimuli of various perceptual domains (lexical stress, intonation, emphatic stress, lexical stress in sentence contexts, language identification using prosodic cues, and prosody in discourse) to examine discrimination and production of aspects of linguistic prosody. For discrimination of emphatic stress three short sentences in which stress could occur in one of the four places with the emphasis in meaning changing according to the stress placement. Each subject was made to hear each sentence twice and asked to tap the phrase and indicate the stressed word. A total of 12 items were used in the test. For the production of emphatic stress two sentences each having two clauses joined by the conjunctions 'and' or 'but' were constructed and each item was depicted in two clearly drawn pictures. The two pictures were placed in front of the subject and were asked to describe with the expected stress pattern. The utterance was recorded and judged by an independent observer in terms of stress placement. For the discrimination of lexical stress subjects were asked to discriminate between compound words whose meaning changed depending upon the location of the stress. For the repetition of lexical stress pattern, five pairs of words from each of the discrimination tests were selected randomly. Each word was produced once and the subject was instructed to repeat it. The responses were assessed for similarity of stress placement by an independent judge. Production of lexical stress was assessed by selecting five pairs from each of the two types of lexical items with each word illustrated by a line drawing. Subject was asked to name the picture and responses were recorded and an independent observer judged stress patterns. Comprehension of lexical stress in a sentence context was assessed using noun/noun phrases and noun/verb. Ten items from the discrimination test were selected, for each of which two sentences were devised. In one sentence the target word was stressed correctly and in the other it was incorrectly stressed. The sentences were recorded on to a tape and presented randomly. Subjects were made to hear each sentence twice and asked to indicate whether or not it sounded correct. Discrimination changes in intonation were assessed by a set of 30 sentences produced either in statement or question form. The subjects were made to hear each sentence twice and asked to point one of the two cards indicating same or not same. Comprehension of intonation was assessed by using same set of sentences but which were spoken either as a statement or a question. Each sentence was presented twice and subjects were asked to judge it as a statement or question by pointing to the appropriate card. Results of their study indicated that individuals with RHD were impaired on all 13 tasks of linguistic prosody relative to the NBD and on 8 tasks relative to the individuals with LHD, favoring a right hemisphere basis for this processing. However, it is noteworthy that, individuals with LHD reported by Bryan (1989) were significantly impaired relative to the NBD on 10 of the 13 tasks as well; a finding the author conceded may be suggestive of bilateral control for at least some aspects of linguistic prosody. The authors also indicated that the parieto-temporal area seemed to be particularly important in prosodic processing in the right hemisphere. However, the results indicated that there might be difficulties in the deficit according to the exact site of the damage. Also, the results supported the notion of specific linguistic prosodic disorder after right hemisphere damage.

Bradvik, Dravins, Holtas, Rosen, Ryding, & Ingvar (1991) also noted inferior performance of their RED individuals on both linguistic and emotional tasks and arrived at conclusion of essential role for the right hemisphere in the processing of both (linguistic and affective) prosody, irrespective of the domain over which prosodic cues were perceived. They compared the performance of 20 Swedish-speaking patients with stable right hemisphere lesions and 18 normal controls on tasks of both linguistic and affective prosody (e.g. emphatic stress perception, identification of linguistic and emotional intonation).

The omission of a comparable LHD group in the latter two studies (Weintraub et. al. 1981, Bradvik et. al.. 1991) again impedes an appropriate understanding of each hemisphere's potential involvement in prosodic perception. Therefore, evidence of a bilateral substrate for emotional prosody comprehension is lacking.

Pell (1998a) studied prosodic perception in LHDs, RHDs and age matched NBDs. Short utterances distinguished solely by their prosodic features (stimuli differed with respect to emphasis assignment, linguistic modality, and emotional tone) were presented over headphones to 11 LHD, 9 RHD and 10 normal

Individuals. Subjects listened to this common set of utterances over several conditions, which manipulated the strength of particular acoustic parameters of stimuli and were to independently judge either the location of emphatic stress within the sentence (initial, final, none) or the emotional tone (happy, angry, sad, neutral). Results indicated that although emphasis perception was uniquely disturbed in the LED, accuracy in recognizing emotional attributes of the same stimuli was significantly impaired in both RED and LHD relative to age matched NBDs. For emotional prosody, this pattern advances the position that distributed mechanisms in both hemispheres of the brain may be necessary for such processing. However, the observation that RHD were selectively impaired in the emotion condition relative to the linguistic (emphasis) condition (the accuracy of the LHD did not differ across conditions) implies that the locus of certain operations inherent to emotional perception and evaluation may stem from a unique right hemisphere mechanism. Delineating the components within this functional system that favor right versus left hemisphere-processing mechanisms, remain a considerable challenge for further research.

Van Lancker & Sidtis (1992) formulated a different perspective on the contributions of left and right hemisphere mechanisms in the comprehension of affective-prosodic stimuli and put forth a third hypothesis, the differential cue laterlization hypothesis. In their hypothesis, Van Lancker & Sidtis stated that the hemispheric specialization is dictated by the acoustic characteristic of prosodic structure where right hemisphere dominance exists in processing the frequency characteristic of of the acoustic signal and the left hemisphere processes the temporal information contained within prosodic structures. The hypothesis was based on the results of their study, which compared the performance of participants with LHD and RHD, and non-brain damaged (NBD) individuals on an emotional prosody identification task observing a similar level of impairment in the accuracy of both clinical groups. The authors further explored whether the comprehension errors of LHD and RHD could be predicted in terms of one or a combination of the acoustic parameters underlying emotional prosodic meanings. The authors determined mean and variability measures of F0, amplitude, and duration for the stimuli they had presented to patients for perceptual recognition. Discrimination function analyses were then performed to ascertain which of the acoustic cues served to signal the intended emotional meanings of the stimuli initially presented, and which cues predicted the comprehension errors made by each clinical group on the identification task; this procedure involved receding each emotional stimulus according to the most frequent error response observed for that stimulus, independently for each group. In this way, the authors sought to determine the extent to which the LHD and RHD subject's emotional comprehension deficits were related to impaired perception of specific acoustic features of the stimuli.

Despite the similar level of impairment of LHD and RHD on the emotional identification task, analyses performed on each group's recognition errors suggested that LHD and RHD were using the acoustic cues to prosody differently in judging affective meanings. Interestingly, the discriminant analysis of the LHD errors revealed that these patients might have been basing their decisions on F0 information (particularly F0 variability); whereas an analysis of RHD subject's affective misclassifications indicated a reliance on durational cues in identifying the stimuli. This pattern of results suggested to the authors that receptive disturbances of emotional prosody might be perceptual in nature, possibly reflecting the superiority of each hemisphere in processing different acoustic parameters that signal prosodic meaning. Van Lancker & Sidtis (1992) concluded that mechanisms sub serving prosodic processing are bilaterally distributed with right hemisphere more specialized for processing FO and the left hemisphere more specialized for processing temporal acoustic parameters. More generally, the authors concluded that the comprehension of prosody is best described as a multifaceted process sub served by distributed (i.e. bilateral) mechanisms that are strictly localizable to the right hemisphere, contrary to previous assertions (Ross 1981). The hypothesis got support from the results of Klouda et. al. (1988) who reported contribution of right hemisphere in processing FO information.

This hypothesis also received support from the results of a study of ERPs in RHD and LHD patients (Twist, Squires, Spielholz & Silverglide, 1991) and Positron Emission Tomography (PET) study by Zatorre, Evans, Meyer, & Giedde (1992). RHD patients were shown to exhibit abnormal ERP patterns in non-speech frequency discrimination tasks as well as in an affective prosody discrimination task. LHD only displayed abnormalities in a semantic discrimination task. Twist & colleagues interpreted the ERP results as supporting the right hemisphere's role in prosodic processing, despite the absence of differences between the two brain-damaged groups on standard behavioral measures of prosodic abilities. Zatorre et. al. (1992) in a PET study with non-brain-damaged individuals compared activation patterns in tasks requiring phonetic judgments and pitch judgments. The result demonstrated increased activity in Broca's area during tasks requiring phonetic judgments concerning CVC syllables; in contrast, tasks requiring pitch judgments of the same CVC syllables elicited right prefrontal activation, suggesting that identification of F0 is associated with right hemisphere mechanisms. These findings may support dissociation in the lateralized processing of specific acoustic parameters. A good deal of evidence has supported RH involvement in pitch discrimination in the nonspeech domain (Robin, Tranel, & Damasio, 1990; Sidtis & Feldmann, 1990; Zatorre, 1988; Zatorre, Evans, & Meyer, 1994). Unfortunately, to date little comparable research has been reported in the speech domain.

Further evidence on the role of right hemisphere comes from the study by Baum (1998). She investigated the role of F0 and duration in the perception of linguistic stress by individuals with brain damage and non-brain damage (NBD). Specifically F0 or duration cues were neutralized in phonemic and emphatic stress stimuli to ascertain the effects of such manipulations on identification accuracy. Twelve LHD patients, 10 RHD patients and 10 age-matched NBD individuals participated in the study. Stimuli consisted of two sets of base stimuli comprising of phonemic or lexical stress pairs (pairs of utterances that were phonologically identical and differed in stress placement) and emphatic or contrastive stress pairs (pairs of utterances that differ in terms of which content word receives primary focus or emphasis). Phonemic stress stimuli included 12 two-syllabic utterances that formed either a compound noun or noun phrase, depending on which syllable was stressed. Emphatic stress stimuli comprised of 12 short NP V NP utterances that could receive contrastive stress on the initial or final noun. The meaning of phonemic stress pairs were depicted by line drawing and emphatic stress pairs were printed in orthographic form with either the first or last noun highlighted. From a set of naturally produced base stimuli, two additional stimulus sets, duration equivalent and F0 equivalent, were derived. In one, F0 cues to stress were neutralized, whereas in the other duration cues were effectively neutralized. F0 equivalent stimuli was created by extracting the F0 contour from the unstressed version of the target syllable in each utterance and then re-synthesized with the filter function of the stressed version to create stimuli that retained the temporal cues to stress, but neutralized the F0 cues. Participants were tested individually by presenting stimuli in each of six subtests (phonemic stress - full cue, phonemic stress - duration equivalent, phonemic stress - F0 equivalent, emphatic stress - full cue, emphatic stress - duration equivalent, emphatic stress - F0 equivalent). With the simultaneous presentation of the auditory signal, a choice of two pictures depicting contrasting stress or two orthographic stimuli with contrasting highlighted nouns was randomly presented.

For the phonemic stress, the results indicated that patients with LHD exhibited an impaired ability to make phonemic stress judgments even when stimuli contained full complement of acoustic cues to stress. Further, individuals with RHD also exhibited a deficit relative to normal participants in identifying phonemic stress contrasts. On the full-cue stimuli, the performance of RHD patients significantly exceeded that of patients with LHD and was significantly better than chance. Patients with RHD performed at chance level when either F0 or duration was neutralized. NBD control participants also could not identify phonemic stress contrasts with better-than-chance accuracy, for stimuli in which

FO cues were unavailable, suggesting a heavy reliance on FO information in making such judgments. RHD as a group did not show better performance on duration equivalent stimuli as compared to FO-equivalent stimuli and LED as a group did not show differential performance on duration equivalent and FO-equivalent stimuli, contradicting a greater reliance by individuals with LHD on FO cues and RHD on duration cues.

On emphatic stress subtest, only the performance of LHD patients differed from NBD individuals suggesting impairment on linguistic stress identification task by LHD patients. Accuracy rates for RHD fell between those of the NBD and LHD and did not differ significantly from either group, suggesting that RHD may not consistently inhibit identification of emphatic stress. Identification of the full-cue stimuli was better than stimuli in the other two conditions across groups. However, only LHD patients demonstrated chance performance in the FO-equivalent condition indicating that the FO manipulation had a much smaller effect on the RHD and NBD individual's emphatic stress judgments compared to their phonemic stress judgments. There was high individual variability in the results obtained from both subtests. Based on the results obtained through both subtests, Baum (1998) concluded that neural substrates of prosody remain elusive, undoubtedly both hemispheres involve in the processing of prosody. But, there is differential preference for temporal and spectral cues for processing stress in the brain damaged.

High individual variability seen in the performance of the subjects warrants the presence of other factors influencing the performance. The most contributing factor may be differences seen in terms of site and extent of lesion. Ross (1981) reported marked differences in prosodic processing, depending on site of lesion. Further Pell & Baum (1997a) suggested that presence of associated deficit like severity of deficit and accompanying neurological symptoms may reflect a more severe impairment and thus indicate poor performance. In Baum's study no clear-cut relationship between severity and prosodic processing was established as both severely and mildly impaired were considered as subjects. Some inter individual variability seen in the performance of normal control group in terms of relative reliance on durational or FO cues to stress warrants examination of individual performance as well as group trends in analyzing the perception of prosody.

In Kannada, a Dravidian language, there is no phonemic stress. Stress is used at a phrase/sentence level to bring about emphasis. Sarah, Prakash & Savithri (2000) investigated the perception of stress in three Kannada speaking adults with left hemisphere damage and their age matched normal subjects. Ten noun-adjective phrases as spoken with and without stress on the first word by a native Kannada speaker was the original material. FO in the unstressed word were changed to that in stressed word. Similarly, intensity and duration in the unstressed word were changed to that in stressed word individually and in combinations. The original unstressed phrase was paired with the edited phrase. Subjects listened to the sample and said whether the phrases in a pair were the same or different. The results indicated that patients with the left hemisphere damage perceived word stress poorly compared to normal subjects. The authors also noted that duration was a prominent cue in the perception of word stress in Kannada.

Subsequently, Sarah (2000) studied the perception of stress in Kannada speaking individuals with RHD (1), LHD (5) and normal controls (5). The stimuli considered for the study were five two-word phrases with adjective-noun combination. These phrases as spoken by a normal Kannada speaker with and without stress on the adjective were audio-recorded and acoustically analyzed to extract F0 and intensity (every 10 ms), and word duration of the stressed and unstressed adjectives. Synthetic stimuli were generated in which a single acoustic parameter (FO/intensity/duration) of the stressed word was transposed to the counterpart unstressed word. Therefore, three types of synthetic phrases - one with F0 cue, one with intensity cue, and one with duration cue - were generated. Each synthetic phrase was paired with its original unstressed phrase to make phrase pairs. Subjects listened to the phrase pairs and responded on a binary response sheet indicating whether the two phrases in a pair were the same or different. The results indicated that individuals with LHD performed poorly on task involving temporal cue (duration) and those with RHD performed poorly on task involving F0 cue. The results supported the differential lateralization hypothesis. It appeared that both the hemispheres are involved in prosodic processing. While the right hemisphere processes the frequency parameters, the left hemisphere processes the temporal parameters. However, the study was limited to one RHD, and 5 LHD. Hence, based on the response of one RHD subject, the results could not be generalized on RHD population.

The extent to which a cue contributes to prosodic processing and the effects of spectral manipulations on comprehension of prosody is less well understood. For example, both F0 (Fairbanks & Pronovost, 1939; Ladd & Silverman, 1985; Lieberman & Michaels, 1962; Ross, Edmondson, & Seibert, 1986; Van Lancker & Sidtis, 1992; Williams & Stevens, 1972) and duration (Fairbanks & Hoaglin, 1941) have been shown to be important cues in distinguishing affect conveyed in speech, but their respective contribution is still debated (Lakshminarayanan, Shalom, Wassenhove, Orbeelo, Houde, & Poeppel, 2003).

Traditionally, F0 that carries pitch information is assumed to be the most crucial cue for prosody. This view is referred to as the F0 hypothesis. The F0 hypothesis was weakened by the findings of Grant & Walden (1996), who tested the comprehension ability of normally hearing speakers in six different spectral manipulations of sentences and phrases (linguistic prosody), each manipulation preserving a different part of the acoustic spectrum. They evaluated several lexical prosodic phenomena, specifically syllable number and stress, which were perceived better in some 'high' band-pass filter conditions (that omitted the F0 spectral range) compared to a low-band-pass filter conditions (that included the F0 spectral range). Nevertheless, overall performance was remarkably good in all six different band-pass manipulations. The main conclusion drawn by Grant & Walden (1996) concerned the robustness of prosodic processing across the acoustic frequency spectrum. The authors interpreted this robustness as indicating a differential distribution of prosodic information across the speech spectrum. Hence, the same prosodic function is sub served by multiple frequency cues. On their view higher frequency bands provide more information about the stress pattern and syllable number while lower frequency bands provide more information with regard to intonation patterns.

The questions as to the extent to which linguistic and affective prosody are differentially manipulated by the signal manipulation and which signal manipulations affect the perception of prosodic contrasts remain unanswered. Lakshminarayanan et. al. (2003) investigated the effect of various spectral manipulations on the identification of sentential prosody. The primary purpose of the study was to investigate (a) to what extent linguistic and affective prosody are differentially modulated by the signal manipulations introduced and (b) which signal manipulations selectively / differentially affect the perception of prosodic contrasts. Two main categories of prosody - affective (happy, angry, sad) and linguistic (statement, question, continuation) - were studied. Thirty-six normal subjects in the age range of 18 to 34 years were presented with stimuli that were recorded by a female native speaker of American English. Four semantically neutral sentences formed the test items using which an affective and linguistic stimulus sets were constructed. There were three conditions in each of the sets. Affective (AFF) comprised of angry (ANG), happy (HAP), and sad (SAD) intonation conditions and linguistic (LING) comprised of statement (STM), question (QUE) and continuation (CON) intonation conditions. The second experiment comprised of different spectral manipulations of each condition. Such as (1) natural (NAT - high-quality recorded original utterances), (2) synthesized (SYNTH - a re-synthesized version of the NAT stimulus using a vocoder), (3) re-entrant (RENT - auditory signal convolved with a steady -state signal), (4) low band-pass (LBP - SYNTH signal filtered with bandwidth 80-300 Hz) and (5) high band-pass (HBP - SYNTH signal filtered with bandwidth 1830-2240 Hz). The stimuli were presented using Syncope. A two-block design was used to separate affective and linguistic conditions. Each block consisting of 60 trials was further sub-divided into two sub-blocks. The synthesized and re-entrant stimuli were presented in a pseudo-random order in the first sub-block (24 trials) and the natural and filtered conditions were presented in the second-block (36 trials). Subjects were asked to listen to the stimuli and categorize them by an appropriate key press. A preliminary practice session comprising of two sentences was presented in each of the NAT, SYNTH, LBP and HBP forms in random order. Subjects were asked to identify the prosodic conditions they heard. Results indicated that overall, subject performance was significantly degraded in LBP (0.83) compared to NAT (0.92), SYNTH (0.90) and HBP (0.89). REENT was significantly worse (0.74) compared to NAT (0.92), SYNTH (0.90), LBP (0.83) and HBP (0.89). A relative ordering of performance in accordance with the F0 hypothesis revealed best performance in the natural and re-synthesized conditions, which had complete F0, duration, amplitude, and phonetic information, followed by medium performance in the re-entrant condition, which had all but phonetic information, followed by the low-band-passed that retained the F0 spectral region but lost some phonetic information, followed finally by high-band-passed conditions that did not include the FO spectral region. Results of a forced-choice discrimination paradigm showed that, in general, performance was remarkably robust despite spectral manipulation, even when there was relatively little spectral information. However, performance was significantly degraded in the low band-pass and re-entrant conditions. In general, the data of the study appear to be more in line with the differential cue hypothesis that individual acoustic cues are lateralized differently.

An important novel aspect of the above work is the use of the re-entrant (REENT) signal, which seems to be a promising de-lexicalization tool. One might expect to find a flat FO contour in the REENT condition since it is primarily synthesized from a steady-state vowel. However, contrary to intuition, it has the advantage of preserving the duration and pitch cues while removing phonetic information. Another important feature of this study concerns the degradation of performance in REENT condition, raising the possibility of syllabification as a critical cue for the identification of some forms of prosody. Further studies specifically addressing the relation between (both acoustic and linguistic) syllable structure and prosody are needed to clarify the issue.

Although intriguing, the hypothesis that individual acoustic cues to prosody are independently lateralized (Van Lancker and Sidtis, 1992) remains speculative and awaits future explanation.

To summarize, there are three hypotheses on the perception of prosody. The first hypothesis functional lateralization hypothesis (Van Lancker, 1980) claims that linguistic prosody is processed in the left hemisphere, whereas emotional prosody is controlled by the right hemisphere. It has also been suggested that the level of linguistic function may play a role in functional laterizations (Behrens, 1988: Candour, Dechongkit, Ponglorpisit, and Khunadom, 1994). A second hypothesis posits that all aspects of prosody are processed in the right hemisphere and integrated across the corpus callosumwith linguistic representations (Klouda, et. al., 1988). A third important hypothesis that has recently gained some experimental support contends that individual acoustic cues to prosody are lateralizedto different hemispheres, with fundamental frequency parameters processed by the right hemisphere and temporal parameters by the left hemisphere (Van Lancker & Sidtis, 1992). Ten studies support the first hypothesis, five studies support the second hypothesis and seven studies supports the third hypothesis. Table 2 provides a summary of these studies.

