REVIEW OF LITERATURE

The verbal communication consists of linguistic, prosodic, paralinguistic, and non-verbal attributes such as facial expressions and non-speech sounds (clicks, sighs, etc.). Prosody/suprasegmental aspects of speech are the units superimposed on the segmental elements to impart greater meaning to the message. The constituents of these suprasegmental features include intonation, stress, rhythm, speech rate, and pause. Among suprasegmental features, intonation is the most prominent and conveys most of the semantic load of an utterance. All the languages across the globe are characterized by intonation which has its own internal constituents.

1.0 Intonation

Intonation is defined as “the combination of tonal features into larger structural units associated with the acoustic parameter of voice fundamental frequency or F0 and its distinctive variations in the speech process” (Botinis et al., 2001). It involves the occurrence of recurring pitch patterns, each of which is used with a set of relatively consistent meanings, either on single words or on groups of words of varying length (Cruttenden, 1986). Being a vital part of prosody of speech, intonation serves a variety of linguistic functions such as signaling yes/no questions, contrastive questions, WH-questions (Lehiste, 1970; Waibel, 1979; Waibel, 1988), syntactic ambiguity (Streeter, 1978; Hirschberg & Avesani, 1997; Schafer, Speer, Warren, & White, 2000; Snedeker & Trueswell, 2003) and emotions as well (Banziger & Scherer, 2005).
2.0 Structure of Intonation

2.1 Intonation unit

It has long been recognized that spoken language is organized into segments of speech that can be accounted for by their suprasegmental structure. The suprasegmental unit which aids in segmentation of spoken language is conceived to be dependent mainly on tone or intonation. Segments of tone and intonation which aid in this segmentation are termed 'tone group', 'intonation group', 'tone unit', 'intonation(al) phrase', or 'intonation unit' (Selkirk, 1984; Beckman & Pierrehumbert, 1986; Halliday, 1989; Chafe, 1994; Brazil, 1997; Cruttenden 1997; Hirst & Di Cristo, 1998; Halliday, 2004). Grammatical constituents of any level up to a sentence consist of separate intonation units having their own meaningful tune. The intonation unit encapsulates a functional, coherent segmental unit, be it syntactic, semantic, or informational. The major perceptual and acoustic cues for intonation unit boundaries are phrase final lengthening, initial rush of syllables in a phrase, pitch reset at successive intonation units, and pause between intonation units (Cruttenden, 1997; Hirst & Di Cristo, 1998; Amir, Silber-Varod, & Izre‘el, 2004; Silber-Varod, 2005). Based on the prosodic analysis of Mandarin dialect of Chinese language, Yufang and Bei (2002) contended that significant pitch reset and insertion of silence are the prime acoustic cues to intonation unit boundaries and that larger the prosodic boundary, greater is the extent of pitch reset and longer the pause between intonation units. They also reported the acoustic cues contributing to the intonation unit boundary markers. In a hierarchy, these included pauses followed by pitch reset and preboundary lengthening.
2.2 Intonation contours

The intonation contours represent patterns of F0 fluctuations over the course of an utterance. The contours consist two types of tonal specification - tones which have a prominence-lending function, referred to as 'nuclear tones' and those which delimit intonational phrases, referred to as 'boundary tones' (Pierrehumbert, 1980; Beckman & Ayers, 1994). The nuclear tones are associated with the nuclear stress syllables of intonation units while the boundary tones are found at the edges of intonation units.

Palmer (1922) was one of the pioneers who carried out a systematic analysis of the nuclear tones and its configuration in English language. He described nuclear tone configurations as falling, high rising, falling-rising, and low rising. Variations were later reported by other investigators. For example, Kingdon (1958), described 5 types of nuclear tones in English language as rising, falling, falling-rising, rising-falling, and rising-falling-rising, and Halliday (1967) also described 5 tones which included falling, high rising, low rising, rising-falling-rising, and falling-rising-falling.