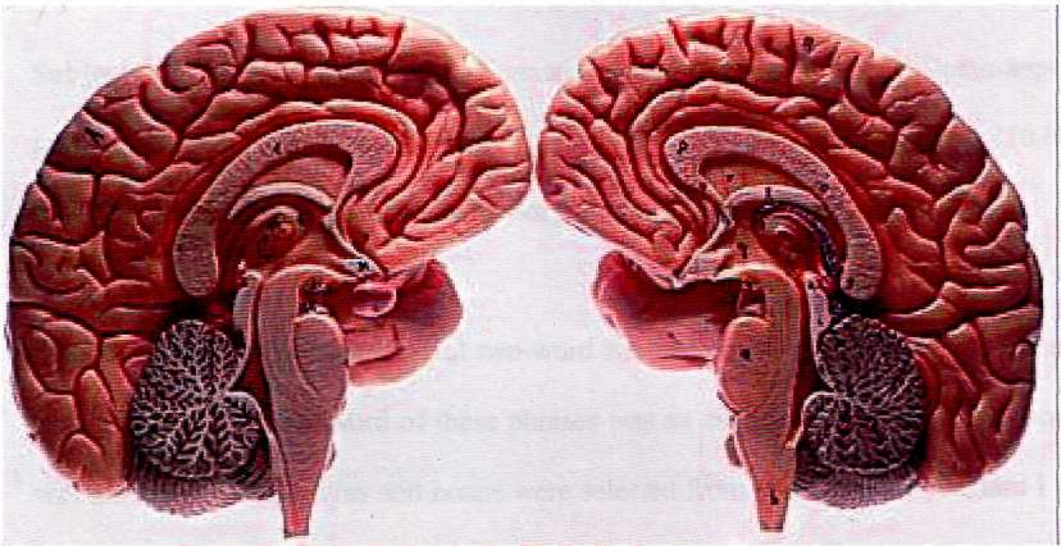
Hypotheses	**Authors**	**Supporting studies**	**Subjects**
Functional lateralization hypothesis: Linguistic prosody is processed in the left hemisphere and emotional prosody is processed in the right hemisphere.	Van Lancker, 1980	Blumstein & Goodglass, 1972	LHD: 17 NBD:13
		Weniger, 1978	LHD, NBD
		Baum et. al., 1982	LHD: 8, NBD: 8
		Pashek & Brookshire, 1982	LHD, RHD, NBD:
		Emmorey, 1984	LHD:15, RHD:7, NBD: 22
		Kimelan & McNeil, 1987	LHD: 9, NBD: 5
		Emmorey, 1987	LHD:15, RHD:7, NBD: 22
		Behrens, 1988	RHD, NBD
		Kimelman, 1991	LHD: 10 , RHD, NBD
		Baum, 1998	LHD:12,RHD:10,NBD: 10
		Walker et. al., 2002	LHD:8, RHD:8, NBD: 8
All aspects of prosody are processed in the ***right hemisphere and integrated across the corpus*** **ca/tosum** with linguistic representations	Klouda, Robin, Graff-Radford, & Cooper, 1988.	Weintraubet. al., 1981	RHD: 9, NBD: 10
		Grant & Dingwall, 1985	LHD:9, RHD:9, NBD:9
		Bryan, 1989	LHD:30,RHD:30,NBD:30
		Bradviket. al., 1991	RHD:20, NBD: 18
		Pell, 1998a	LHD:11, RHD:9, NBD:10
Differential cue lateralization hypothesis: Individual acoustic cues to prosody are lateralized to different hemispheres, with fundamental frequency parameters processed by the right hemisphere and temporal parameters by the left hemisphere	Van Lancker & Sidtis, 1992.	Klouda et. al., 1988	BD:1
		Twist et. al., 1991	LHD, RHD
		Zatorreet. al., 1992	NBD
		Baum, 1998	LHD:12,RHD:10,NBD: 10
		Sarah et. al., 2000	LHD: 3, NBD: 3
		Sarah 2000	LHD:5 , RHD: 1 , NBD:5
		Lakshminarayan et. al., 2003	NBD: 36

Table 2: Summary of studies supporting 3 hypotheses on the perception of prosody.

All these studies are in non-Indian languages, mostly in English except two studies that was done in Kannada. Further, most studies do not have sufficient number of subjects to conclude. Kannada, a Dravidian language, is syllabic in nature. In this language stress is not phonemic but used for emphasis at phrase/sentence level. The studies conducted so far have used linguistic, emphatic and phonemic stress. In these, stress will change the word meaning or linguistic component is involved. In a language like Kannada, stress is used to emphasize a word. Neither stress will change the meaning of a word nor does it have a linguistic component. Kannada has duration as a major cue for stress, but English has pitch as a major cue for stress. Also, the ratio between short and long vowel is 1: 2 in Kannada (Savithri, 1986), while it is 1:1.54 in English (Klatt, 1976). Therefore, the perceptual responses of Kannada speaking patients with brain damage for stimulus with altered duration would be different than those of English speaking patients. Thus, if the left hemisphere is specialized in processing temporal acoustic parameters (duration), it should be better reflected in left brain damaged patients speaking Kannada. (Kannada is a Dravidian language spoken by 20,000,000 persons in Kamataka, a state of south India - H. M. Nayak, 1967). In this context, the present study was planned. The objective of this study was to investigate perception of stress in subjects with CVA, and normal controls speaking Kannada.

Chapter III

Method



"It is impossible to understand human behavior without some level of understanding of the physical structure-the brain-that enables behavior. While a sense of the molar (general or large-scale) structure is essential for a basic recognition of the master organ of the body, an appreciation of the molecular (denser,inner-intricacies) provides foundation and insight to the complex nuances of human behavior".

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The objective of the study was to investigate perception of stress in subjects with cerebro-vascular accident (CVA), and normal controls speaking Kannada. Three experiments were conducted to achieve this objective. Experiment 1 dealt with acoustic analyses of Kannada phrases with and without word stress, experiment II dealt with generation of synthetic phrases and experiment HI dealt with perception of stress in normal control subjects and in subjects with CVA.

Experiment I: Acoustic analyses of Kannada words with and without stress

Subject: A 42-year old native Kannada speaking female speech pathologist participated in the experiment. She had normal speech and hearing (< 15 dB at 250 Hz to 8000 Hz in both ears) and had no sensory or motor deficits.

Material: Twenty-five meaningful two-word Kannada phrases were selected by the experimenter. The first word of these phrases was an adjective and the second word was a noun. The adjectives and nouns were selected from text books of standard I to HI so that they were familiar. All adjectives and nouns were bisyllabic. Each phrase was written on a card which formed the material. Table 3 shows the material.

SI. No.	Phrases
1.	kari ko:ti
2.	mir.ru pa:vu
3.	mond.u magu
4.	bili katte
5.	gund u kallu
6.	bili but t.i
7.	kandu ko:tu
8.	benki tjend.u
9.	a:ru pa:ti
10.	ni:li bassu
11.	ka-.li but. t.i
12.	na:ku na:yi
13.	sihi tin.d i
14.	ent.u tale
15.	ni:li angi
16.	kari kannu
17.	kempu gud.de
18.	mu:ru ko:li
19.	aidu ka:ru
20.	kempu bat t e
21.	kahi ka:fi
22.	tju:pu katti
23.	ni:li pat. t.i
24.	kari ka:ge
25.	bil.i tat.t.e

Table 3: Material for experiment I.

Procedure: Subject was visually presented with the material one at a time. She was instructed to speak each phrase five times without stress on any words in to a microphone connected directly to the computer. The same procedure was repeated, but this time the subject spoke the phrases with stress on the first word/adjective (subject recorded till she was satisfied that the key word was stressed). The data was acquired on to the computer memory using the acquire program of the SSL Pro2V2 software (Voice & Speech Systems, Bangalore) at a sampling frequency of 16 k Hz. Using the signal edit program of SSL Pro2V2, these phrases (clear and without noise) was stored on to a separate wave file. Two speech pathologists listened to these phrases and wrote the word stressed. Three of five recordings of each phrase that were agreed upon by both speech pathologists (r = 0.99) as having the key word stressed were considered for further analyses.

Analyses: FBAS (formant-based acoustic analysis) program was used to extract acoustic parameters of stress. A 15 ms block duration and a 10 ms resolution was used. Low and high frequencies were set at 80 Hz and 500 Hz, respectively. Pre-emphasis factor was set at '1'. Fundamental frequency (F0), intensity, open quotient (OQ), speed quotient (SQ), and leakage quotient (LQ) were extracted for each phrase. OQ, SQ, and LQ refer to glottal opening and closure and were not edited in the present study. F0 and intensity at every 10 ms of each phrase was noted using the View & Edit program. Figure 3 illustrates FBAS extracted F0 and intensity information (graphical) and figure 4 shows numerical values of these parameters as extracted from FBAS.

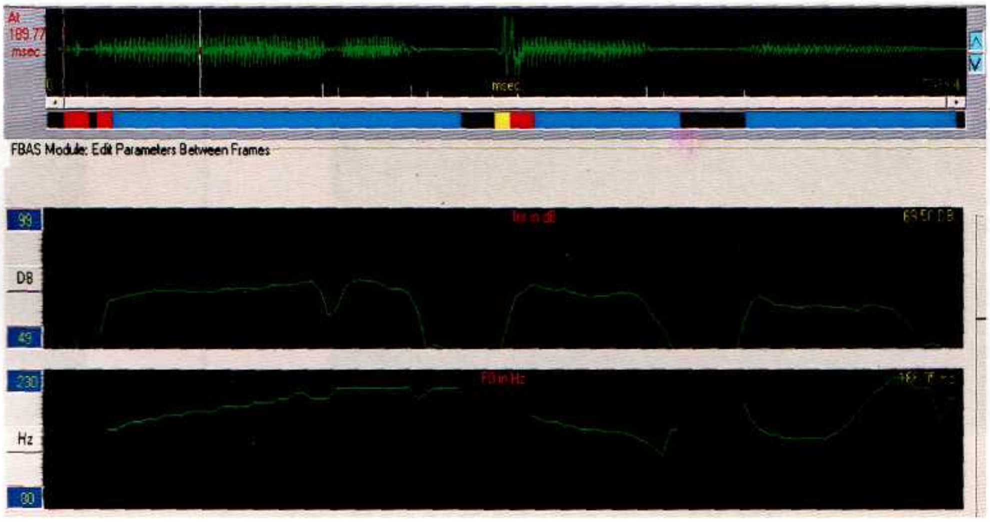
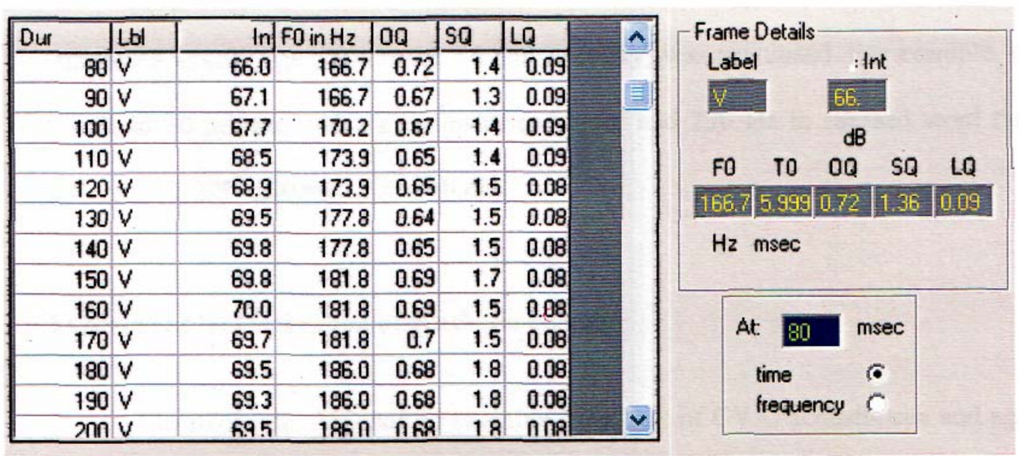


Figure 3: Illustration of FBAS extracted F0 and intensity information (phrase /a:ru pa:ti/).



Dur	Lbl	In	F0 in Hz	OQ	SQ	LQ
80	V	66.0	166.7	0.72	1.4	0.09
90	V	67.1	166.7	0.67	1.3	0.09
100	V	67.7	170.2	0.67	1.4	0.09
110	V	68.5	173.9	0.65	1.4	0.09
120	V	68.9	173.9	0.65	1.5	0.08
130	V	69.5	177.8	0.64	1.5	0.08
140	V	69.8	177.8	0.65	1.5	0.08
150	V	69.8	181.8	0.69	1.7	0.08
160	V	70.0	181.8	0.69	1.5	0.08
170	V	69.7	181.8	0.7	1.5	0.08
180	V	69.5	186.0	0.68	1.8	0.08
190	V	69.3	186.0	0.68	1.8	0.08
200	V	69.5	186.0	0.68	1.8	0.08

Frame Details

Label: V

:Int: 66. dB

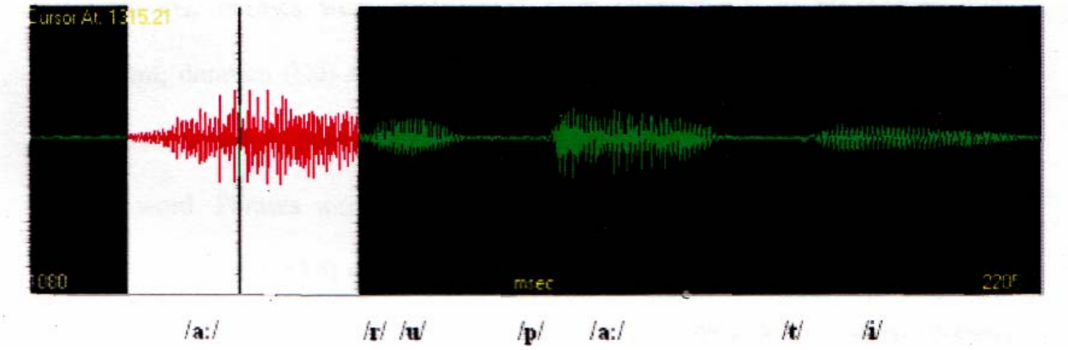
F0	T0	OQ	SQ	LQ
166.7	5.999	0.72	1.36	0.09
Hz	msec			

At: 80 msec

time ●
frequency ○

Figure 4: Numerical values of source parameters as extracted (every 10 ms) from FBAS program {Lable (Lbl - V - voiced, U - Unvoiced, S - Silence), intensity (dB), FO (Hz), Open quotient (OQ), Speed quotient (SQ), and leakage quotient (LQ)}.

Duration of individual phonemes and first word of each phrase was measured from waveform. Duration was measured as the time difference between the onset and offset of the phoneme / word as depicted on the waveform. Figure 5 illustrates the measurement of phoneme duration.



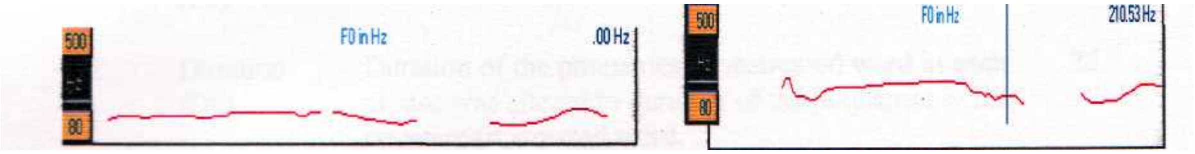
From 1191.224 to 1446 491 Duration = 255.265

Figure 5: Illustration of measurement of phoneme duration (highlighted part shows vowel /a:/ in the phrase /a:ru pa:ti/).

FO, intensity and duration in stressed and unstressed words were noted and the difference between these parameters (S-Ratio) in stressed and its counterpart unstressed words (every 10 ms for F0 and intensity) was calculated. For example, if the F0 at 10 ms was 180 Hz in unstressed word and 220 Hz in stressed word the difference is 220 -180 = 40 Hz at 10 ms.

Experiment II: Generation of synthetic phrases

The study was designed to examine the effect of CVA, acoustic cue and age on the perception of stress. In order to test this, words with only F0 cue, only duration cue and only intensity cue to stress were required. Further, words with combination of cues were required to examine the effect of multiple cues on stress perception. Acoustic measures extracted in experiment I were used to generate synthetic tokens. Using the "PATPLAY" program of SSL Pro2V2 software, seven sub-experiments were conducted in which various parameters cueing stress were altered in isolation and in combination. In the first sub-experiment, F0 of the unstressed word in each phrase was altered to match F0 of the counterpart stressed word. This was done at every 10 ms. Phrases were synthesized after altering F0. In the second sub-experiment, duration (DO) of each of the phoneme in the unstressed word in each phrase was altered to match the duration of the same phoneme in the counterpart stressed word. Phrases were synthesized after altering duration. In the third sub-experiment, intensity (A0) of the unstressed word in each phrase was altered to the intensity of the counterpart stressed word. This was done at every 10 ms. Phrases were synthesized after changing intensity. Multiple acoustic parameters - F0 and A0, F0 and DO, A0 and DO, and F0, A0, and DO - of the unstressed word in each phrase were altered to match the same parameters in the counterpart stressed word in the next four sub-experiments. In this manner 25 synthetic phrases were generated in each sub-experiment and a total of 175 synthetic phrases were generated. Figures 6 to 8 illustrates F0 and A0 curves and duration in unstressed and synthetic phrases. Table 4 shows the details of the experiments.



Unstressed Stressed

Figure 6: Fundamental frequency curve of phrase (/ka:l.i butti/) with unstressed and stressed words.

Unstressed Stressed

Figure 7: Intensity curve of phrase (/ka:l.i butti/) with unstressed and stressed words.

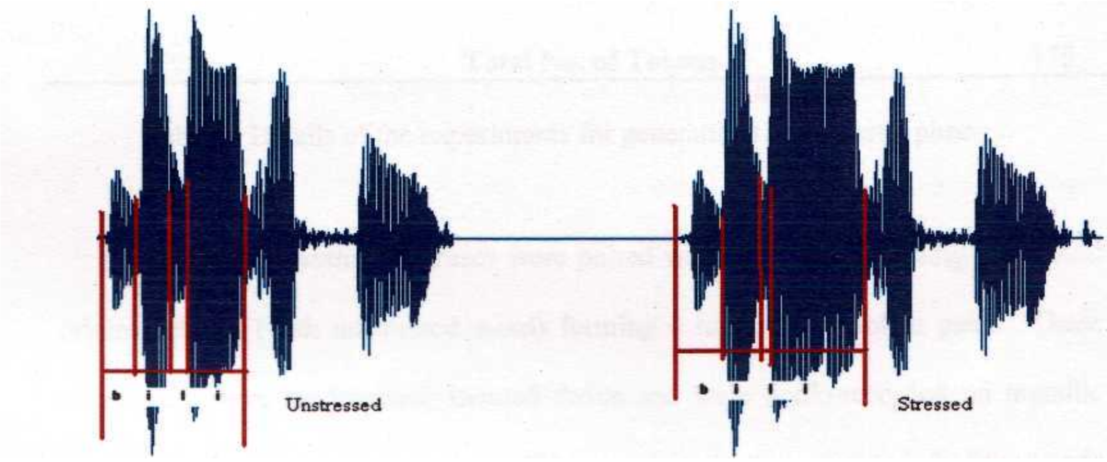


Figure 8: Duration of phonemes in unstressed and stressed words word /bili/ of the phrase /bil.i but.t.i/.

Sub-expt. No.	**Parameter altered**	**Details**	**Total no. of Tokens**
	Fundamental Frequency (FO)	FO of the unstressed word in each phrase was altered to FO of the counterpart stressed word every 10 ms.	25
2	Duration (DO)	Duration of the phonemes in unstressed word in each phrase was altered to duration of the phonemes in the counterpart stressed word.	25
3	Intensity (A0)	A0 of the unstressed word in each phrase was altered to A0 of the counterpart stressed word every 10 ms.	25
4	FO & A0	FO & A0 of the unstressed word in each phrase was altered to FO & A0 of the counterpart stressed word every 10 ms.	25
5	F0&D0	F0& DO of the unstressed word in each phrase was altered to FO & DO of the counterpart stressed word.	25
6	A0 & DO	FO & DO of the unstressed word in each phrase was altered to A0 & DO of the counterpart stressed word.	25
	FO, A0 & DO	FO, A0 & DO of the unstressed word in each phrase was altered to FO, A0 & DO of the counterpart stressed word.	25
		Total No. of Tokens	**175**

Table 4: Details of the experiments for generating the synthetic phrases.

These 175 synthetic phrases were paired with their corresponding unstressed original phrase (with unstressed word) forming a total of 175 token pairs. These token pairs were randomized, iterated thrice and were audio-recorded on metallic cassettes with an inter-token interval of 2 seconds and inter-pair interval of 5 seconds using the 'Play Bat' program of SSLPro2V2. Thus, a total of 525 pairs of tokens formed the material for perceptual evaluation. Table 5 shows an example of token pairing. In the first row of table 5, only FO of the unstressed word is altered to match the FO of its counterpart stressed word and synthesized. S1-US1 means the synthetic phrase (with FO cue only) is paired with its counterpart unstressed phrase. Similarly, all 25 synthetic phrases are paired with their counterpart unstressed phrases. In the second row, S1-US1 mean that the synthetic phrase (with duration cue only) is paired with its counterpart unstressed phrase. Synthetic phrases altered in intensity are paired with their counterpart unstressed phrases in row 3. Phrases with altered multiple acoustic parameters are illustrated in the next four rows.

SI. No.	Details of the token pair	Parameter altered
1-25	S1-US1 TO S25-US25	FO
26-50	S1-US1 TO S25-US25	DO
51-75	S1-US1 TO S25-US25	A0
76-100	S1-US1TOS25-US25	F0 + A0
101-125	S1-US1TOS25-US25	F0 + D0
126-150	S1-US1TOS25-US25	A0+D0
151-175	S1-US1 TO S25 -US25	FO, AO and DO

Table 5: Details of synthetic phrase pairs (S = Stressed, US = Unstressed).

Experiment III: Perception of stress in normal control subjects and in subjects with CVA.

(a) Perception of stress in normal controls: Knowledge of the perceptual response by normal controls was necessary for the understanding of stress perception in individuals with CVA. Therefore, normal subjects were tested initially.

Subjects: Fifty normal Kannada speaking subjects (29 males and 21 females, 29 young and 21 old) in the age range of 21 - 80 years (mean age = 43.9 years) participated in the experiment. None of the subjects had any past/present history of any neurological or psychological disorders and any sensory or motor deficits. All subjects had Kannada as their mother tongue. All subjects had formal education for a period of at least 10 years. Table 6 shows the details of subjects.

Age group		**No. of males**	**No. of females**
Young	21-30	4	6
	31-40	7	4
	41-45	4	4
Old	46-50	4	4
	51-60	4	1
	61-70	3	2
	71-80	3	
	Total	**29**	**21**

Table 6: Details of normal control subjects.

Material: 525 synthetic phrases generated in experiment II were used as material.

Procedure: Subjects were tested individually. Stimuli were audio presented through headphones at comfortable listening levels. Subjects were instructed to listen to each phrase pair carefully and indicate whether two phrases in a pair were 'same'' or 'different' on a binary forced choice response sheet by marking V under the category 'same' or 'different'. The same procedure was followed for all the seven sub experiments. Appendix I shows the binary forced choice response sheet.

Analyses: The responses of the subjects were tabulated and percent" same' or' different' for each token and for each subject was calculated. The mean percent 'different' response was calculated for each of the 25 phrase pairs using the following formula:

$$\text{Percent 'different'} = \frac{\text{Total no. of 'different' response}}{\text{Total no. of 'different' phrase pairs}} * 100$$

The mean percent different response (discrimination score) for each of the 25 phrase pairs was tabulated and plotted on a graph. Those phrase pairs that were discriminated more than 70 % of times were considered as material for experiment in subjects with CVA.

(b) Perception of stress in subjects with CVA

Subjects: Two groups of subjects participated in this experiment. Group I consisted of 50 patients with left hemisphere damage (LHD) and group II consisted of 50 patients with right hemisphere damage (RHD). 59% of these subjects had CVA and the other subjects had varying lesion sites. Only subjects with CVA (MCA infarct and hemorrhage) were considered for the study. This was done in order to control lesion site. The diagnosis was made by a neurologist and supported by computerized tomography (CT) scan.

All subjects were native Kannada speakers and were referred from neurocenters and speech pathologists. Subjects were tested at the Department of Speech-Language Sciences at the All India Institute of Speech and Hearing, Mysore, Kamataka Institute of Medical Sciences, Hubli, Neurocenter, Hubli, SDM Medical College, Dharwad, Speech and Hearing Center, Shimoga, Bapuji Medical College, Davanagere, Manipal Academy of Higher Education, Manipal, MV Shetty College, Mangalore, and Neurocenters, Belgaum.

The age of the subjects with CVA ranged from 26 years to 79 years (CVA mean age = 50.4 years, LHD mean age= 49.8 years, RHD mean age = 50.8 years). The following criteria were used in subject selection:

1. All subjects were diagnosed by neurologists.
2. Both adult males and females were considered for the study.
3. A post onset period of greater than 6 months, but less than 1-year was considered (on an average young subjects* were tested at 7-8 months post-onset and old subjects* were tested at 8-9 months post-onset).
4. Only subjects who had Kannada as their mother tongue were considered.
5. Participants with no hearing and, or visual deficits (corrected) were considered. This was ensured by talking to subjects and their family members and informal testing.

Considering that the subject's age range was vast, and as age could be one factor affecting their performance, subjects were grouped into young and old stroke subjects. Subjects below the age of 45 years were grouped under young subjects* and those above 45 years were grouped under old subjects*. This was done as per the recommendation of the pre-thesis colloauium committee. There were 19 young subjects and 40 old subjects. Tables 7 and 8 show subject details and demographic data, respectively (Appendix II shows a questionnaire used to collect demographic data).

LHD	Young Male	Young Female	Old Male	Old Female	Total
Number	10	0	12	5	27
Age range	26-45		49-66	53-79	
Mean Age	37.30		55.16	62.0	
RHD	Young Male	Young Female	Old Male	Old Female	
Number	7	2	20	3	32
Age range	38-45	31-39	46-75	46-54	
Mean Age	41.71	35.0	55.60	51.33	

Table 7: Details of subjects with CVA in parenthesis.

	LHD			RHD		
Young	Age	Gender	Lesion	Age	Gender	Lesion
	43	M	Lt MCA infarct	44	M	Rt MCA infarct
	35	M	Lt MCA infarct	39	F	Rt MCA infarct
	45	M	Lt MCA infarct	31	F	Rt MCA infarct
	26	M	Lt MCA Infarct	43	M	Rt MCA infarct
	41	M	Lt MCA infarct	42	M	Rt MCA Hemorrhage
	40	M	Lt MCA infarct	41	M	Rt MCA infarct
	33	M	Lt MCA Hemorrhage	38	M	Rt MCA infarct
	34	M	Lt MCA infarct	39	M	Rt MCA Infarct
	42	M	Lt MCA infarct	45	M	Rt MCA Infarct
	34	M	Lt MCA infarct	0		
Old	53	M	Lt MCA infarct	65	M	Rt MCA infarct
	50	F	Lt MCA infarct	51	M	Rt MCA Infarct
	60	F	Lt MCA infarct	53	M	Rt MCA infarct
	50	M	Lt MCA infarct	49	M	Rt MCA infarct
	53	F	Lt MCA infarct	60	M	Rt MCA Hemorrhage
	68	F	Lt MCA Hemorrhage	48	M	Rt MCA infarct
	79	F	Lt MCA Infarct	58	M	Rt MCA infarct
	66	M	Lt MCA Infarct	62	M	Rt MCA infarct
	50	M	Lt MCA infarct	54	M	Rt MCA Hemorrhage
	58	M	Lt MCA Hemorrhage	51	M	Rt MCA infarct
	65	M	Lt MCA infarct	56	M	Rt MCA infarct
	52	M	Lt MCA infarct	48	M	Rt MCA infarct
	49	M	Lt MCA Hemorrhage	54	F	Rt MCA Hemorrhage
	55	M	Lt MCA infarct	47	M	Rt MCA infarct
	49	M	Lt MCA infarct	75	M	Rt MCA infarct
	61	M	Lt MCA infarct	46	F	Rt MCA infarct
	54	M	Lt MCA infarct	48	M	Rt MCA infarct
				46	M	Rt MCA Infarct
				54	F	Rt MCA infarct
				54	M	Rt MCA infarct
				47	M	Rt MCA infarct
				75	M	Rt MCA infarct
				65	M	Rt MCA Hemorrhage

Table 8; Demographic data of subjects with left and right CVA.

Material: Sixty-seven phrase pairs that were discriminated correctly by more than 70% of times were used as material. These phrase pairs were randomized, iterated thrice and audio-recorded with an inter pair interval of 5 seconds and inter-token interval of 2 seconds. Thus, a total of 201 phrase pairs formed the material. The details of the material are in table 9.

Altered parameters	No. of Phrase pairs
Frequency	7
Amplitude	0
Duration	12
Frequency and amplitude	5
Frequency and duration	14
Amplitude and duration	13
Frequency, amplitude and duration	16
Total	67

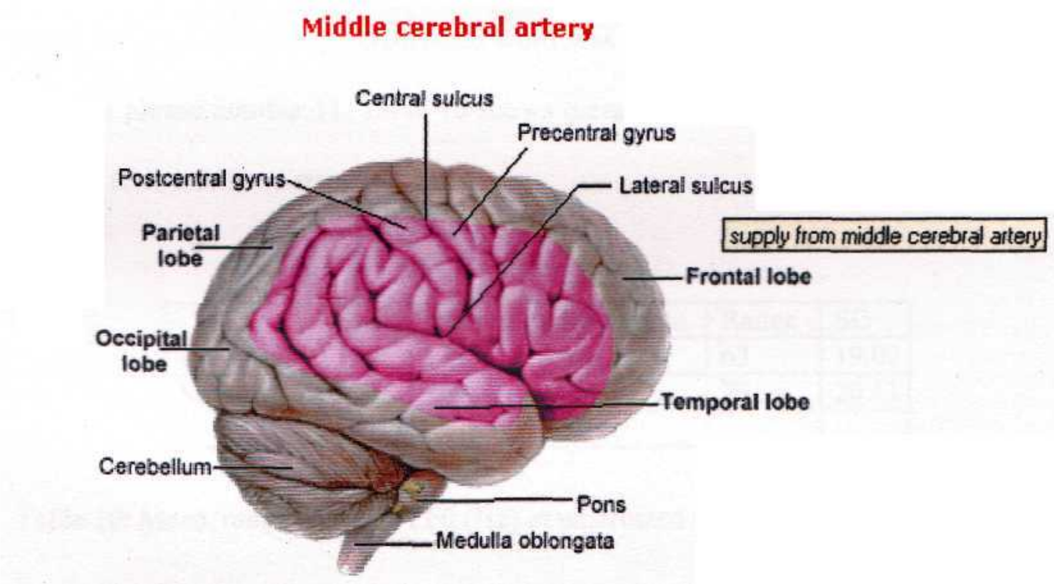
Table 9: Number of phrase pairs used in subjects with CVA.

Procedure and analyses: Procedure and analyses were similar to that in experiment IE with normal controls. However, subjects with CVA were permitted to do the task by any other means in case they had problem in marking manually.

Statistical analyses: The data thus obtained from normal control subjects and subjects with CVA was tabulated and subjected to statistical analysis using a commercially available Statistical Package for Social Science (SPSS - version 10). The mean and standard deviation were obtained for parameters in experiment I and S-Ratio (difference between unstressed and stressed condition for a parameter) was calculated. Two-way ANOVA was used to test main effects of group [(a) normal controls and subjects with CVA, and (b) LED and RHD], age and interaction between age and group. Independent t-test was used to compare scores within and between age (young and old), and group (LED and RHD). Repeated measures ANOVA were used to compare sub-experiments. Bonferroni multiple comparison was used to find pair wise differences across sub-experiments.

Chapter IV

Results



"The beauty of the brain lies in its incredible complexity. the neuroscience challenge is to transform the mind boggling appreciation of the central nervous system's complexity into manageable proportions".

www.innerbody.com/tutorial2/tutorial.htm

Experiment 1: Acoustic analyses of Kannada words with and without stress

Fundamental frequency (F0): The results indicated that F0 in the unstressed words varied from 118 Hz to 181 Hz with a mean of 158 Hz. F0 in stressed word was in the range of 164 Hz to 237 Hz with a mean of 198 Hz. Paired T-Test showed significant difference [t (24) =7.27, p<0.000] between F0 of stressed and unstressed words. F0 in stressed words was significantly higher than their unstressed counterparts. All stressed words had higher F0 compared to unstressed words. It was observed that the difference between F0 of stressed and unstressed word was maximum for phrase number 10 and least for phrase number 11. Table 10 shows mean, range and standard deviation of F0 (Hz) in unstressed and stressed words.

	Mean	Minimum	Maximum	Range	SD
Unstressed	158	118	181	63	19.02
Stressed	198	164	237	73	20.11
S-U	40	46	56		

Table 10: Mean, range and SD of F0 (Hz) in unstressed (U) and stressed (S) words.

Intensity: Intensity in unstressed words varied from 51 dB to 64 dB with a mean of 58 DB. Intensity in stressed words was in the range of 56 dB to 66 dB with mean of 62 dB. Paired T-Test showed significant difference [t (24) = 4.73, p<0.000] between intensity of stressed and unstressed words. Intensity in stressed words was significantly higher than that in unstressed words. Table 11 shows mean, range and SD of intensity in stressed and unstressed words.

	Mean	Minimum	Maximum	Range	SD
Unstressed	58	51	64	13	3.19
Stressed	62	56	66	10	2.84
S - U	4	5	2		

Table 11: Mean, range and SD of intensity (dB) in unstressed (U) and stressed (S) words.

Duration: Duration of unstressed words varied from 289 ms to 501 ms with a mean of 377 ms. Duration of stressed word was in the range of 430 ms to 647 ms with a mean of 513 ms. Paired T-Test [t (24) =11.51, p<0.000] indicated significant difference between the duration of stressed and unstressed words. Duration of stressed words was significantly longer than their unstressed counterparts. Duration of stressed words was longer than that of unstressed words in all phrases. The difference between the duration of stressed and unstressed words was longest in phrase pair 13 and shortest in phrase pair 8. Table 12 shows mean, range and SD of duration in stressed and unstressed words.

	Mean	Minimum	Maximum	Range	SD
Unstressed	377	289	501	212	60.04
Stressed	513	430	647	217	73,32
S - U	136	141	146		

Table 12: Mean, range and SD of duration (ms) in unstressed (U) and stressed (S) words.

Frequency, intensity and duration of unstressed and stressed words in each phrase are in appendix III.

Experiment II: Using the values obtained from acoustic analyses in experiment I, a total of 525 synthetic phrase pairs were generated as described in the method.

Experiment III: Perception of stress in normal controls and in subjects with CVA

(a) Perception of stress in normal controls

The results of the seven sub-experiments conducted were as follows:

Sub-experiment 1: Altered fundamental frequency (F0)

In this experiment, F0 of the unstressed words was altered to match that of its stressed counterpart. The altered phrase was paired with the original unstressed phrase for perceptual evaluation. Table 13 shows the mean percent scores (percent 'discrimination') in each of the 25 phrase pairs. Of the 25 phrase pairs, 7 phrase pairs were discriminated by more than 70% of times. These 7 pharse pairs (bold in table 13) were considered for further experimentation in subjects with CVA.

Phrase pair no	Percent discrimination score	SD
1	41.66	3.12
2	51.66	6.45
3	**76.66**	2.43
4	**78.66**	2.56
5	**71.66**	3.23
6	10.11	6.58
7	32.33	5.85
8	41.45	2.62
9	10.11	7.05
10	17.33	3.42
11	37.33	5.76
12	0	0
13	0	0
14	**74.33**	2.44
15	41.33	2.45
16	**70.33**	3.42
17	26.45	4.32
18	71.42	2.12
19	11.33	2.13
20	0	0
21	0	0
22	16.11	2.12
23	70.33	3.43
24	3.33	3.23
25	36.45	4.15

Table 13: Percent discrimination score on phrase pairs altered in F0.

Sub-experiment 2: Altered duration

Duration of the unstressed words was altered to match that of its stressed counterpart in this experiment. The altered phrase was paired with the original unstressed phrase for perceptual evaluation. The results indicated that 12 out of 25 phrase pairs were discriminated by more than 70% of times. These 12 phrase pairs (bold in table 14) were considered for further experimentation in subjects with brain damage. Table 14 shows the percent discrimination score on each of the 25 phrase pairs.

Phrase pair no.	Percent discrimination score	**SD**
1	23.33	2.01
2	0	**0**
3	46.41	**6.91**
4	**84.33**	3.55
5	**93.68**	2.76
6	**77**	5.23
7	**90.3**	2.12
8	57.78	2.08
9	3.92	**4.14**
10	37.99	2.12
11	47.25	2.08
12	**80.33**	5.78
13	10.11	5.05
14	**97.25**	2.63
15	**87.56**	2.08
16	63.33	3.06
17	93.97	2.14
18	77.33	4.32
19	77.33	3.23
20	30.33	2.13
21	17.33	2.14
22	70.47	2.18
23	60.06	4.09
24	0	**0**
25	**83.33**	2.04

Table 14: Percent discrimination score on phrase pairs altered in duration.

Sub-experiment 3: Altered intensity

Intensity of the unstressed word was altered to match that of its stressed counterpart in this experiment. The altered phrase was paired with the original unstressed phrase for perceptual evaluation. The results indicated that none of the phrase pairs were discriminated by more than 50% of times. Therefore, none of these phrase pairs were considered for further experimentation in subjects with CVA. Table 15 shows percent discrimination scores in each of the 25 phrase pairs.

Phrase pair no	Percent discrimination score	SD
1	9.99	2.56
2	0.66	1.01
3	39.33	3.23
4	26.66	4.15
5	10.66	2.22
6	9.33	1.21
7	11.99	2.54
8	10.66	3.12
9	45.33	2.03
10	30.66	2.34
11	1.33	1.01
12	8.66	2.32
13	8.66	2.04
14	0	0
15	20.66	2.22
16	8.66	1.21
17	4.66	1.01
18	9.99	2.03
19	0	0
20	0	0
21	3.33	1.11
22	8.66	2.32
23	1.33	1.02
24	1.99	1.24
25	7.33	2.32

Table 15: Percent discrimination score on phrase pairs altered in intensity.

Sub-experiment 4: Altered frequency and intensity

Frequency and intensity of the unstressed words were altered to match those of its stressed counterpart. The altered phrase was paired with its original unstressed phrase for perceptual evaluation. The results indicated that 5 out of 25 phrase pairs were discriminated by more than 70% of times. These 5 pharse pairs (Bold in table 16) were considered for further experimentation in subjects with CVA. Table 16 shows the percent discrimination score in each of the 25 phrase pairs.

Phrase pair no.	Percent discrimination score	SD
1	45.33	2.11
2	9.99	1.21
3	10.66	1.23
4	30.66	2.34
5	20.66	2.02
6	.1.33	0.11
7	30.66	2.15
8	45.33	2.67
9	77.33	6.07
10	4.66	1.03
11	0.00	0
12	39.33	2.62
13 i	37.33	3.21
14	41.33	2.22
15	**71.66**	1.21
16	63.33	2.45
17	63.33	2.09
18	**71.66**	2.89
19	**70.66**	3.45
20	30.66	3.76
21	45.33	3.32
22	39.66	2.70
23	20.66	2.01
24	48.33	2.67
25	**71.66**	2.45

Table 16: Percent discrimination score on phrase pairs altered in frequency and intensity.

Sub-experiment 5: Altered frequency and duration

Frequency and duration of the unstressed words were altered to match those of its stressed counter part in this experiment. The altered phrase was paired with the original unstressed phrase for perceptual evaluation. The results indicated that 14 out df 25 phrase pairs were discriminated by more than 70% of times. These 14 pharse pairs (bold in table 17) were considered for further experimentation in subjects with CVA. Table 17 shows percent discrimination score in each of the 25 phrase pairs.

Phrase pair no.	Percent discrimination score	**SD**
1	56.90	2.32
2	61.31	4.54
3	77.34	3.20
4	84.30	4.57
5	80.27	2.31
6	84.07	2.03
7	77.40	3.09
8	64.34	1.23
9	56.16	3.57
10	20.26	4.32
11	77.21	2.07
12	50.34	2.87
13	12.12	3.65
14	**93.23**	2.76
15	**77.46**	2.31
16	**79.20**	2.54
17	**81.17**	3.43
18	**93.27**	1.23
19	61.21	3.21
20	20.32	3.21
21	10.32	4.32
22	**86.14**	3.21
23	**71.32**	3.21
24	**0**	**0**
25	**90.43**	3.32

Table 17: Percent discrimination score on phrase pairs altered in FO and duration.

Sub-experiment 6: Altered intensity and duration

Intensity and duration of the unstressed words were altered to match those of its stressed counterpart. The altered phrase was paired with the original unstressed phrase for perceptual evaluation. The results indicated that 13 out of 25 phrase pairs were discriminated by more than 70% of times. These 13 pharse pairs (bold in table 18) were considered for further experimentation in subjects with CVA. Table 18 shows percent discrimination score in each of the 25 phrase pairs.