One of the well-known approaches to nuclear tone/pitch accent analysis is the ToBI or Tone and Break Indices system. It was originally designed for use in labeling intonation and prosody in Mainstream American English (MAE) (Beckman and Hirschberg 1994). The pitch accent contours/nuclear tones are defined in this system as consisting of H*, L* and their bitonal counterparts L*+H, L+H*, and H+!H* (Beckman & Ayers, 1994). The asterisk is associated with nuclear stressed syllables. In bitonal accents, the asterisk appears on a stressed syllable whereas the other tone either precedes
or follows the stressed syllable. It has been applied to other languages like German (Grice et al., 2005), Korean (Jun, 2000), and Japanese (Venditti, 1995). Chahal (1999) reported 7 types of pitch accents in Lebanese Arabic language as: H*, L+H*, L*, L*+H, !H*, H+!H* and H*+L.

The boundary tones are F0 excursions which occur at the end of intonational phrases. There are three types of phrase-final contours which are commonly reported and they include level, falling, and rising tones (Ambrazaitis, 2005). The ToBI system analyzes these boundary tones as high or low tone (H% or L%). An additional boundary tone was observed in German language as falling-slightly-rising contour. The phonetic aspects of this tone was thought to lie on a continuum between fall and fall-rise contours, while on a functional basis it signaled pragmatic attributes like ‘submission’ of the speaker towards the addressee (Ambrazaitis, 2005), openness for discussion (Peters, 1999; Ambrazaitis, 2005), or feeling of insecurity (Peters, 2000; Ambrazaitis, 2005). The falling boundary contour may suggest utterance finality like in a declarative statement as in English (Hirschberg, 2002), or the conclusion of an argument, or categoricalness as in German (Peters, 1999, 2000; Ambrazaitis, 2005). Among the different types of boundary tones, the final rising tone received considerable attention. Ogden and Routarinne (2005) in their review of the meaning and functions of final rises cited some semantic/pragmatic functions of these contours: Accordingly the final rises are used as an/a:

- index of social relations between participants wherein the final rises indicate ‘authoritativeness’ (Horvath, 1985)
- index of turn-taking in narratives (Guy & Vonwiller, 1989)
• request for response (Ladd, 1996)

• marker to describe and express opinion (Horvath, 1985)

• clue to speaker’s attitude as being friendly or attentive (Guy & Vonwiller, 1989).

Other reported pragmatic functions of the final rises include issuing warnings or threats and astonished utterances (Peters, 1999; Ambrazaitis, 2005) and polite offers (Grice & Baumann, 2002; Ambrazaitis, 2005).

The phrase final rising contours may indicate a question or utterance continuation/incompleteness (Essen, 1964; Meinhold, 1967; Caspers, 1998, 2001; Gilles, 2000, 2003; Dombrowski & Niebuhr, 2005). The association of final rises with interrogatives has been found in many languages such as English (Cruttenden, 1986), Swedish (House, 2005), Dutch (van Heuven, Hann, & Kirsner, 1999; House, 2005), Neapolitan Italian (D’Imperio & House, 1997; House, 2005), German (Kohler, 2004; House, 2005), Kannada (Manjula, 1997), among others.

The phrase final rises are not restricted to production of interrogatives. The final rises may serve to signal interest of the speaker for the addressee (Kohler, 2004; House, 2005). Ogden and Routarinne (2005) reported that the final rises are a fairly common occurrence in declaratives and narrative sequences in Finnish language and they serve to project the speaker’s intention to talk more and thus recline a co-participant to be a mere recipient in the communication process. Another pragmatic function i.e., turn-taking is thought to be closely associated with the pattern of phrase-final tonal contour (Dombrowski & Niebuhr, 2005). A raised pitch on the accented syllable followed by a
restrained pitch movement in the final contour in German suggests that the speaker is not keen on inviting the listener to speak. Whereas, a lowered pitch on the accented syllable and extended pitch movement in the tail of the contour signals the listener the liberty to speak (Dombrowski & Niebuhr, 2005).

2.2.1 Intonation contours in Indian Languages

There are few studies on the nature of intonation in Indian languages (Sethi, 1971; Nataraja, 1981; Ravisankar, 1987). In Kannada language, which is one of the major Dravidian languages spoken in Southern state of India, very few studies have addressed the feature of intonation, although there are studies, which investigated the nature of intonation in emotive utterances (Manjula, 1979; Nataraja, 1981; Nandini, 1985). Other studies report the linguistic nature of intonation in various modes such as questions, statements, narration, and simulated dialogues, and its association with the segmental constituents of Kannada language (Rathna et al., 1976; Rathna et al., 1982; Patil, 1984; Manjula, 1997; Krishna, 2002). The features of intonation such as the initial and terminal contours, peak F0, excursions of F0, declination of F0, tonal groups, the relationship of all these features with the segmental correlates of the linguistic units and others have been addressed in these studies. In Telugu language, 7 types of nuclear pitch movements viz., low fall, high fall, low rise, high rise, fall-rise, rise-fall, level tones, and 3 types of terminal contours i.e., falling, rising, and level tones have been identified (Girija & Neeraja, 2003). In a study involving contrastive analysis of Hindi and Malayalam language, Geethakumary (2002) inferred that both these languages are characterized by 4 pitch levels and 3 terminal contours. The pitch levels found to occur were Extra high,
High, Mid, and Low while the terminal contours included rising, falling, and level tones. Specific intonation patterns that express different attitudes were reported in Malayalam language (Asher, 1997; Girish, 2004). A less extended fall conveyed politeness, rise-fall tone expressed annoyance, fall-rise expressed dissatisfaction or doubt, low level tone suggested differences, high level tone issued a warning (Asher, 1997). A low falling tone on declaratives and a low rising tone on interrogatives are reported to be the characteristic boundary tones in Tamil language (Ravisankar, 1987). Sadanand and Vijayakrishnan (1993, 1998) outlined a three-way tonal contrast in Punjabi language - neutral, falling tone, and falling-rising tone.

2.3 Declination of fundamental frequency (F0)

One of the salient features of intonation is the gradual downtrend of the fundamental frequency (F0) contour known as declination. It refers to the pattern of pitch of voice which is generally lower at the end of a sentence than it is at the beginning (Cruttenden, 1986). The declination phenomenon has been observed in languages like Finnish (Hirvonan, 1970), French (Vaisiierre, 1971), Dutch (Collier & t’Hart, 1971; t’Hart & Cohen, 1973; Gussenhoven & Rietweld, 1988), English (Maeda, 1976), Italian (Mango-Caldognetto, Ferrero, Lavagnoli, & Vagges, 1978), Danish (Thorsen, 1980), Japanese (Fujiisaki & Hirose, 1984), Hindi (Rajendran & Yegnanarayana, 1996), Kannada (Manjula, 1997). It is also observed in tone languages like Cantonese (Vance, 1976), Thai (Abramson & Svastikula, 1983; Tseng, 1990; Gandour et al., 1997), Hausa (Lindau, 1986), Mandarin (Garding, 1987; Shen, 1989; Tseng, 1990, Liao, 1994; Yang, 1995, Xu & Wang, 1997; Shih, 2000), and a large number of African languages (Welmers, 1973;
Silverstein, 1976), thus reflecting its existence as a universal phenomenon. In fact, Hauser and Fowler (1992) demonstrated that fundamental frequency declination was not unique to human speech; it is evidenced in non-human primates such as vervet monkeys and Rhesus macaques.

The linguistic basis for the downdrift in F0 is also put forth. According to some investigators, declination is thought to be dependent on sentence structure and it may not be seen in all types of sentences (Pierrehumbert, 1979; Lieberman & Tseng, 1980). Experiments by Cooper and Sorenson (1977) showed that intonation group is strictly coextensive with syntactic units; a new declination line is frequently started at a major syntactic boundary even without inhalation. The declination tendency has also been considered to be a byproduct of the perceptual system (Pierrehumbert, 1979).

Several reasons are offered to explain the declination in fundamental frequency. The phenomenon has been attributed to the physiological factors such as declining subglottal pressure (Collier, 1975; Strik & Boves, 1995), tracheal pull (Maeda, 1976), laziness principle i.e. the rise is supposedly harder to produce than the falls (Ohala & Ewan, 1973). It is even speculated to have a cognitive basis for the reason that different types of declination patterns were observed for parenthetical and main clauses (Kutik & Cooper, 1983).
3.0 Intonation in discourse

Intonation plays a vital role in discourse structure cohesion at macro- and micro­levels (Schiffrin, 1987). Aspects of intonation are used extensively in analyzing spontaneous speech and it serves as indicators of discourse structure. Some of the reported functions of intonation in discourse are to:

a) serve as boundary markers between topic units (Grosz & Hirschberg, 1992)
b) serve as internal boundary markers within topic units (Hirschberg & Pierrehumbert, 1986)
c) express contrast between 'new' and 'given' information (Nooteboom & Kruyt, 1987)
d) signal speech acts, for instance, a sentence with a rising intonation indicates yes/no question rather than a declarative (Geluykens, 1987).