Phrase pair no.	Percent discrimination score	**SD**
1	57.33	2.09
2	18.66	3.56
3	26.66	**6.07**
4	34.63	3.65
5	**88.42**	2.76
6	63.96	3.12
7	**77.97**	5.19
8	64.33	6.68
9	50.66	2.76
10	62.66	6.90
11	**71.33**	3.55
12	50.66	3.21
13	51.19	8.19
14	**79.99**	3.68
15	**77.32**	2.63
16	**79.99**	6.45
17	**80.33**	3.44
18	**83.92**	2.76
19	38.66	3.10
20	**71.33**	3.68
21	**73.33**	2.45
22	**79.95**	4.55
23	**73.33**	2.07
24	51.97	2.34
25	**81.33**	4.32

Table 18: Percent discrimination score on phrase pairs altered on intensity and duration.

Sub-experiment 7: Altered F0, intensity and duration

Frequency, intensity and duration of the unstressed words were altered to match those of its stressed counter part in this experiment. The altered phrase was paired with the original phrase for perceptual evaluation. The results indicated that 16 out of 25 phrase pairs were discriminated by more than 70% of times. These 16 pharse pairs (bold in table 19) were considered for further experimentation in subjects with CVA. Table 19 shows percent discrimination score in each of the 25 phrase pairs.

Phrase pair no.	Percent discrimination score	**SD**
1	41.66	2.12
2	42.85	**3.49**
3	**73.33**	**4.32**
4	**74.40**	**5.01**
5	**87.49**	**2.65**
6	**71.42**	**2.15**
7	**88.68**	**2.98**
8	55.95	2.34
9	67.85	5.43
10	66.06	2.23
11	83.92	**4.67**
12	67.25	2.13
13	53.56	2.14
14	**89.28**	**2.54**
15	**77.97**	**2.87**
16	**85.11**	**2.31**
17	**82.73**	**4.32**
18	**80.94**	**6.03**
19	58.92	4.39
20	**73.21**	**4.23**
21	**74.99**	**3.67**
22	**83.92**	**6.59**
23	**86.33**	**5.19**
24	**51.78**	3.64
25	**77.97**	**5.05**

Table 19: Percent discrimination score on phrase pairs altered in frequency, intensity and duration.

To summarize, results indicated that phrase pairs altered in individual / multiple parameters (except that in intensity) were discriminated by normal subjects. However, the number of such phrase pairs depend on the parameter altered. Percent discrimination scores were higher for phrase pairs altered in multiple parameters compared to those altered in single parameters. Subjects discriminated maximum number of phrase pairs when duration was altered compared to other single cue conditions. Also, subjects discriminated maximum number of phrase pairs when all 3 parameters -F0A0D0 - were altered compared to other multiple cue conditions.

The total number of phrase pairs discriminated were 7, 12, 0, 5, 14, 13, and 16 when the parameter/s altered was F0, duration (DO), intensity (A0), F0 and intensity (F0A0), F0 and duration (F0D0), intensity and duration (A0D0), and all the three parameters (F0A0D0), respectively. Table 20 summarizes the results of experiment III in normal subjects.

Phrase pair no.	F0	DO	A0	F0A0	F0D0	A0D0	F0A0D0
1	41.66	23.33	9.99	45.33	56	57.33	41.66
2	51.66	0	0.66	9.99	61	18.66	42.85
3	76.66	46.41	39.33	10.66	77	26.66	73.33
4	78.66	84.33	26.66	30.66	84	34.63	74.40
5	71.66	93.68	10.66	20.66	80	88.42	87.49
6	10.11	77	9.33	1.33	84	63.96	71.42
7	32.33	90.3	11.99	30.66	77	77.97	88.68
8	41.45	57.78	10.66	45.33	64	64.33	55.95
9	10.11	3.92	45.33	77.33	56	50.66	67.85
10	17.33	37.99	30.66	4.66	20	62.66	66.06
11	37.33	47.25	1.33	0.00	77	71.33	83.92
12	0	80.33	8.66	39.33	50	50.66	67.25
13	0	10.11	8.66	37.33	12	51.19	53.56
14	.74.33	97.25	0	41.33	93	79.99	89.28
15	41.33	87.56	20.66	71.66	77	77.32	77.97
16	70.33	63.33	8.66	63.33	79	79.99	8fUl
17	26.45	93.97	4.66	63.33	81	80.33	82.73
18	71.42	77.33	9.99	71.66	93	83.92	80.94
19	11.33	77.33	0	70.66	61	38.66	58.92
20	0	30.33	0	30.66	20	71.33	73.21
21	0	17.33	3.33	45.33	10	73.33	74.99
22	16.11	70.47	8.66	39.66	86	79.95	83.92
23	70.33	60.06	1.33	20.66	71	73.33	86.33
24	3.33	0	1.99	48.33	0	51.97	51.78
25	36.45	83.33	7.33	71.66	90	81.33	77.97
Average	33.95	55.5	10.82	37.85	60.12	61.30	70.24
No. of phrase pairs perceived as 'different'.	7	12	0	5	14	13	16
Total	67						

Table 20: Summary of the results of experiment III in normal control subjects.

A total of 67 phrase pairs of 175 phrase pairs were discriminated by normal subjects. These 67 phrase pairs were randomized, iterated thrice and audio recorded. Thus a master tape was created with a total of 201 pharse pairs. These phrase pairs were used for perceptual evaluation in subjects with CVA.

As performance of subjects with CVA was compared with that of normal controls and as subjects with CVA were grouped as young and old, scores of normal subjects for these 67 phrase pairs were computed. Independent t - test showed no significant difference (P<0.001) between young and old normal controls on any of the 6 sub-experiments. However, young subjects performed better compared to old subjects on all the seven sub-experiments. Both young and old subjects scored highest on altered DO condition and least on altered F0A0 condition. Table 21 shows percent discrimination scores in both groups on six sub-experiments (No phrase pair with altered AO was discriminated by more than 50 % of times and therefore, it was not included as a test in subjects with CVA).

Sub-experiments	Young **	SD	Old **	SD	t (48)*
FO	75.09 (72.23-79.7)	3.11	71.59 (68.30-74.87)	3.55	1.968
DO	85.31 (79.94-90.68)	8.45	83.50 (78.29-88.71)	8.20	0.532
FOAO	73.23 (69.79-76.66)	2.77	71.96 (68.73-75.20)	2.61	-1.786
FODO	82.98 (79.18-86.78)	6.58	81.16 (77.17-85.15)	6.91	0.713
AODO	78.60 (75.46-81.75)	5.20	78.09 (75.02-81.17)	5.10	0.114
F0A0D0	81.94 (78.82-85.06)	5.85	79.52 (76.19-82.85)	6.25	1.132

Table 21: Percent discrimination scores in young and old normal controls on 6 sub-experiments (** - 95% confidence interval of mean).

(b) Perception of stress in subjects with CVA

CVA subjects included subjects with MCA infarct and hemorrhage. Percent discrimination scores of all subjects, and subjects without hemorrhage were calculated to , find out any significant difference between these two groups. Independent t - test showed no significant difference (P<0.001) between these two groups. Therefore, subjects with hemorrhage were retained in the study. Appendix IV shows percent discrimination scores in both groups.

(i) Comparison of performance of subjects with CVA and normal subjects:

Two-way ANOVA showed significant main effect of group (normals and CVA subjects) on all six sub-experiments and main effect of age on altered FO condition. Further significant interaction between group and age was seen on altered FO condition. Subjects with CVA performed significantly poorer than normal subjects. Young subjects had significantly higher score on altered FO condition compared to old subjects. Normal subjects obtained highest score on altered DO condition and subjects with CVA obtained highest score on altered F0A0D0 condition. Also SD was higher in subjects with CVA compared to normal controls. Table 22 and figure 9 show percent discrimination score in both groups on 6 sub-experiments. Table 23 shows F and P values.

Sub-experiments	Normal **	SD	CVA	SD	t **(107)***
FO	73.34 (71.21-75.47)	3.68	19.53 (15.23-23.83)	16.51	25.033
DO	84.41 (80.95-87.87)	8.19	28.11 (23.57-32.64)	17.39	24.864
FOAO	72.59 (70.72-74.47)	2.62	25.30 (20.05-30.57)	20.18	17.997
FODO	82.07 (79.48-84.67)	6.69	21.02 (14.90-27.14)	23.48	19.968
AODO	78.35 (76.31-80.39)	5.05	22.12 (17.45-26.79)	17.92	24.109
F0A0D0	80.73 (78.54-82.92)	6.08	30.86 (25.44-36.28)	20.81	18.405

Table 22: Percent discrimination scores in normals and subjects with CVA on 6 sub experiments (** - 95% confidence interval of mean).

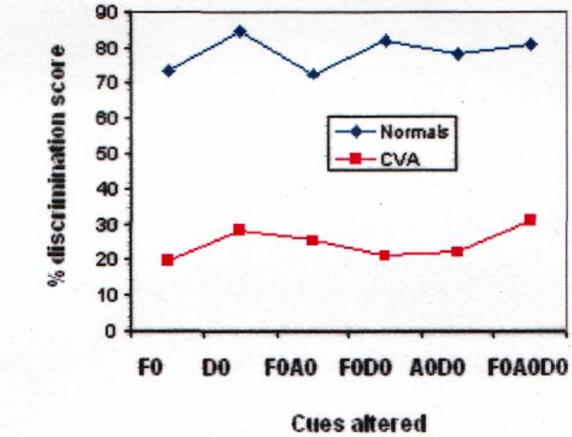


Figure 9: Percent discrimination scores in normal controls and subjects with CVA on 6 sub experiments.

Sub-experiments	Group (PO.OOl)	Age	Group * Age
FO	758.897	48.497 (PO.001)	25.554 (PO.001)
DO	561.553	3.696	7.059
FOAO	444.891	7.173	4.376
FODO	1115.825	0.583	0.055
AODO	1015.675	0.734	1.304
F0A0D0	564.458	0.062	0.807

Table 23: F and P values for group, age, and group * age interaction (degrees of freedom (1,105)]

(ii) Across group and acrross age comoarisons in subjects with CVA: Two-way ANOVA showed significant main effect of group (LHD, RHD) on FODO and F0A0D0 and significant main effect of age on F0 and DO. No significant interaction between group and age was observed. LHD scored significantly higher on altered FODO and F0A0D0 conditions compared to RHD. Young subjects had significantly higher score on altered FO condition compared to old subjects. But old subjects had significantly higher score on altered DO condition compared to young subjects. Table 24 shows percent discrimination score in two groups, and young and old CVA subjects on 6 sub-experiments. Figures 10 and 11 show percent discrimination score in two groups and young and old CVA subjects. Table 26 shows F and P values.

Group/age	FO **	DO **	F0A0 **	F0D0 **	A0D0 **	F0A0D0 **
LHD Young	37.14 (27.40-46.88)	18.33 (8.54-28.12)	36.66 (20.11-53.22)	27.62 (7.81-47.42)	23.33 (11.53-35.14)	35.21 (19.19-51.22)
LHD old	15.40 (8.73-22.08)	37.42 (24.23-50.60)	28.23 (13.97-42.50)	31.23 (13.65-48.82)	20.81 (7.83-33.80)	38.97 (23.07-54.87)
Total	23.45 (16.81-30.10)	30.35 (21.00-39.69)	31.36 (21.07-41.64)	29.89 (17.46-42.33)	21.75 (13.10-30.49)	37.58 (26.63-48.52
RHD young	31.21 (13.18-49.25)	22.84 (13.92-31.76)	27.40 (17.01-37.79)	15.08 (8.74-21.42)	15.67 (3.95-27.39)	24.07 (15.08-33.06)
RHD old	10.35 (8.32-12.38)	27.53 (23.88-31.19)	17.39 (13.15-21.62)	12.94 (9.03-16.85)	25.08 (19.64-30.52)	25.63 (21.65-29.62)
Total	16.21 (10.54-21.90)	26.21 (22.79-29.63)	20.21 (15.10-21.41)	13.54 (10.39-16.70)	22.43 (17.45-27.41)	25.19 (21.66-28.73)

Table 24: Percent discrimination scores in LHD and RHD on 6 sub-experiments (** -

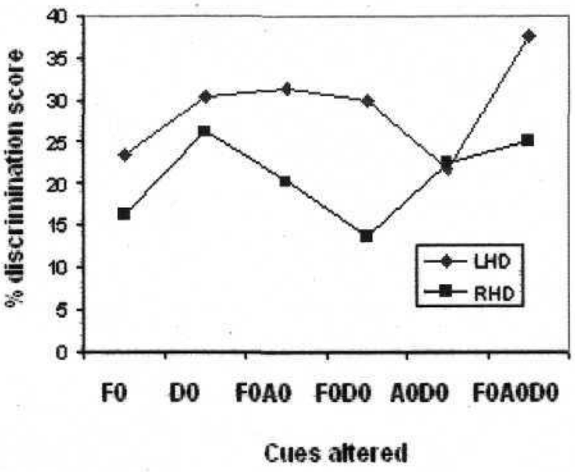


Figure 10: Percent discrimination scores in LHD and RHD subjects on 6 sub-experiments.

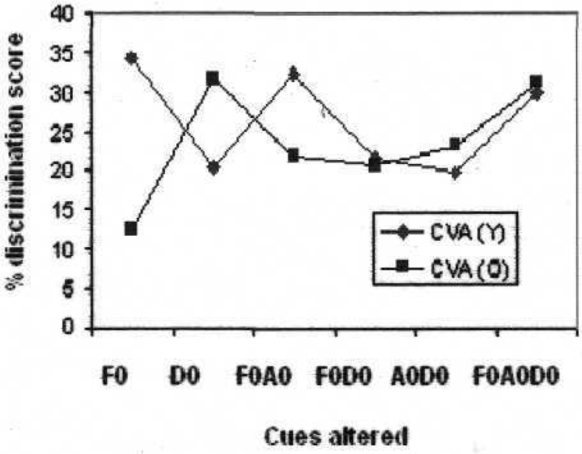


Figure 11: Percent discrimination scores in young and old CVA subjects on 6 sub-experiments.

Sub-experiments	Group	Age	Group * Age
F0	2.286	34.409 (P<0.001)	0.014
D0	0.341	6.678 (P<0.05)	2.445
F0A0	3.425	2.884	0.021
F0D0	5.967 (P<0.05)	0.014	0.208
A0D0	0.112	0.464	1.388
F0A0D0	4.614 (P<0.05)	0.218	0.037

Table 25: F and P values for effects of group (LHD and RHD), age, and group * age interaction [Degrees of freedom (1, 55)].

(iii) Within group comparison of young and subjects with CVA

LHD group: Independent t - test * showed significant difference between young and old subjects on altered FO (P<0.001) and DO (P<0.05) conditions. Young subjects had significantly higher score on altered FO condition and significantly lower score on altered DO condition compared to old subjects. Table 26 and figure 12 show percent discrimination scores in young and old LHD subjects.

Sub-experiments	Young	SD	Old **	SD	t(25)*
FO	37.14 (27.40-46.88)	13.62	15.40 (8.73-22.08)	12.99	4.126
DO	18.33 (8.54-28.12)	13.68	37.42 (24.23-50.60)	25.65	2.167
FOAO	36.66 **(20.11-53.22)**	23.15	28.23 (13.97-42.50)	27.74	0.808
FODO	27.62 (7.81-47.42)	27.68	31.23 (13.65-48.82)	34.20	0.283
AODO	23.33 (11.53-35.14)	16.50	20.81 (7.83-33.80)	25.25	0.281
F0A0D0	35.21 (19.19-51.22)	22.38	38.97 (23.07-54.87)	30.93	0.335

Table 26: Percent discrimination scores in young and old LHD subjects on 6 sub-experiments (** - 95% confidence interval of mean).

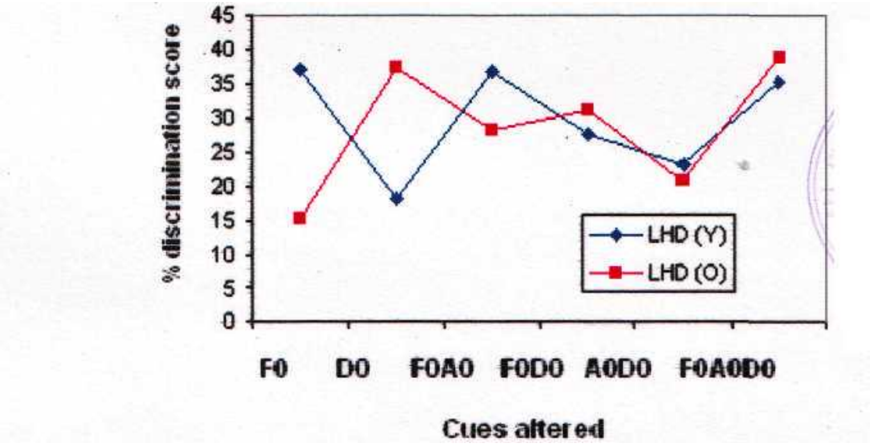


Figure 12: Percent discrimination scores in young and old LHD subjects.

RHD group: Significant difference between young and old subjects on altered FO (P<0.001) and FOAO (P<0.05) conditions was observed. Young subjects had significantly higher scores compared to old subjects on both conditions. Mann-Whitney test also showed the same results as t-test. Table 27 and figure 13 show percent discrimination scores in young and old RHD subjects.

Sub-experiments	Young **	SD	Old **	SD	t(30)*
FO	31.21 (13.18-49.25)	23.46	10.35 (8.32-12.38)	4.69	4.158
DO	22.84 (13.92-31.76)	11.60	27.53 (23.88-31.19)	8.45	1.271
FOAO	27.40 (17.01-37.79)	13.52	17.39 (13.15-21.62)	9.80	2.335
FODO	15.08 (8.74-21.42)	8.25	12.94 (9.03-16.85)_	9.05	0.615
AODO	15.67 (3.95-27.39)	15.25	25.08 (19.64-30.52)	12.58	1.794
F0A0D0	24.07 (15.08-33.06)	11.70	25.63 (21.65-29.62)	9.22	0.399

Table 27: Percent discrimination scores in young and old RHD subjects on 6 sub-experiments (** - 95% confidence interval of mean).

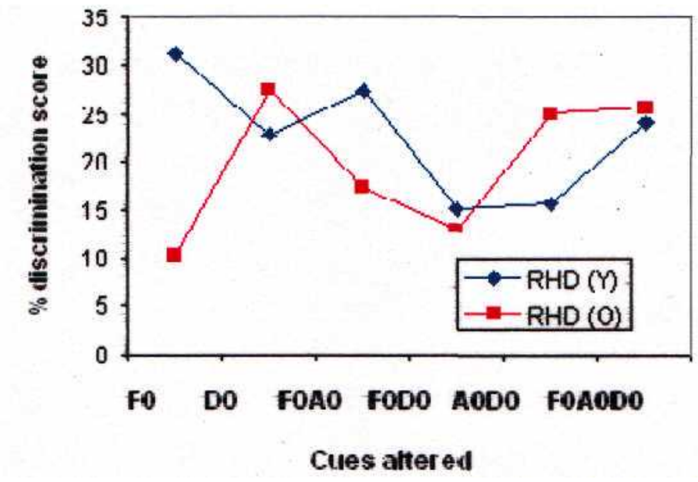


Figure 13: Percent discrimination scores in young and old RHD subjects.

(iv) Within age group comparison of subject with CVA: No significant difference between young subjects with LED and RHD was noticed. However, significant difference [t (38) =2.461, P0.05] between old subjects with LHD and RHD was observed on altered FODO condition. LHD had higher score compared to RHD. Percent discrimination scores are already presented in tables 26 and 27.

(v) Sub-experiment comparison: Significant difference [F (5,110) = 23.797, P<0.001] between sub-experiments in RHD old subjects was observed. Altered DO, A0D0 and altered F0A0D0 conditions had significantly higher score compared to F0, F0A0, and FODO conditions. Repeated measures ANOVA showed no significant difference between sub-experiments in (a) LHD young subjects [F (5, 45) = 3.124, P> 0.05], (b) LHD old subjects [F (5, 80) = 3.478, P>0.05], and (c) RHD young subjects [F (5, 40) = 1.467, P>0.05]. However, LHD and RHD young subjects had higher scores on altered F0 condition and LHD old subjects had higher scores on altered FOA0D0 condition compared to other conditions. Pair-wise comparison was obtained from Bonferroni test. Table 28 shows P values on Bonferroni multiple comparison in RHD old subjects and figures 14 to 19 show percent discrimination score in LHD, RHD and normal controls on 6 sub-experiments.

	F0	D0	F0A0	F0D0	A0D0	F0A0D0
F0		0.000	1.000	0.035	0.000	0.000
D0			0.000	0.006	1.000	1.000
F0A0				1.000	0.001	0.000
F0D0					0.052	0.021
A0D0						1.000

Table 28: Significant differences between sub-experiments - P value on Bonferroni multiple comparison in RHD old subjects.

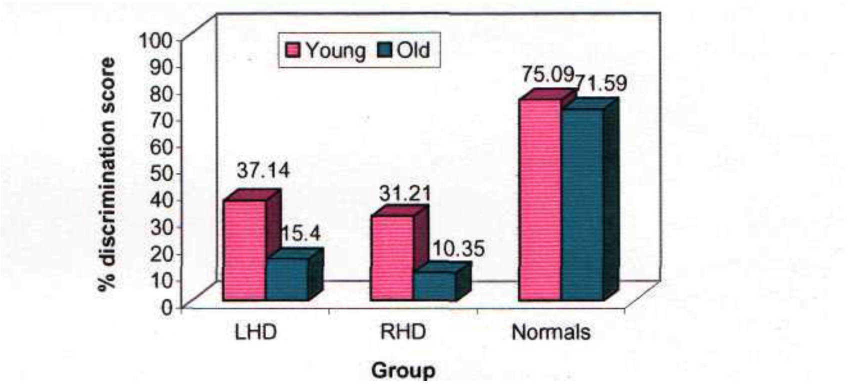


Figure 14: Percent discrimination scores on altered F0 condition.

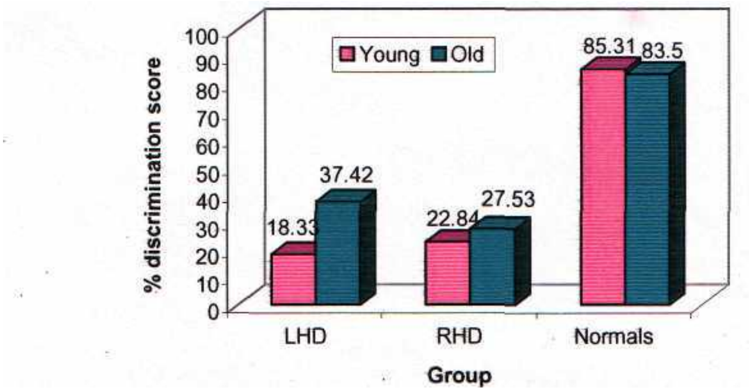
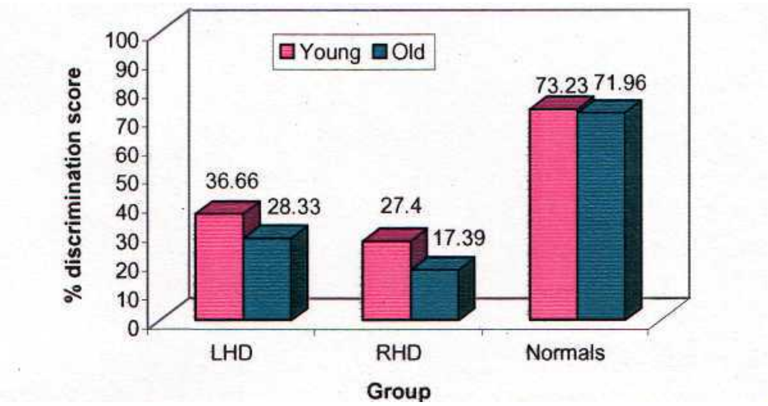
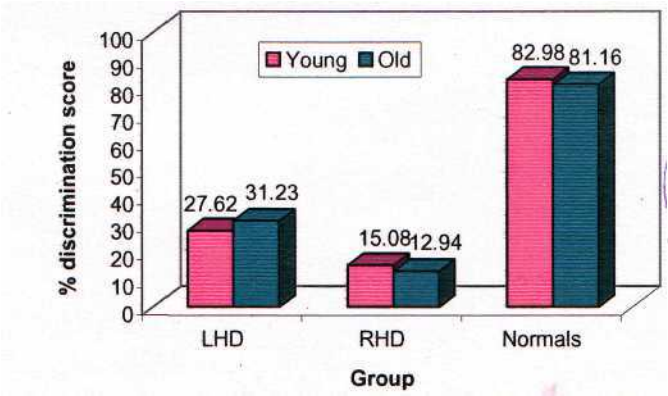


Figure 15: Percent discrimination scores on altered D0 condition.





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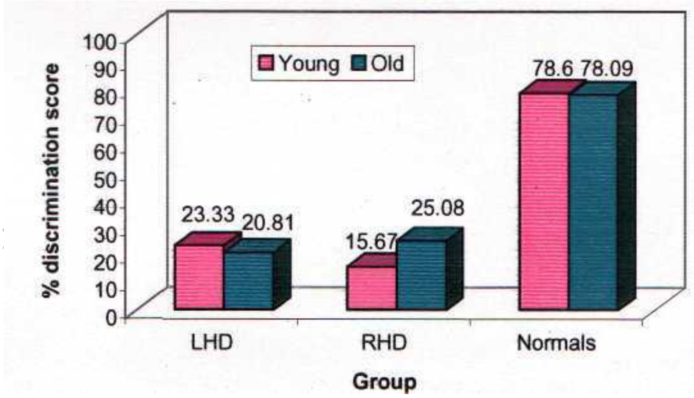

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Figure 18: Percent discrimination scores on altered A O D O condition.

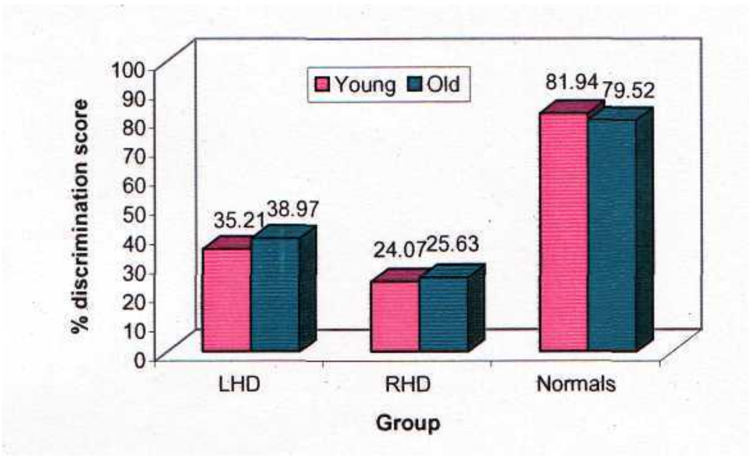
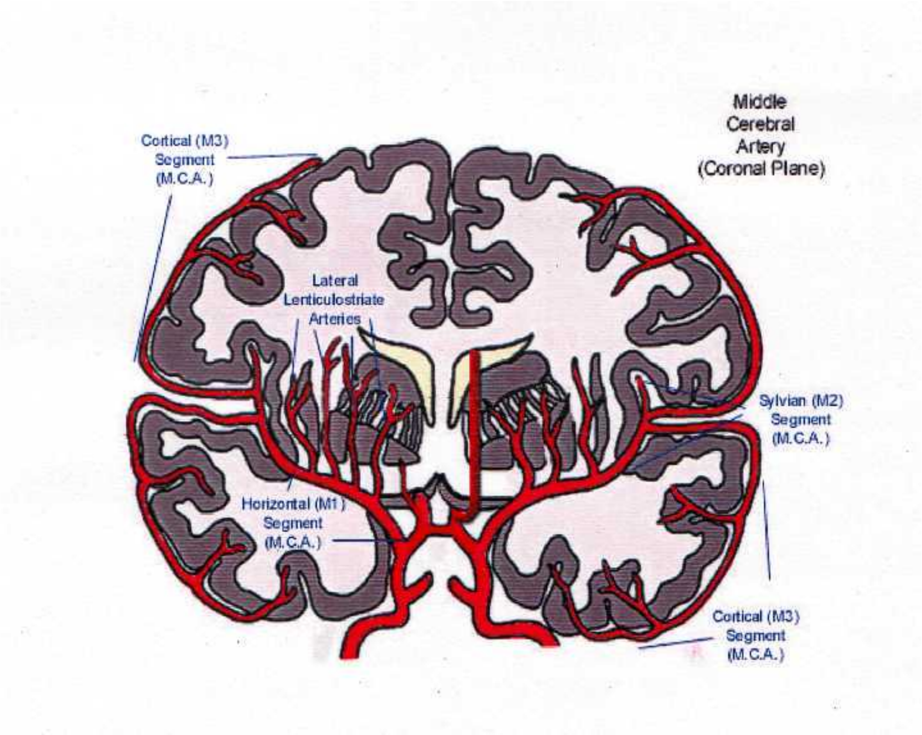


Figure 19: Percent discrimination scores on altered F0A0D0 condition.

To summarize, the results of experiment I indicated significantly higher F0, intensity, and longer duration in stressed words compared to unstressed words. Based on these results, 525 synthetic phrase pairs in 7 sub-experiments were generated in experiment II. Experiment III investigated the ability of two groups of subjects (normal controls and subjects with CVA) to discriminate these phrase pairs. Seven sub-experiments were conducted in which individual and multiple parameters of stress were altered. Two hundred and one phrase pairs with 6 sub-experiments were retained following investigation in normal subjects. Results of experiment III indicated that subjects with CVA scored significantly lower than normal subjects on all six sub-experiments. Among CVA subjects, LHD had higher scores on altered F0D0 and F0A0D0 conditions compared to RHD. Young subjects had significantly higher score on altered F0 condition and significantly lower score on altered D0 condition compared to old subjects. Significant difference between sub-experiments was observed only in RHD old subjects. RHD old subjects had significantly higher score on altered D0, A0D0 and altered F0A0D0 conditions compared to altered F0, F0A0, and altered F0D0 conditions.

Chapter V

Discussion



"If the human brain were so simple that we could understand it, we would be so simple that we couldn't"

Emerson.M.P.Quotes

The results of experiment I indicated significantly higher F0, intensity and word duration in stressed words compared to their counterpart unstressed words. The S-ratio (difference between stressed and unstressed words) was 40 Hz, 4 dB, and 136 ms for F0, intensity, and word duration, respectively. It appears that duration is a major acoustic cue of stress (in Kannada) followed by F0. The results are in consonance with those of Fant (1958 - Swedish), Lehiste (1968a - Estonian), Bertinetto (1980 - Italian), Balasubramanian (1981 - Tamil), Savithri (1987), Rajupratap (1991), and Savithri (1999) (all in Kannada). The data supports the notion that acoustic cues of stress differ from one language to another. In languages like Swedish, Tamil, and Kannada where the ratio between the duration of short and long vowels is 1: 2, short and long vowels are distinct. Therefore, duration may be used to indicate stress. Conversely, in languages like English, the ratio between lax and tense vowels is around 1: 1.54. Therefore, lengthening of vowel will change the lax vowel to tense vowel or change the quality of vowel. Thus, vowel lengthening can't be presumably used to indicate stress. The other options are F0 and intensity and therefore, F0 may be the major cue of stress in English. The fact that duration emerged as a major cue of stress in Kannada made one to expect better scores in RHD on altered duration phrase pairs given the hypothesis that right hemisphere process F0 and left hemisphere process temporal parameter (duration).

The results of experiment HI on control normal subjects indicated that 67 of 175 phrase pairs were discriminated by more than 70% of times. The number of phrase pairs discriminated was 7 (F0) and 12 (duration) when F0 or duration in the unstressed word was altered to match that of its counterpart stressed word. The results indicated that more number of phrase pairs was discriminated when duration was altered than when FO was altered in a single cue altered condition. This again supports the notion that duration is a major acoustic cue of stress in Kannada. An examination of the mean difference between FO in stressed and unstressed words (appendix III) indicated that perhaps the steepness of FO increase, and not FO difference, is important in discriminating phrase pairs. This needs to be examined further. It was interesting to note that none of the phrase pairs altered in intensity was discriminated by more than 50% of times. Jassem et. al. (1968) report that intensity was effective only when the difference was greater than 6 dB. In the present study there were phrase pairs that differed by more than 6 dB. But, subjects did not discriminate phrase pairs that differed even by 11 dB (maximum). The JKD for FO and intensity in discriminating words with stress needs to be investigated. An inspection of multiple condition indicated that 5 (F0A0), 14 (F0DO), 13 (A0D0), and 16 (F0A0D0) phrase pairs were discriminated. In altered duration single cue condition, 12 phrase pairs were discriminated. Addition of cue enhanced discrimination score (FO DO - from 12 phrase pairs to 14, F0A0D0 - from 12 phrase pairs to 16). On the other hand in FO single cue condition, the number of phrase pairs discriminated was 7. Addition of intensity (F0A0) cue reduced the number of phrase pairs discriminated from 7 to 5. Subjects discriminated more number of phrase pairs in F0D0 condition (14) compared to F0A0 condition (5). Also, normal subjects had highest scores on duration altered phrase pairs among single or multiple cue altered condition.

Results also indicated that CVA (both LHD and RHD) subjects had significantly lower scores compared to normal control subjects in all the six sub-experiments. This supports the notion of bilateral (both hemispheres) involvement in processing stress.

LHD performed significantly better than RHD on altered FODO, and altered F0A0D0 conditions. Also, LHD scores were better than those of RHD on all sub-experiments except when AODO was altered. Poor performance of RHD compared to LHD on duration altered phrase pairs does not support the results of Baum (1998). Baum (1998) investigated the role of FO and duration in the perception of linguistic stress by individuals with brain damage and non-brain damage. FO or duration cues were neutralized in phonemic and emphatic stress stimuli. Stimuli consisted of two sets of base stimuli comprising of phonemic or lexical stress (12 pairs of utterances that were phonologically identified and differed in stress placement - compound noun or noun phrase) and emphatic or contrastive stress pairs (12 pairs of utterances that differ in terms of which content word receives primary focus or emphasis - NP utterances). Six conditions - (a) phonemic stress - full cue, (b) phonemic stress - duration equivalent, (c) phonemic stress - FO equivalent, (d) emphatic stress - full cue, (e) emphatic stress - duration equivalent, (f) emphatic stress - FO equivalent were presented to subjects. Results indicated that subjects with LHD performed poorly on duration equivalent stimuli and those with RHD performed poorly on FO equivalent stimuli (phonemic stress). On emphatic stress subtest, LHD subjects demonstrated chance performance in the FO equivalent condition indicating that FO manipulation had a much smaller effect on the RHD and NBD individual's emphatic stress judgments compared to their phonemic stress judgments. Baum (1998) concluded that both hemispheres involve in the processing of prosody and that there is differential preference for temporal and spectral cues for processing stress in the brain damaged. Results of present study did not support this differential preference with right hemisphere processing FO (spectral) information and left hemisphere processing temporal information (FO). However, the type of stress and the type of responses are different in these two studies.This result that LHD performed better compared to RHD on altered FO condition (though not significantly) is in consonance with that of Sarah (2000), who used the same type of stimuli and response. However, the scores in RHD in Sarah's study were much higher than those in the present study (figure 20). This may be attributed to the number of RHD in the two studies. While Sarah had one RHD subject, the present study examined 32 RHD subjects.

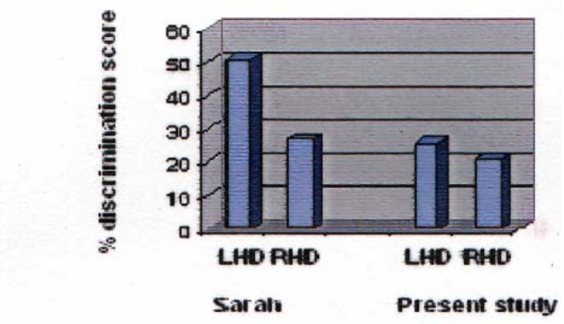


Figure 20: Comparison of results of two studies in F0 altered condition.

Another interesting finding was the difference between young and old subjects. Young subjects (both RHD and LHD) had higher scores on altered F0condition (spectral) and old subjects (both RHD and LHD) had higher scores on altered DO (temporal) condition. There is psychoacoustic evidence of age-related changes in temporal processing. Speech cues can be coded by at least 3 different types of auditory temporal processing. Voice cues such as voice quality and pitch rely on synchrony coding (phase-locking or neural firing timed to the cycles per second of the input sound). Second, some word level contrasts (for e.g. slit vs. split) rely on gap or duration coding (specialized neural responses to the onsets and offsets of sound energy). Third, syllabic rhythms and ability to follow different rates of speech rely on coding of prosodic patterns. Kathleen Pichora-Fuller (2000) reported that older listeners were less able than younger listeners to use synchrony coding to detect signals in noise better with two ears than with one ear. Also, rapid patterns are more challenging for older listeners than for young listeners. In the present study, F0 of the unstressed word in each phrase was changed to F0 of the counterpart stressed word every 10 ms and duration of the phonemes in unstressed word in each phrase was changed to duration of the phonemes in the counterpart stressed word. Thus, F0 changes are rapid patterns compared to duration and hence old subjects might have discriminated altered DO phrase pairs better than altered F0 phrase pairs.

Variations in the use of stress cause different languages to have different rhythms. In the present study all subjects had Kannada as their native language and 30% of them were also exposed to English. English is stress-timed language which makes far use of differences in stress than do most of the languages of the world. English uses phonemic stress wherein word meaning changes depending on change in stress on syllables. A native speaker of English might be influenced by the stress pattern of his language while perceiving stress of a non-native language which has stress patterns other than phonemic stress. But, in Kannada, stress is used for emphasis. Even if subjects of this study were exposed to English, it is highly unlikely that they are influenced by the phonemic stress pattern of English as most of the subjects used English as influenced by Kannada.

As no difference between male and female subjects was noticed separate data for gender is not presented.

Lastly, high individual variability was seen in the performance of LED and RHD and further in young and old subjects. This warrants the presence of other factors that influence the performance. In the present study, LHD and RHD were restricted to MCA infarct and hemorrhage. However, the extent of lesion was not a factor considered. Future studies may consider a correlation between discrimination of stress and extent of lesion by using FMRI.

Theoretically the results of the study have enriched the information about the neuroanatomical regions active in prosodic processing, and the specific role of hemispheres in stress processing. It appears that both the hemispheres and the regions supplied by middle cerebral artery are involved in stress processing. Further research in subjects with specific lesions, and with sub-cortical lesions may provide useful information on stress processing.

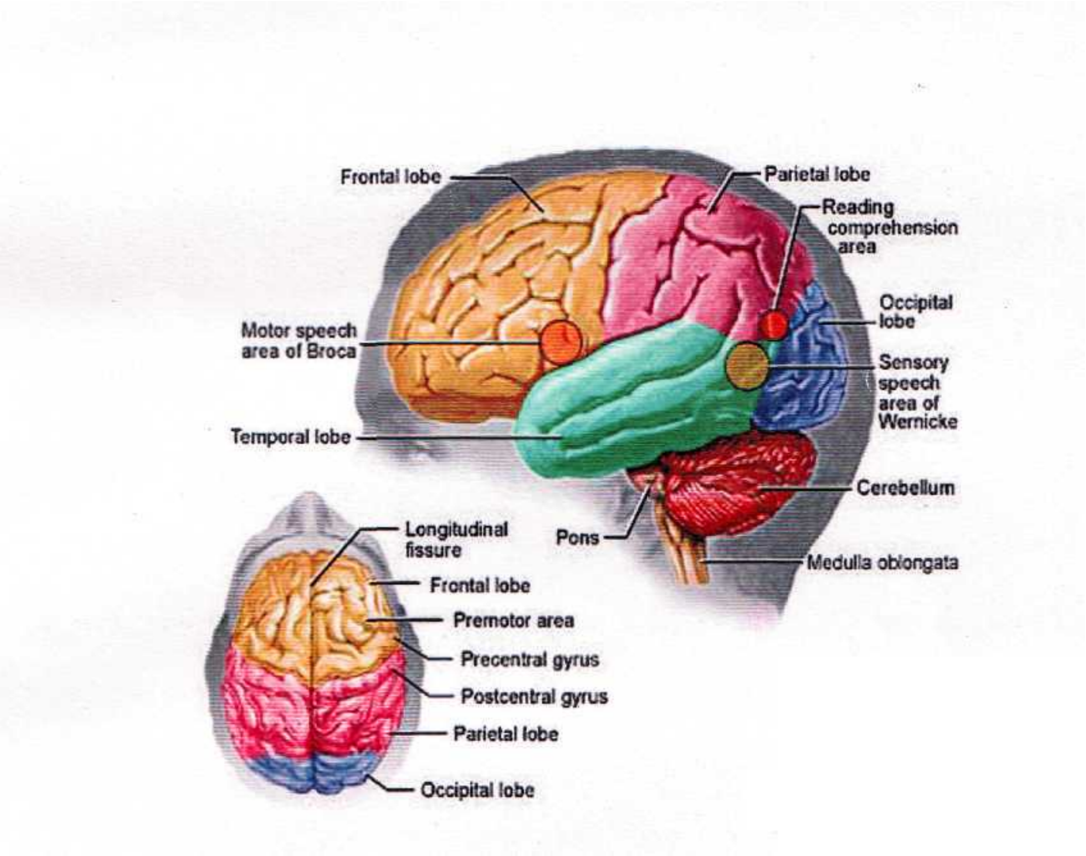
The acoustic correlates of stress vary from language to language and currently, at the national level, research has been done only in Tamil and Kannada. India being a multilingual country provides ample opportunity for cross-linguistic research concerning the neural substrate of prosody and future investigations can be focused on the type of stress and their perception in various Indian languages.

The information obtained through this research would help us in formulating diagnostic procedures and planning intervention goals directed to tap and improve the stress comprehension ability of persons with CVA. The material developed for perceptual evaluation in subjects with CVA in the present study may be used to evaluate comprehension of phrase level stress in subjects with CVA. Further, information on specific cues used by individual patient in the comprehension of phrase level stress may be used to plan appropriate therapeutic program to work on improving the perception of stress in subjects with CVA. For example, if the subject has the poorest score on FO, then training can be geared towards discriminating FO patterns. Also, duration may be a useful therapeutic parameter in old patients with CVA. For example, time warped (time expanded) stimulus can be used in old patients with CVA. Thus, clinically the research would be of immense help in providing effective diagnostic and rehabilitative methods in subjects with CVA.

Investigations of acoustic correlates of stress in tonal languages and perception of stress in speakers of such languages will be interesting (although some studies have been conducted) as speakers of tonal languages use FO to indicate tone. Therefore, it is logical to assume that they use an acoustic cue other than FO for stress. Also, the cue lateralization hypothesis that FO is processed in right hemisphere and duration in left hemisphere may not hold good for tone languages. In such languages FO is linguistic and, therefore, may not be used largely at a suprasegmental level. If listeners of such language are using duration as the only acoustic cue to stress, then investigation in subjects with brain damage using tonal language should clearly show the hemisphere processing of duration. What are the acoustic cues of stress and how do normal subjects and subjects with brain damage using tonal language perceive such cues is a question to be answered in future research.

Chapter VI

Summary and Conclusions



"The good lord gave me a brain that works so fast that in one moment I can worry as much as it would take others a whole year to achieve".

Emerson M.Pugh quotes

In the search for neuroanatomical correlates of behaviour, a great deal of attention has been focused on language processing. Prosody serves a variety of functions in language processing and it is an important component of the linguistic system. Prosody or suprasegmental incorporates intonation, rhythm, stress and quantity. Intonation is the change in fundamental frequency (F0) over a period of time. Rhythm refers to an event repeated regularly over a period of time, quantity is the duration of speech sounds and stress refers to extra energy. Stress has been called the most elusive of all prosodic features (Lehiste, 1970) signaled by at least three acoustic correlates i.e. a change in fundamental frequency, amplitude and duration (Lieberman, 1960).

In most models of speech production (Levitt, 1989), the prosody generator is considered as a distinct component of the speech production system or a subcomponent of the phonological system. To date, majority of neurolinguistic research in this area has focused in some detail on the neural basis of the segmental aspects of speech. But far less attention has been devoted to speech prosody. Thus, despite its importance in communication, the neural systems responsible for the production and comprehension of prosody remain largely unspecified.

Some of the continuing questions posing those interested in the neural substrates for the processing and controlling of prosody are (a) is the function (linguistic vs. emotion) lateralized or are the acoustic cues (F0 vs. duration) lateralized?, (b) given that the linguistic prosodic system is part of several grammatical components (phonological, lexical and syntactic), to what extent does a particular break down in the prosodic system effect these components? (c) are the comprehension and production of prosodic cues similarly affected by brain damage under the hemisphere control?

Three views on prosodic processing have been put forth. The first hypothesis, functional lateralization hypothesis (Van Lancker, 1980), claims that linguistic prosody is processed in the left hemisphere, whereas emotional prosody is controlled by the right hemisphere. A second hypothesis posits that all aspects of prosody are processed in the right hemisphere and intergrated across the corpus callosum with linguistic representations (Klouda, et. al., 1988). A third important hypothesis that has recently gained some experimental support contends that individual hypithesis cues to prosody are lateralized to different hemispheres, with fundamental frequency parameters processed by the right hemisphere and temporal parameters by the left hemisphere (Van Lancker & Sidtis, 1992). Several researchers have investigated the role of hemispheres in prosodic processing. However, the results are inconclusive and are contradicting. Further, the type and perception of prosody (especially stress) differs from one language to another. Thus, the existing contradictory evidences on stress perception in brain damaged and the language dependency of stress perception provoked the present study. The present study investigated perception of stress in Kannada speaking subjects with cerebro-vascular accidents (CVA). If the left hemisphere is specialized in processing temporal acoustic parameters (duration), it should be better reflected in left hemisphere damaged individuals speaking Kannada. Studies in language like Kannada, where duration is a major acoustic cue of stress, would be interesting in that the role of left hemisphere in processing temporal cue would be better emphasized compared to a language like English where the major acoustic cue of stress is F0. Therefore, the ability to perceive stress in Kannada speaking subjects with CVA in left hemisphere and right hemisphere was compared with Kannada speaking normal controls. Further, subjects were grouped as young and old patients and their performance was compared to study the effect of age on stress perception. The following research questions were asked: (1) Are there differences between subjects with CVA and normal controls in perception of stress? (2) Are there differences between LHD and RHD (CVA) subjects in perception of stress? (3) Are there differences between young and old CVA subjects in perception of stress? (4) Do LHD and RHD (CVA) subjects use different acoustic cues to perceive stress? and (e) Are there differences between single and multiple cue conditions?

To approve or reject the speculation, independent and combined manipulation of the acoustic parameters - fundamental frequency, intensity and duration - available in the stimuli was performed. Three experiments were conducted.

Experiment I dealt with acoustic analyses of Kannada words with and without stress. Twenty-five meaningful two-word Kannada phrases (adjective + noun) as uttered by a native female Kannada speaker (42 year old) with and without stress on the first word of each phrase were directly recorded into the computer at 16,000 Hz sampling frequency and were stored on to the computer memory. The phrases were acoustically analyzed using the 'FBAS' program of SSL Pro2V2 (Voice and Speech Systems, Bangalore). The fundamental frequency (F0) and intensity (A0) of each syllable of the stressed and unstressed words were extracted at every 10 ms. The duration of individual phoneme in the stressed and the unstressed words were measured from the waveform display. These parameters in stressed and unstressed words were compared and the difference between the stressed and unstressed words for each parameter was calculated.

Experiment II dealt with generation of synthetic phrases. Using the "PATPLAY" program of SSL software, seven experiments were conducted, in which various parameters cueing stress were altered in isolation and in combination as in table 29.

Expt. No.	**Parameter changed**	**Details**	**Total No. of Tokens**
1	Fundamental Frequency (FO)	FO of the unstressed word in each phrase was changed to FO of the counterpart stressed word every 10 ms	**25**
2	Intensity (AO)	AO of the unstressed word in each phrase was changed to AO of the counterpart stressed word every 10 ms	**25**
3	Duration (DO)	DO of each phoneme in the unstressed word in each phrase was changed to DO of the counterpart phoneme in the stressed word	**25**
4	FO&AO	FO & AO of the unstressed word in each phrase was changed to FO & AO of the counterpart stressed word every 10 ms	**25**
5	FO&DO	FO & DO of the unstressed word in each phrase was changed to FO & DO of the counterpart stressed word.	**25**
6	AO&DO	FO & DO of the unstressed word in each phrase was changed to AO & DO of the counterpart stressed word	**25**
7	FO, AO & DO	FO, AO & DO of the unstressed word in each phrase was changed to FO, AO & DO of the counterpart stressed word.	**25**
		Total No. of Tokens	**175**

Table 29: Details of the experiments for generating the synthetic phrases.

These 175 synthetic phrases were paired with their corresponding unstressed original phrase forming a total of 175 phrase pairs. These phrase pairs were randomized, iterated thrice and were audio-recorded. Thus, a total of 525 phrase pairs formed the material for perceptual evaluation.

Experiment III investigated perception of stress in normal controls and in subjects with CVA. Fifty Kannada speaking normal subjects (below 45 years - young: 29, above 45 years - old: 21) in the age range of 21 - 80 years participated this experiment. Stimuli were audio presented to each subject through headphones and subjects were instructed to listen to the material carefully and indicate whether two phrases in a pair were 'same" or 'different' on a binary forced choice response sheet. A discrimination task was used. The same procedure was followed in all seven sub-experiments. The responses of the subjects were tabulated and percent' same' or different' for each token and for each subject was calculated. The mean percent 'different' was calculated for each of the 25 phrase pairs.

The mean percent different response (discrimination score) for each of the 25 phrase pair was tabulated and plotted on a graph. The phrase pairs that were discriminated by more than 70 % of times were considered as material in subjects with CVA. Fifty-nine subjects with CVA participated in the experiment. Subjects were diagnosed by neurologists and supported by CT scan. The age of subjects with CVA ranged from 26 years to 79 years. Subjects with CVA were further subdivided into two groups - subjects with CVA in left hemisphere (27) and subjects with CVA in right hemisphere (32). These subjects were further grouped into young and old subjects. Subjects below the age of 45 years were grouped under young patients and those above 45 years were grouped under old patients. There were 19 young subjects

Sixty-seven phrase pairs discriminated by more than 70 % of times by normal controls were iterated thrice and randomized. Thus, a total of 201 (67 * 3 = 201) phrase pairs were used in subjects with CVA. The procedure was the same as in normal controls.

The results of experiment I indicated that F0, intensity and word duration in stressed words were significantly higher/ longer (at P< 0.005) than their unstressed counterparts. The S-ratio (difference between stressed and unstressed words) was 40 Hz, 4 dB, and 136 ms for F0, intensity, and word duration, respectively.

Using the values obtained from acoustic analysis in experiment I, a total of 525 synthetic phrase pairs were generated in experiment II.

The results of experiment III on normal controls indicated that subjects discriminated phrase pairs altered in individual / multiple parameters (except that in intensity). However, the number of such phrase pairs depended on the parameter altered. Percent discrimination scores were higher on phrase pairs altered in multiple parameters compared to those altered in single parameters. Not all phrase pairs were discriminated by normal subjects. Only those phrase pairs that were discriminated by more than 70 % of times were considered for further study in subjects with brain damage. A total of 7, 12, 0, 5, 14, 13, and 16 phrase pairs were discriminated in 1-7 sub-experiments, respectively. No phrase pair was discriminated by more than 50 % of times on sub-experiment 3 in which intensity was altered. A total of 67 of the 175 phrase pairs were discriminated by normal subjects.

Results of experiment HI in subjects with CVA indicated that subjects scored significantly lower ($P < 0.001$) than normal controls on all six sub-experiments. Among CVA subjects, LHD had significantly higher scores ($P < 0.001$) on altered F0D0 and F0A0D0 conditions compared to RHD. Young subjects (both RHD and LHD) scored significantly higher ($P < 0.001$) on altered F0 condition (spectral) and old subjects scored significantly higher ($P < 0.001$) on altered DO (temporal) condition. Table 30 shows percent discrimination scores in young and old LHD and RHD subjects.

Group/age	FO	DO	F0A0	F0D0	A0D0	F0A0D0
LHD Young	37.14 (27.40-46.88)	18.33 (8.54-28.12)	36.66 (20.11-53.22)	27.62 (7.81-47.42)	23.33 (11.53-35.14)	35.21 (19.19-51.22)
LHD old	15.40 (8.73-22.08)	37.42 (24.23-50.60)	28.23 (13.97-42.50)	31.23 (13.65-48.82)	20.81 (7.83-33.80)	38.97 (23.07-54.87)
Total	23.45 (16.81-30.10)	30.35 (21.00-39.69)	31.36 (21.07-41.64)	29.89 (17.46-42.33)	21.75 (13.10-30.49)	37.58 (26.63-48.52
RHD young	31.21 (13.18-49.25)	22.84 (13.92-31.76)	27.40 (17.01-37.79)	15.08 (8.74-21.42)	15.67 (3.95-27.39)	24.07 (15.08-33.06)
RHD old	10.35 (8.32-12.38)	27.53 (23.88-31.19)	17.39 (13.15-21.62)	12.94 (9.03-16.85)	25.08 (19.64-30.52)	25.63 (21.65-29.62)
Total	16.21 (10.54-21.90)	26.21 (22.79-29.63)	20.21 (15.10-21.41)	13.54 (10.39-16.70)	22.43 (17.45-27.41)	25.19 (21.66-28.73)

Table 30: Percent discrimination scores in LHD and RHD on 6 sub-experiments (95% confidence interval of mean in parenthesis).

The results of the present study indicated that acoustic cues of stress differ from one language to another and supported the notion that duration is a major acoustic cue of stress in Kannada. Results suggested that both hemispheres involve in the processing of stress. However, results did not support the differential cue lateralization hypothesis which stated that the right hemisphere is specialized in processing FO (spectral) information and left hemisphere is specialized in processing temporal information (DO). However, this may be because of difference in the type of stress used in earlier and present studies.

A significant difference ($P< 0.05$) between young and old CVA subjects on altered FO, altered DO and altered F0A0 conditions was noticed. CVA young subjects scored significantly higher on altered FO and F0A0 conditions compared to old subjects. CVA old subjects scored significantly higher on altered DO condition compared to CVA young subjects. There is psychoacoustic evidence of age-related changes in temporal processing. Speech cues can be coded by at least 3 different types of auditory temporal processing. Voice cues such as voice quality and pitch rely on synchrony coding (phase-locking or neural firing timed to the cycles per second of the input sound). Second, some word level contrasts (for e.g. slit vs. split) rely on gap or duration coding (specialized neural responses to the onsets and offsets of sound energy). Third, syllabic rhythms and ability to follow different rates of speech rely on coding of prosodic patterns. Kathleen Pichora-Fuller (2000) reported that older listeners were less able than younger listeners to use synchrony coding to detect signals in noise better with two ears than with one ear. Also, rapid patterns are more challenging for older listeners than for young listeners. In the present study, F0 of the unstressed word in each phrase was changed to F0 of the counterpart stressed word every 10 ms and duration of the phonemes in unstressed word in each phrase was changed to duration of the phonemes in the counterpart stressed word. Thus, F0 changes are rapid patterns compared to duration and hence old subjects might have discriminated altered DO phrase pairs better than altered F0 phrase pairs.

Lastly, high individual variability was seen in the performance of LHD and RHD and further in young and old subjects. This warrants the presence of other factors that influence the performance. In the present study, LHD and RHD were restricted to MCA infarct and hemorrhage. However, the extent of lesion was not a factor considered. Future studies may consider a correlation between discrimination ofstress and extent oflesion by using FMRI.

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Investigations of acoustic correlates of stress in tonal languages and perception of stress in speakers of such languages will be interesting (although some studies have been conducted) as speakers of tonal languages use F0 to indicate tone. Therefore, it is logical to assume that they use an acoustic cue other than F0 for stress. Also, the cue lateralization hypothesis that F0 is processed in right hemisphere and duration in left hemisphere may not hold good for tone languages. In such languages F0 is linguistic and therefore may not be used largely at a suprasegmental level. If listeners of such language are using duration as the only acoustic cue to stress, then investigation in subjects with brain damage using tonal language should clearly show the hemisphere processing of duration. What are the acoustic cues of stress and how do normal subjects and subjects with brain damage using tonal language perceive such cues is a question to be answered in future research.

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Appendix I

Binary forced choice response sheet (Normal subjects)

Name: Age/Gender: Occupation: Date:

List I			List II			List III		
Phrases	S	D	Phrases	S	D	Phrases	S	D
a:ru pa:ti			kari ka:ge			aidu ka:ru		
benki cendu			ni:li bassu			kari ka:ge		
bili butti			mu:ru ko:li			kahi ka:pi		
bili katte			a:ru pa:ti			gundu kallu		
bili tatte			ni:li angi			entu tale		
cu:pu katti			bili tatte			cu:pu katti		
entu tale			kari ko:ti			ni:li bassu		
gundu kallu			kempu gudde			ni:li patti		
aidu ka:ru			mu:ru pa:vu			kempu gudde		
kahi ka:pi			cu:pu katti			bili butti		
ka:li butti			kandu ko:tu			mondu magu		
kandu ko:tu			nidi patti			a:ru pa:ti		
kari ka:ge			ka:li butti			ka:li butti		
kari kannu			bili butti			sihi tindi		
kari ko:ti			benki cendu			benki cendu		
kempu batte			mondu magu			kari ko:ti		
kempu gudde			gundu kallu			kempu batte		
mondu magu			bili katte			na:ku na:yi		
mu:ru ko:li			kempu batte			bili katte		
mu:ru pa:vu			kari kannu			mu:ru pa:vu		
na:ku na:yi			sihi tindi			mu:ru ko:li		
ni:li angi			entu tale			ni:li angi		
ni:li bassu			na:ku na:yi			kari kannu		
ni:li patti			aidu ka:ru			bili tatte		
sihi tindi			kahi ka:pi			kandu ko:tu		

S: Same
D: Different

Binary forced choice response sheet (Subjects with CVA)

Name: Age/Gender: Occupation: Date:

Provisional Diagnosis:

F0 as Cue

Listl			List II			List III		
Phrases	S	D	Phrases	S	D	Phrases	S	D
1. biliKatte			1. bill katte			1. ni:li angi		
2. mondu magu			2. kempu gudde			2. bili katte		
3. cu:pu katti			3. ni:li angi			3. sihi tindi		
4. sihi tindi			4. curpu katti			4. kempu gudde		
5. gundu kallu			5. mondu magu			5. cu:pu katti		
6. ni:li angi			6. sihi tindi			6. gundu kallu		
7. kempu gudde			7. gundu kallu			7. mondu maeu		

D0 as cue

List 1			List II			List III		
Phrases	S	D	Phrases	S	D	Phrases	S	D
1. bili butti			1. bili butti			1. karika:ge		
2. bilikatte			2. ka:li butti			2. bili butti		
3. kahi ka:pi			3. kari ka:ge			3. kahi ka:pi		
4. entu tale			4. kempu gudde			4. mu:ru koli		
5. sihi tindi			5. bilikatte			5. gundu kallu		
6. ka:li butti			6. kari kannu			6. ka:li butti		
7. kandu ko:tu			7. sihi tindi			7. bilikatte		
8. gundu kallu			8. entu tale			8. kempu gudde		
9. kari ka:ge			9. mu:ru ko:li			9. kari kannu		
10. kempugudde			10. kandu ko:tu			10. sihi tindi		
11. kari kannu			11. gundu kallu			11. entu tale		
12. mu:ru ko:li			12. kahika:pi			12. kandu ko:tu		

S: Same
D: Different

FODO as Cue:

List 1			List II			List III		
Phrases	S	D	Phrases	S	D	Phrases	S	D
1. bilibutti			1. bili katte			1. kahika:pi		
2*. bili katte			2. kari ka:ge			2. cu:pu katti		
3. cu:pu katti			3. kahi ka:pi			3. kempu gudde		
4. entu tale			4. kari kannu			4. kandu ko:tu		
5. gundu kallu			5. gundu kallu			5. ni:li bassu		
6. kahi ka:pi			6. mondu magu			6. ni:li angi		
7. kandu ko:tu			7. cu:pu katti			7. bili butti		
8. kari ka:ge			8. sihi tindi			8. kari kannu		
9. kari kannu			9. bili butti			9. sihi tindi		
10. kempugudde			10. kempu gudde			10. gundu kallu		
11. mondumagu			11. kandu ko:tu			11. mondu magu		
12. ni:li angi			12. ni:li bassu			12. entu tale		
13. ni:libassu			13. entu tale			13. bili katte		
14. sihi tindi			14. ni:li angi			14. kari ka:ge		

AODO as Cue:

Listl			List II			List III		
Phrases	S	D	Phrases	S	D	Phrases	S	D
1. sihi tindi			1. nidi bassu			1. ni:li bassu		
2. kandu ko:tu			2. sihi tindi			2. gundu kallu		
3. aiduka:ru			3. gundu kallu			3. kahi ka:pi		
4. kahi ka:pi			4. kempu gudde			4. kempu gudde		
5. kempubatte			5. kari kannu			5. kempu batte		
6. entu tale			6. entu tale			6. cu:pu katti		
7. kari kannu			7. kahi ka:pi			7. aidu ka:ru		
8. gundu kallu			8. ni:li angi			8. ni:li angi		
9. kari ka:ge			9. kandu ko:tu			9. kari ka:ge		
10. ni:li bassu			10. kempubatte			10. sihi tindi		
11. ni:ll angi			11. curpukatti			11. kandu ko:tu		
12. kempu gudde			12. aidu ka:ru			12. kari kannu		
13. cu:pukatti			13. karika:ge			13. entu tale		

S:Same
D:Digerent

AOFO as Cue:

Listl			List II			List III		
* Phrases	S	D	Phrases	S	D	Phrases	S	D
1. entu tale			1. a:rupa:ti			1. kempu gudde		
2. a:ru pa:ti			2. entu tale			2. entu tale		
3. kempu gudde			3. mu:ruko:li			3. a:ru pa:ti		
4. kari ka:ge			4. kari ka:ge			4. kari ka:ge		
5. mu:ru ko:li			5. kempu gudde			5. mu:ru ko:li		

A0F0D0 as Cue:

List 1			List II			List ni		
Phrases	S	D	Phrases	S	D	Phrases	S	D
1. aiduka:ru			1. aiduka:ru			1. aidu ka:ru		
2. a:ru pa:ti			2. kandu ko:tu			2. cu:pu katti		
3. bili butti			3. bili butti			3. kandu ko:tu		
4. bili katte			4. kempu batte			4. bili katte		
5. cu:pukatti			5. kari kannu			5. kempu gudde		
6. entu tale			6. kahi ka:pi			6. bili butti		
7. gundu kallu			7. gundu kallu			7. kahi ka:pi		
8. kahi ka:pi			8. kempu gudde			8. kari ka:ge		
9. kandu ko:tu			9. entu tale			9. kari kannu		
10. kari ka:ge			10. a:rupa:ti			10. gundu kallu		
11. kari kannu			11. karika:ge			11. a:ru parti		
12. kempu batte			12. nidi angi			12. nirli angi		
13. kempu gudde			13. Bilikatthe			13. benki cendu		
14. benki cendu			14. ni:li bassu			14. sihi tindi		
15. ni:li angi			15. sihi tindi			15. entu tale		
16. ni:li bassu			16. cu:pukatti			16. kempu batte		
17. sihi tindi			17. benki cendu			17. ni:li bassu		

S:Same
D:Different

Appendix II

Questionnaire for demographic data on subjects

Name: Age/Gender: Occupation: Date:

Address:

Present complaint:

Brief history of the problem:

Language history: (encircle the mother tongue)

SI. No.	Comprehend	Speak	Read	Write
1				
2				
3				
4				
5				

Language commonly used at:

Home:

Neighbors:

Office:

Friends:

Pre morbid and post morbid handedness:

a) For writing:

b) Other skills (throwing, cutting, grasping, combing, locking):

Reports:

a) Neurological/ Physician findings

b) Psychological findings

c) Physiotherapist/occupational therapist findings

d) Other reports (E.N.T, Audiological, ophthalmologic, medico social workers)

On going treatments if any:

Communication behaviors including Speech & Language (pre & post morbid)

a) Orofacial mechanism examination

Structure	Appearance	Movement
Lips	Normal/cleft repaired/unrepaired If repaired: satisfactory/deviated/scared	Normal/abnormal/retraction/ pursing/symmetrical/asymmetrical
Teeth	Normal/missing/supernumerary Cross bite/over bite/ labio vertion/ Lingua version/others	
Tongue	Normal/microglossia/macroglossia/ Bifid tongue/tongue tie/ tongue thrust/spastic/atrophic	Normal/abnormal/protrusion/ Retraction/lateral/retroflex/ Elevation: front/back
Hard palate	Normal/repaired/unrepaired/fistula/ Scarred/high arched/low arched	
Soft palate	Normal/repaired/unrepaired/fistula/ Scarred/short/sub mucous cleft	Normal/abnormal/elevation Symmetrical/asymmetrical/ Sluggish/deviation to R/L
Uvula	Normal/repaired/unrepaired/bifid/ Missing/short/elongated	
Pharynx	Normal/abnormal	
Nose	Normal/abnormal	
Jaw	Symmetrical/asymmetrical Micrognathia/macrognothia	Normal/deviation to R/L Exaggerated/jerky

b) Language tests administered:

Results: (Not used in the study)

c) Speech evaluation

i) Voice:

Pitch: Loudness: Quality:

ii) Articulation:

iii) Prosody:

Stress: Intonation: Rhythm:

-

Overall Impression:

Recommendations:

Appendix III

Mean values of FO (Hz), AO (dB) and DO (ms) in stressed (S), and unstressed (US) words and the mean difference between S and US (S-US) for all the 25 phrases

Phrase No.	F0			A0			D0		
	S	US	S-US	S	US	S-US	S	US	S-US
1.	182	166	16	59	58	1	396	371	25
2.	174	157	17	62	55	7	464	385	79
3.	182	166	16	65	58	7	518	426	92
4.	206	169	37	66	58	8	511	398	113
5.	180	172	08	64	57	7	525	357	168
6.	209	180	29	68	61	7	527	349	178
7.	181	176	05	62	56	6	460	313	147
8.	201	172	29	63	59	4	582	500	82
9.	168	151	17	66	60	6	441	295	146
10.	225	178	47	61	59	2	552	403	149
11.	164	141	23	65	57	10	647	374	273
12.	176	124	52	62	51	11	642	501	141
13.	201	180	21	63	54	9	492	289	203
14.	201	176	25	61	57	4	609	378	231
15.	217	181	36		58	5	645	493	152
16.	197	149	48	63	54	9	437	300	137
17.	200	118	82	61	53	8	573	391	182
18.	210	152	58	64	60	4	531	441	90
19.	222	160	62	62	60	2	540	348	192
20.	199	157	42	64	58	6	473	355	118
21.	180	163	17	63	56	7	430	306	124
22.	230	221	09	61	57	4	449	342	107
23.	237	142	95	62	55	7	451	379	72
24.	220	135	85	62	58	4	456	345	111
25.	208	168	40	65	61	4	508	373	135

Appendix IV

Percent discrimination scores in all subjects with CVA and subjects without hemorrhage (A-all subjects, -H - without hemorrhage).

Sub-expts.	LHD				RHD				CVA			
	Young_		Old		Young		Old		Young		Old	
	A	-H	A	-H	A	-H	A	-H	A	-H	A	-H
FO	37.14	37.56	15.40	16.00	31.21	32.11	10.34	10.47	34.17	34.83	12.87	13.23
DO	18.33	19.75	37.41	37.30	22.84	24.30	27.53	27.63	20.58	22.02	32.47	32.46
FOAO	36.66	36.51	28.23	29.90	27.40	26.66	17.38	18.66	32.03	31.58	22.80	24.28
FODO	27.61	29.62	31.23	34.01	15.07	14.58	12.93	13.68	21.34	22.10	22.08	23.84
AODO	23.33	24.49	20.81	23.44	15.66	14.74	25.08	25.64	19.49	19.61	22.94	24.54
F0A0D0	35.20	35.87	38.96	40.47	24.07	22.91	25.63	25.72	29.63	29.39	32.29	32.09

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Fundamental Frequency as a Cue to Stress in Kannada

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ABSTRACT

The melody of speech is conveyed through Prosodic features. Stress is one of the prosodic features, the other two being intonation and rhythm. Stress refers to extra effort and is perceptually correlated by increased pitch, quantity and loudness. The acoustic correlates of stress are increased FO, intensity and duration, and change in vowel quality. These perceptual and acoustic correlates vary from language to language. The present study investigated the importance of fundamental frequency as a perceptual cue in the perception of stress in Kannada language. Twenty-Five meaningful two-word Kannada phrases (adjective + noun) as uttered by a Kannada normal female speaker with and without stress on the first word of each phrase formed the original material. Twenty-Five synthetic phrases were created altering the fundamental frequency of the phonemes of unstressed word to match the FO of phonemes in the counterpart stressed word. The original unstressed phrases were paired with the corresponding synthesized phrases. These pairs were randomized, iterated thrice and were audio recorded. Finally a total of 75 pairs of phrases were audio presented to 50 Kannada speaking normal subjects in the age range of 40-60 years for perceptual evaluation of stress. Results indicated that fundamental frequency was not a cue for the perception of word stress in Kannada.

INTRODUCTION

Prosody or supra segmental features convey the melody in speech. Intonation, stress, rhythm and quality are four prosodic features. Of these, stress is created by subtle changes in pitch, duration and intensity of a syllable or a word Price, P.J., Ostendorf, M., Shaltuck - Hufnagel, S., & Fong, L. (1991) [1]. Emphatic stress is one of the divisions in understanding stress. Emphatic stress in a phrase or sentence is used to indicate the word, which needs to be focused, to indicate the syntactic relationships between words or parts of word, and has a linguistic function in distinguishing between a compound and a noun. Acoustic parameters such as increased fundamental frequency, increased intensity, prolonged duration or. change in the vowel quality, cue stress Fry, D. B., (1958)[2]; Jassem, W. (1959) [3]; Rigault, A., (1962) [4]; Fant,C.G.M.,(1958)[5]

Savithri.S.R., (1987)[6]; Rajupratap, S., (1991) [7] Savithri.S.R ,(1999a) [8]; Savithri, S.R, (1999b) [9]. However theses acoustic cues used for stress perception vary from one language to another Fry, D. B., (1958)[2]; Jassem, W. (1959) [3]; Rigault, A., (1962) [4]; Fant,C.G.M.,(1958) [5] Savithri.S.R., (1987)[6]; Rajupratap, S., (1991) [7]; Savithri.S.R ,(1999a) [8] Savithri, S.R, (1999b) [9]. Various investigations have been done to note the cues for stress perception in variety of languages, Pitch prominence is considered as primary cue in perception of stress in English Fry, D. B., (1958)[2], Polish Jassem, W. (1959) [3] and French Rigault. A., (1962) [4]. While in languages like Swedish and Kannada, duration iS considered to be the major cue Fant, CGM,(1958) [5] Savithri.S.R., (1987)(6); Rajupratap, S., (1991) [7]; Savithri.S.R ,(1999a) [8]. Savithri(1999b)[9] had investigated the relative importance of FO, intensity and duration in signaling word stress. Results indicated that the increment in duration was a major cue for stress perception followed by increment of FO aid Intensity. Though different opinions exist among the investigators regarding the prominent cues of stress, there is a consensus that increase in FO, intensity, duration and alterations in vowel quality are primary cues for stress. Keeping in view the hypothetical contribution of FO the current investigation was carried out to understand the contribution of fundamental frequency in cueing stress in words.

METHOD

MATERIAL: 25 meaningful two-word Kannada phrases (adjective + noun) as uttered by a native female Kannada speaker with and without stress on the first word of each phrase were directly recorded into the computer at 16,000 Hz sampling frequency and were stored on to the memory of the computer. The phrases were acoustically analyzed using the 'FBAS' program of SSL Pro2V2 (Voice and Speech systems, Bangalore). F0 of individual phonemes in the first word of each phrase and the difference in the F0 of individual phonemes between the stressed and the unstressed word was calculated. The F0 of individual phonemes in the unstressed word was scaled to match those of its stressed counterpart word. These 25 edited phrases were paired with the corresponding original unstressed phrases. These phrase pairs were randomized, iterated thrice and audio recorded on to a cassette. Finally a total of 75 phrase pairs formed the material.

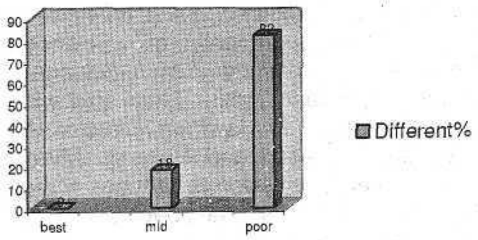
SUBJECTS: Fifty normal, Kannada speaking subjects in the age range from 40-60 yrs, participated in the study.

PROCEDURE: Subjects were tested individually. The stimuli were audio presented through headphones. They were instructed to listen to the material carefully and to indicate whether two phrases in the pairs were` same` or` different` on a binary forced choice response sheet.

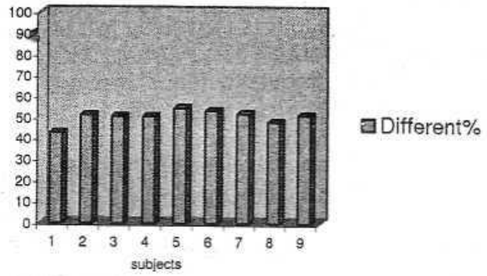
ANALYSIS: The responses of the subjects were tabulated and percent` same` or` different` for each token and for each subject was calculated. The mean percent same or different were calculated for all the 75 phrases using the formula – Total no. of same or different/50 * 100. The total number of same/ different responses for the 75 phrases were tabulated and the percent same/ different response for each phrase was plotted on a graph.

RESULTS AND DISCUSSION

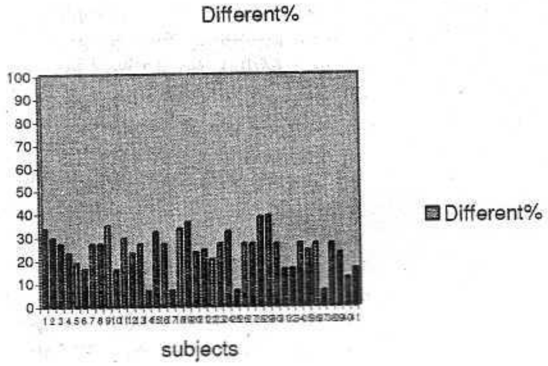
None of the subjects perceived two phrases in a pair as "***different***". The results indicated that fundamental frequency alone was not a cue for stress perception in Kannada. Depending on their "***different***" responses, subjects were classified under three categories as having (a) best (> 60%) (b) poor (<40%), and (c) in between perception (40-60%). Graphs 1-3 show the responses of subjects. The percentage response shows that none of the subjects were in the category 'best'. This shows that F0 variation was not a major cue for stress perception in normal native Kannada listeners. Savithri [9] investigated the relative importance of F0, intensity and duration in signaling word stress. Her results indicated that duration alone was a major cue followed by F0 and intensity in Kannada. In the current study 0% of subjects perceived two phrases as 'different' and 78% of the subjects perceived two phrases as 'same'. Also individual variations were evident. Though F0 was not a major cue, in-between responses suggested that some of the subjects might perceive F0 as cue for stress. It might be speculated that F0 combined with duration may yield a better perception of word stress in Kannada. It can be concluded that F0 alone is not a major cue for perception of word stress in Kannada



Graph 1: Percentage of responses in three categories.



Graph 2: In-between responses



Graph 3: Poor responses

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the syntactic relationships between words or parts of word and it has a linguistic function in distinguishing between a compound and a noun. Stress is cued by acoustic parameters such as increased fundamental frequency, increased intensity, prolonged duration or change in the vowel quality. The importance of these parameters indicating stress is language dependent. While in languages like English, where durational difference between long and short are not very clear, increments in fundamental frequency signal stress (Savithri, 1987). While this has been found in speech production studies, it is not clear whether the cues have the same function in perception of stress. In this context the present study is aimed at investigating the importance of temporal parameter: word duration on the perception of word stress in Kannada.

Methods

Material: Twenty five meaningful two word Kannada phrases (adjective + noun) as uttered by a native female Kannada speaker with and without stress on the first word of each phrase was recorded at 16,000 Hz sampling frequency using a 12 bit A/D converter. All the phrases were stored on to the memory of the computer. Using the program wave spec (SSL-Voice and Speech, Bangalore), the duration of individual phonemes in the first word of each phrase was calculated. The difference in the duration of individual phonemes between the stressed and the unstressed word was calculated. The duration of the individual phonemes in the stressed word was truncated to match those of its unstressed counterpart word. These 25 edited phrases were paired with the corresponding original phrases. These phrases were randomized, iterated thrice and audio recorded on to a cassette. Finally a total of 75 phrase pairs formed the material.

Subjects: 50 normal subjects, Kannada speaking in the age range from 40-60 yrs, participated in the study.

Procedure: Subjects were tested individually. The stimuli were audio presented through headphones. They were instructed to listen to the material carefully and to indicate whether two phrases are 'same' or 'different'.

Analysis: The responses of the subjects were tabulated and percent 'same' or 'different' for each token and for each subject was calculated. The mean percent same or different were calculated for all the 75 phrases. The total number of same / different responses for the 75 phrases were tabulated and the percent same/different response for each phrase was plotted on a graph.

Results and Discussion

The results of the present study do not indicate "duration" as a major cue in the perception of word stress in Kannada. This further suggests a lack of relationship between speech production and speech perception for word stress. Savithri (1999a) studied the importance of vowel duration as a cue for word stress in Kannada and reported that vowel duration was a cue in perceiving word stress in Kannada and suggested a relationship between speech production and speech perception. Savithri (1999b) investigated the relative importance of fundamental frequency, intensity and duration in signaling word stress in Kannada. The results of her study indicated that the increments in duration were a major cue for stress in Kannada followed by increments in F0 and intensity. The results of the present study are in contrast to the results by Savithri

PERCEPTION OF WORD STRESS IN KANNADA

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Abstract

The melody of speech is conveyed through the Prosodic features. Stress is one of prosodic features, the other two being intonation and rhythm. Stress refers to extra effort and the perceptual correlates of stress are increased pitch, duration & intensity of a syllable or a word. The perceptual correlates of stress vary from language to language. The present study aims at investigating the importance of duration as a perceptual cue in the perception of word stress in Kannada language. Twenty-Five meaningful two-word Kannada phrases (adj. + noun) as uttered by a normal Kannada speaker with and without stress on the first word of each phrase formed the original material. Twenty-Five synthetic phrases were created altering the duration of the vowel and the consonant of the stress word. The original stressed phrases were paired with the corresponding synthesized phrases. These pairs were randomized, iterated thrice and was audio recorded. Finally a total of 75 phrases were audio presented to 50 Kannada speaking normal subjects, age ranging from 40 to 60 years for the perceptual evaluation of the stress. Result revealed that duration alone was not an important cue for the perception of word stress in Kannada language.

Introduction

Suprasegmentals or Prosodic aspects are those superimposed upon the smaller speech sound segments combined in words, phrases and sentences and includes intonation, stress, rhythm and quality. While intonation refers to the movement of fundamental frequency in a sentence, stress is the extra energy or effort used to emphasize a syllable or a word. Rhythm is a repetitive event and quality is the duration of individual speech sounds. Stress is viewed from the speakers as well as from the listener's point of view. It is considered as the comparative force with which the separate syllables of the sound groups are pronounced. Speakers and listeners symbolically benefit from the use and interpretation of stress. Speakers emphasize salient aspects of a message to enhance the probability of listener comprehension. Listeners attend to the salient stressed segments of an auditory message, which in turn facilitates listener's comprehension of the entire stress bearing utterance. Stress is also used to indicate the word which needs to be focused, to indicate

(1999a and b). These differences may be attributed to the difference in the methodology used in the present study. While in her studies the duration of individual phonemes in unstressed words was increased to match those in stressed word, in the present study, the individual phonemes in stressed words was truncated to match those of the unstressed words. The results indicated that the subjects differed in their responses. While some subjects identified the difference between the original and edited phrases, some could not. Depending on their responses, subjects were classified under three categories as having (a) best (b) poor, and (c) in between perception. Figures 1 to 3 show the responses of subjects in the three different categories.

Figure 1: Percent response in best listeners

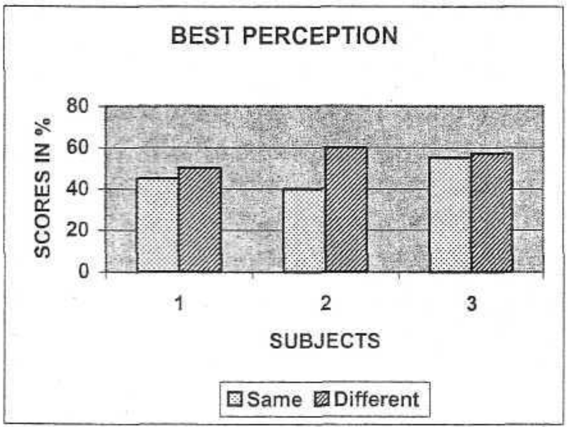


Figure 2: Percentage response in poor listeners

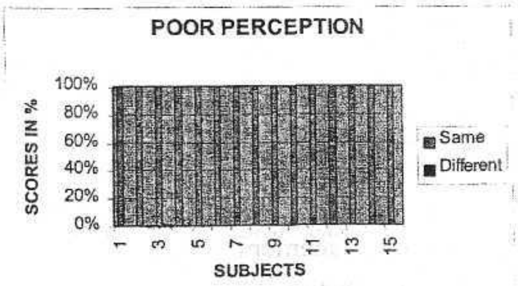
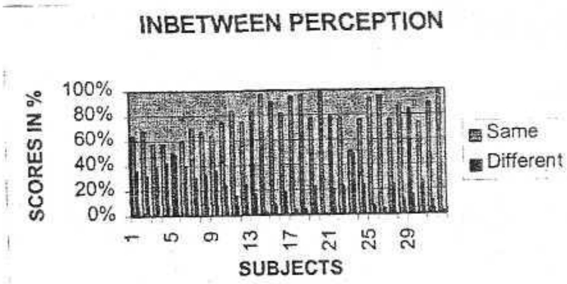


Figure 3: Percentage response in in-between listeners



The results indicated that 6% of the subjects differentiated phrases in pairs of word stress when duration of phonemes in the stressed words was altered. 30% of the subjects could not differentiate the two phrases in the word pairs. 64% of the subjects had in between perception.

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The authors acknowledge the financial support from the Department of Science and Technology, Ministry of Science and Technology, New Delhi. They also wishes to acknowledge Dr. M. Jayaram, Director, All India Institute of Speech and Hearing, Mysore, for having given permission to prepare and present the paper in the 35th ISHACON to be held in Chennai, January, 2003.

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Perception of Word Stress in Brain Damaged: F0 vs. Durational Cue

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ABSTRACT

Research on prosodic deficit in brain-damaged population has focused on the specialized capability of individual hemispheres in processing the global characters of prosody. Stress is one such prosodic feature that has received a considerable amount of interest, the other two being intonation and rhythm. Stress refers to extra effort. The perceptual correlates of stress are increased pitch, vowel length and loudness and the acoustic correlates are increased F0, duration and amplitude of a syllable. The perceptual correlates of stress vary from language to language. Many theories have been put forth in the literature explaining prosodic lateralization to hemispheres. Most of the research investigation in this interesting phenomenon has produced conflicting results. The present study investigated stress perception in Kannada. Three experiments were conducted. In the first experiment 25 phrases (adjective + Noun) as uttered by a Kannada speaker with and without stress on the first word were recorded and acoustically analyzed for F0 and duration of the word. The F0 and duration of the unstressed words in the phrase were edited to match the F0 and duration of the same stressed words. These two cues were operated independently. Twenty-five phrase pairs (original unstressed and the stressed – edited either for F0 or duration) each for F0 and duration cue were iterated thrice, randomized and audio-recorded. Ten non-brain damaged subjects participated in the second experiment. A same-different response was used. Those phrase pairs that were discriminated correctly by at least 70% of subjects were taken for experiment III in which 10 left hemisphere damaged (LHD) and 10 right hemisphere damaged (RHD) individuals participated. The results indicated that stressed word had higher F0 and longer duration compared to unstressed words. Subjects with brain *damage performed poorer than non- brain damaged subjects on discrimination of phrase pairs. Patients with RHD performed better than those with LHD on discrimination of stress involving alteration of F0, and performed poorer compared to LHD on discrimination of stress involving alteration of duration. The results did not support the differential cue lateralization hypothesis.*

INTRODUCTION

Prosody is an important component of the linguistic system. Referred to as the "melody of speech" resulting from a fluctuation of pitch, rhythm, and stress, prosody conveys semantic, syntactic, as well as emotional meaning (Monrad-Krohn, 1947). Stress, which is one among the prosodic features, has been most elusive of all prosodic features, signaled by at least three acoustic correlates: a change in fundamental frequency, amplitude, and duration (Liberman, 1960). Research on the neural substrates of prosody has gained impetus in the recent past (Baum, 1998; Emmeroy, 1987; Pell & Baum, 1997b; Van Lancker & Sidtis, 1992). These studies were on non-pathological subject's performance using dichotic listening technique and or analysis of prosodic abilities in brain damaged individuals. The relation between the prosody and its neural substrates has been variously hypothesized. Van Lancker (1980), proposing the functional lateralization hypothesis, claims that linguistic prosody is processed in the left hemisphere where as emotional prosody is controlled by the right hemisphere. Klouda, Robin, Graff-Radford & Cooper, (1988) posited that all aspects of prosody are processed in the right hemisphere and integrated across the corpus collosum with linguistic representation. However, this theory failed to explain the obvious degradation in prosody in left hemisphere damaged individuals. The differential cue lateralization hypothesis contends that individual acoustic cues to prosody are lateralized to different hemispheres, with fundamental frequency (F0) parameter processed by right hemisphere and temporal parameters by left hemisphere (Van Lancker & Sidtis, 1992).

Several studies have been conducted to explore the prosodic processing. However, contradicting results are obtained by two studies on stress perception in left hemisphere damaged (LHD). Blumstien & Goodglass (1972) found no effect of left hemisphere damage on primary stress perception. Both Wernicke's and Broca's aphasics were found capable of differentiating a meaning change caused by shift in phonemic stress. Contrary to this, Baum, Daniloff, Daniloff& Lewis (1982), found that Broca's patients performed significantly worse than normal controls in comprehending sentences that were disambiguated by stress changes using similar paradigm as Blumstien & Goodglass's picture pointing task. The authors concluded that Broca's aphasics may have a deficit in processing and perceiving variations in the acoustic information that signal stress. Evidence for the differential Lateralization hypothesis comes from the study of Van Lancker & Sidtis (1992). They compared the performance of subjects with left hemisphere damage (LHD) and right hemisphere damage (RHD) and non-brain damaged (NBD) on an emotional prosody identification task. They found that both groups of subject with brain damage performed poorer than NBD. Their performance did not differ much in its accuracy. However, a discriminant analysis was conducted by the authors to determine the acoustic cues that could predict the comprehension errors made by each group. Results of this analysis showed that LHD and RHD subjects used different acoustic cues to make the judgments. Patients with LHD seem to rely on F0 variations where as subjects with RHD seem to rely on durational cues. Thus, Van Lancker & Sidtis (1992) concluded that neural substrates for stress perception are bilaterally distributed with right hemisphere specialized for F0 processing and left hemisphere specialized for processing temporal acoustic parameters. However, a replication and extension study conducted by Pell & Baum (1997b) showed contradicting evidence. On a discriminant analysis, their subjects did not show any differential cue preference for prosody judgments. In view of such equivocal findings "differential cue lateralization hypothesis remains speculative. Sarah, Prakash & Savithri (2000) investigated the perception of emphatic stress in three Kannada speaking adults with left hemisphere damage and their age matched normal subjects. The authors reported that perception of emphatic stress in patients with left hemisphere damage was poor compared to normals. They also noted that duration was a prominent cue in the perception of emphatic stress in Kannada. Further, Sarah (2000) investigated the perception of emphatic stress in patients with left hemisphere damage, right hemisphere damage and normal individuals. The results of her study supported the differential lateralization hypothesis. Duration is the major cue for stress in Kannada (Savithri, 1987, 1999a, 1999b, Raju Pratap, 1991), while pitch is a major cue in English (Fry, 1958). Therefore, the perceptual responses of Kannada speaking patients with brain damage for stimulus with altered duration would be different than those of English speaking patients. If the left hemisphere is specialized in processing temporal acoustic parameters (duration), it should be better reflected in LHD patients speaking Kannada. In this context, the present study investigated perception of word stress in Kannada speaking LHD and RHD patients. It was hypothesized that individuals with left hemisphere damage would perform poorly on a stress discrimination task when only duration is the cue and individuals with right hemisphere damage would perform poorly on a stress discrimination task when only F0 is the cue.

METHOD

Three experiments were conducted. Experiment I dealt with acoustic analysis of stressed and unstressed Kannada phrases. In experiment II, non-brain damaged individuals discriminated phrase pairs differing in only fundamental frequency (F0) or duration as a cue for stress. In experiment III brain damaged individuals discriminated phrase pairs differing in only fundamental frequency (FO) or duration as a cue for stress.

EXPERIMENT I

ACOUSTIC ANALYSIS OF STRESSED AND UNSTRESSED PHRASES

Material: Twenty-five meaningful two-word Kannada phrases (adjective + noun) as uttered by a native female Kannada speaker (42 year old) with and without stress on the first word of each phrase were directly recorded into the computer at 16,000 Hz sampling frequency and were stored on to the computer memory. The phrases were acoustically analyzed using the 'FBAS' program of SSL Pro2V2 (Voice and Speech Systems, Bangalore). Fundamental frequency (F0) of each syllable and word duration in all the phrases with and without stress was extracted. These parameters in stressed and unstressed words were compared and the difference between the stressed and unstressed words for each parameter was calculated.

RESULTS

Fundamental frequency: The results indicated that the fundamental frequency of the unstressed word varied from 160.27 Hz to 205.5 Hz with a mean of 182.3 Hz. The fundamental frequency of stressed word was in the range of 181.6 Hz to 252.6 Hz with a mean frequency of 220.1 Hz. The fundamental frequency of the stressed words was significantly higher than their unstressed counter parts.
Duration: The results indicated that the duration of the unstressed word varied from 289 ms to 501 ms with a mean duration of 377.48 ms. The duration of stressed word was in the range of 430 ms to 647 ms with a mean duration of 513.36 ms. The stressed words were significantly longer than their unstressed counterparts. Table 1 shows the mean F0, and duration of stressed and unstressed words.

Parameters	Stressed			Unstressed		
	Minimum	Maximu	Mean	Minimum	Maximu	Mean
Frequency	182	253	220	160	206	182
Duration	430	647	513	289	501	377

Table I: *F0 (Hz), and duration (ms) in stressed and unstressed phrases*

EXPERIMENT II

DISCRIMINATION OF PHRASE PAIRS DIFFERING IN ONLY FUNDAMENTAL FREQUENCY (F0) OR DURATION BY NON-BRAIN DAMAGED INDIVIDUALS.

Material: The F0 and word duration of the unstressed word were edited individually to match the counterpart stressed word. Thus, 50 synthetic phrases were created. Each synthetic token was paired with its original unstressed phrase. Thus, one of the token in the pair was the original unstressed phrase and the other was the same token with either edited F0 or edited duration. These phrase pairs were iterated trice, randomized and audio recorded. Finally, 150 phrase pairs (75 with edited F0 and 75 with edited duration) formed the material.

Subjects: Ten normal, Kannada speaking subjects in the age range 40-60 years participated in the study. All the subjects had formal education for a period of at least 10 years.

Procedure: Subjects were tested individually. Synthetic token pairs were audio presented through headphones at comfortable listening levels. Subjects were instructed to listen to the phrases carefully and to indicate whether the two phrases in a pair were the 'same' or 'different' on a binary forced choice response sheet.

Analysis: The responses of normal subjects were tabulated and percent 'same' or 'different' was calculated for each token and for each subject. The mean percent same or different were calculated using the formula – total number of same or different/10 * 100. Percent 'different' response for each of the 25 phrase pairs was calculated. The phrase pairs that were perceived as 'different' by more than 70 % of the subjects were considered as material for experiment III.

Results: Of the 25 phrase pairs each for F0 and duration edited, 7 (F0 edited) and 12 (duration edited) pairs were perceived 'different' by more than 70% of the non brain damaged subjects. Thus only 19 phrase pairs were selected for experiment III. Tables 2, 3 and figures 1, 2 show the percent different response on all phrase pairs.

Phrase No.	Percentage difference	Phrase no	Percentage difference
1	41.66	14	74.33
2	51.66	15	41.33
3	76.66	16	70.33
4	78.66	17	26.45
5	71.66	18	71.42
6	10.11	19	11.33
7	32.33	20	0
8	41.45	21	0
9	10.11	22	16.11
10	17.33	23	70.33
11	37.33	24	3.33
12	0	25	36.45
13	0		

Table 2: *Percent* ***'different'*** *response for phrase pairs altered in F0.*

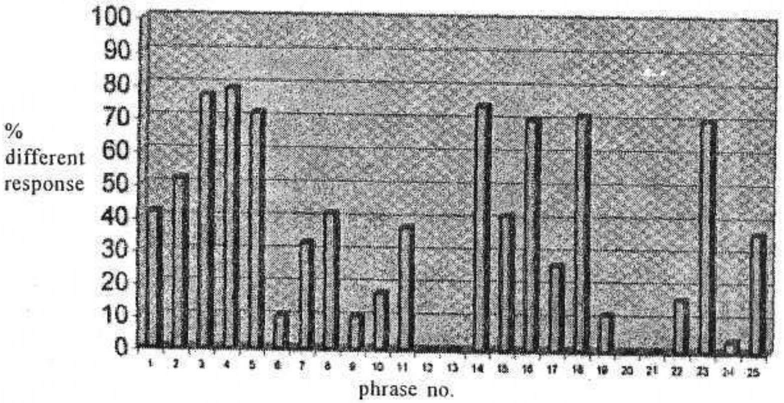

Fig 1: *Percent 'different' response for all the 25 phrases (altered F0)*

Phrase No	Percent 'different'	Phrase no	Percent 'different'
1	23.33	14	97.25
2	0	15	87.56
3	46.41	16	63.33
4	84.33	17	93.97
5	93.68	18	77.33
6	77.00	19	77.33
7	90.3	20	30.33
8	57.78	21	17.33
9	3.92	22	70.47
10	37.99	23	60.06
11	47.25	24	0
12	80.33	25	83.33
13	10.11		

Table 3: *Percent* ***'different'*** *response for altered* duration

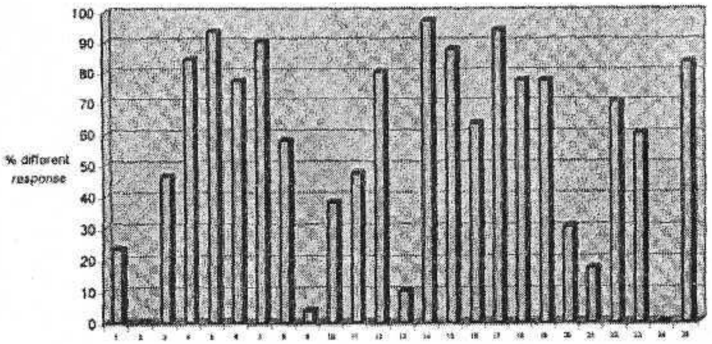

Figure 2: *Percent* ***'different'*** *response for all the 25 phrases (altered duration)*

EXPERIMENT III

DISCRIMINATION OF PHRASE PAIRS DIFFERING IN ONLY FUNDAMENTAL FREQUENCY (F0) OR DURATION BY BRAIN DAMAGED INDIVIDUALS.

Material: The 19 phrase pairs were iterated thrice and randomized to make 57 phrase pairs that formed the material.

Subjects: Ten subjects with left hemisphere damage (LHD) and 10 subjects with right hemisphere damage (RHD) participated in the experiment. All subjects were native Kannada speakers and had cerebro vascular accident in the medial cerebral artery as shown by CT report They were diagnosed for the type of Aphasia by a speech pathologist using WAB. Table 4 shows the details of all the subjects. Of the 10 LHD patients, 5 patients had global aphasia and remaining 5 patients had Broca's aphasia. Of the 10 RHD patients, 7 patients had normal speech and language (NSL), one had anterior aphasia, one had Broca's aphasia, and one was anomic.

S. No.	*Age*	*G*	*CT report*	*Diagnosis*
1	66	M	Lt ICA	Global
2	64	M	Left ICA stenosis	Global
3	69	M	Left MCA infarct secondary to Left ICA	Global
4	60	F	Left MCA territory infarct	Global
5	62	F	Left MCA territory infarct	Global
6	56	M	Left MCA infarction	Broca's
7	62	M	Lt Lacunar infarct in parietal white matter	Broca's
8	40	M	Lt MCA occlusion	Broca's
9	65	M	Lt MCA infarct	Broca's
10	68	F	Acute left MCA infarct	Broca's
11	85	M	Recurrent TIA in Rt ICA/MCA	NSL
12	25	F	Right MCA hemorrhage	NSL
13	35	M	Right Hemiplegia with Left Complete occlusion of CCA	Anterior
14	75	F	Rt MCA infarct	Broca's
15	21	F	CVA in RT MCA territory	Anomia
16	60	F	Rt Parieto-Occipital Lacunar infarct	NSL
17	36	M	Rt Cerebral atrophy	NSL
18	46	F	Rt MCA infarct	NSL
19	54	F	Rt MCA hemorrhage	NSL
20	28	F	Right MCA hemorrhage	NSL

Table 4: *Details of the patients with LHD and RHD (S: Subjects, G: Gender, NSL: Normal Speech & Language).*

Procedure: Procedure was the same as in experiment II. In case when subjects had problem in marking manually, they were permitted to do the task by any other means.

Analysis: The procedure and analysis were similar to experiment II. Percent 'different' response for each group was plotted as discrimination curve.

Results: The results indicated that patients with brain damage scored poorly compared to normal subjects when F0 was edited. No phrase pair was perceived as 'different' by more than 70 % of the brain damaged subjects. Seven phrase pairs were perceived as 'different' by 13.38 % and 25.38 % of LHD and RHD patients, respectively. Patients with RHD scored better than those with LHD. Among the LHDs, Broca aphasics performed better than global aphasics. Subjects responded differently to different phrase pairs. Phrase pair 4, 3 and 2 were the best discriminated by LHD patients, RHDs and normals, respectively. Table 5 shows the percent 'different' values in LHDs and RHDs. Figure 3 shows the percent 'different' response in all three groups.

Phrase pair	*Global*	*Broca's*	*LHD avg*	*RHD*	*Normal*
1	7.14	7.24		18.51	76.66
2	7.14	14.49		29.62	78.66
3	11.9	11.59		33.33	71.66
4	21.42	31.88		29.62	74.33
5	4.76	17.39		29.62	70.33
6	11.9	17.39		18.51	71.42
7	14.28	15.94		18.51	70.33
Avg	11.21	16.56	13.88	25.38	73.341

Table 5: *Percent* ***'different'*** *response in all the subjects for F0 edited phrase pairs*

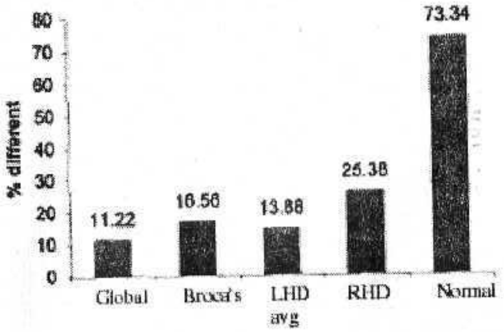

Figure 3: *Percent different response for F0 edited phrase pairs.*

Patients with brain damage performed poorly compared to normals when duration was edited. No phrase pair was perceived as different by more than 70 % of patients with brain damage. The 12 phrase pairs were perceived as 'different' by 25.33 % and 12.95 % of LHD and RHD, respectively. LHD patients scored better than RHD when duration was edited. Among LHD patients, Broca's aphasics scored better than global aphasics. Also, RHD patients scored better than global aphasics. Differences between subjects and phrase pairs were evident. Phrase pair 10 and 6 were best discriminated by global aphasics; pair 8 by Broca's, pair 10 by RHD patients, and pair 6 by normal subjects. There was no consistency among groups of subjects in discriminating phrase pairs. Table 6 and figure 4 show percent 'different' response for phrase pairs in which duration was edited.

Phrase pair	*Global*	*Broca's*	*LHD avg*	*RHD*	*Normal*
1	7.14	30.43		0	84.33
2	4.76	39.12		3.7	93.68
3	9.52	24.63		7.4	77
4	14.28	44.92		7.4	90.3
5	7.14	44.92		7.4	80.33
6	21.42	44.92		22.22	97.25
7	7.14	39.12		18.51	87.56
8	7.14	53.62		11.11	93.97
9	0	31.88		3.7	77.33
10	21.42	52.17		29.62	77.33
11	9.52	31.88		22.22	70.47
12	19.04	42.02		22.22	83.33
Avg	10.71	39.96	25.33	12.95	84.40

Table 6: *Percent **'different'** response for phrase pairs with edited duration*

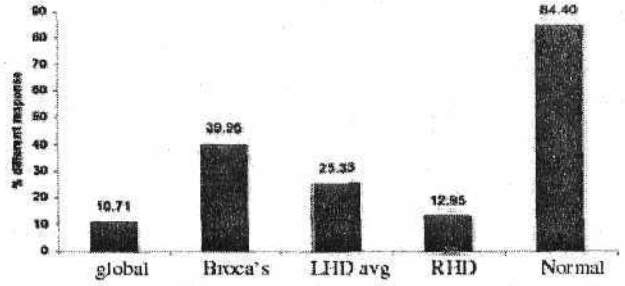

Figure 4: *Percent different response for please pairs edited for duration.*

The results indicated that the performance of global aphasics remained same irrespective of the cue (F0 or duration) provided. But Broca's aphasics performed better on a temporal (duration) cue compared to spectral (FO) cue and RHDs performed vice versa. Table 7 summarizes the results.

Type of Cue	LHD		RHD	Normal
	Global	Broca'a		
Only F0 cue	11	17	25	73
Only Duration cue	11	40	13	84

Table 7: *Summary of percent different response in all the three groups of subjects*

The results indicate several points of interest. First of all brain damaged patients performed poorer than normals on a discrimination task involving word stress in Kannada. This is in consonance with the results of the study by Blumstein & Goodglass (1972), Weintraub et al (1981), Baum et al (1982), Emmorey (1987), and Van Lancker & Sidtis (1992). Second, Broca's aphasics (LHDs) scored better when temporal cue (duration) was presented compared to when spectral cue (F0) was presented. Third, RHDs scored better when stress was indicated by spectral (F0) cue than when it was indicated by a temporal (duration) cue. This is not in consonance with the results of the study by Van Lancker & Sidtis (1992). But it supports the results of Pell & Baum (1997b). The results show contradicting evidence against differential cue lateralization hypothesis in that right hemisphere is specialized for processing of F0 related parameters and left hemisphere specialized for processing of temporal parameters. It also discredits the opinion that right hemisphere is dominant for prosody processing. In LHDs right hemisphere was functionally intact but LHDs could not process stress as that of normals when individual acoustic cues were given. To conclude, the results of this study do not support differential cue lateralization for the perception of stress or hemispheric specialization for spectral or temporal cues for stress processing. However, individual scores and larger data on brain-damaged patients may be useful.

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