3.1 Intonation in spontaneous discourse

Intonation is the key property of the discourse-related functions of prosody (Bruce, 1998). There have been numerous studies on issues relating intonation and spontaneous discourse structure. Certain intonation correlates of spontaneous discourse structure include maxima in pitch movements, general decline in average pitch, rise and fall in F0 at onset and termination of topics, among others. Variations in F0 are used to chunk the discourse into smaller parts and indicate the relationship between those parts (van Donzel & Koopmans-van Beinum, 2000). It has been found that pitch is usually raised at the instance of initiation of discourse and lowered at the discourse final position (Hirschberg & Pierrehumbert, 1986; Sluijter & Terken, 1993; Nakatani, Hirschberg, & Grosz, 1995; Hirschberg & Nakatani, 1996; Shih, 2000). Furthermore, Swerts, Bouwhuis,
and Collier (1994) showed that "finality" within discourse units is signaled by the combined effects of differences in pitch register, pitch range and shape of the pitch contour, all within the same intonational category. The falling tones at the boundaries indicate finality whereas rising or level tones at the boundaries indicate non-finality or continuity (Brown, Currie, & Kenworthy, 1980; Swerts, 1994; Blaauw, 1995; van Donzel & koopmans-van Beinum, 2000). The occurrence of prominence/pitch accents signify the local level of information structure. For instance, F0 variations by way of pitch accent specify the information structure such as new/old information and topic structure (Nooteboom & Terken, 1982; Nooteboom & Kruyt, 1987; van Dozel & Koopmans-van Beinum, 2000).

3.2 Paragraph/text intonation

The paragraph/text intonation reflects the intonation patterns of spontaneous speech discourse. However, prosodic features of read speech tend to be well formulated compared to the spontaneous speech (Fujisaki, 1989). Hakoda and Sato (1980) observed that when one read written texts aloud, the syntactic structure of each sentence gets reflected in intonation parameters - onset, peak, and final F0 values, of each intonational phrase. In a perceptual experiment, Swerts and Geluykens (1993) demonstrated importance of intonation in indicating boundaries of large-scale topical units of a text. For instance, a change in topic may be accompanied by a longer pause and resetting of speaker's F0 baseline and topline. A correlation was observed between prosodic phrasing and paragraph structure in the narration sample of professional announcers (Fujisaki, 1989). Some phonetic cues such as pause duration were reported to be commonly related
to boundaries between large discourse units (Hirschberg & Nakatani, 1996, 1998). Grosz and Hirschberg (1992) analyzed spoken news stories and confirmed that there was a correlation between discourse features such as discourse segment boundaries and prosodic features: F0 range and pause insertion.

Swerts and Ostendorf (1997) based on the research on prosody analysis in monologues, either read-aloud (Brubaker, 1972; Lehiste, 1980; Bruce, 1982; Grosz & Hirschberg, 1992; Sluijter & Terken, 1993) or spontaneous discourse (Swerts & Geluykens, 1994; Swerts, 1994, 1997), remarked that major information units of discourse can be demarcated by means of variations in pitch range, speaking rate, distribution of different types of boundary tones, and by global declination.

4.0 Stress in intonation

Description of intonation of any language remains incomplete without a thorough understanding of the feature of ‘stress’. The intonation contour in any language is determined according to which syllable in the sentence is prominent. This syllable forms the nucleus of the intonation group, which is also referred to as ‘focus/prominence’. Stress is a structural property of a word that specifies which syllable in the word is, in some sense, stronger than any of the others (Lehiste, 1970; Terken, 1991; Ladd, 1996; Streefkerk, 1997). Based on its function, stress is generally divided into ‘word stress’ and ‘sentence stress’.
4.1 Word stress

In certain languages, stress always falls on a syllable in a particular position in the word. It thus performs a delimitative function. The lexical boundaries may also be predicted from the position of stress (Botinis et al., 2001). For example, in Finnish, Czech, and Slovak, stress is on the first syllable; in Italian, Welsh, and Polish, stress is on the penultimate syllable; other languages, such as Farsi, have word-final stress (Laver, 1994). The delimitative function of stress has also been observed in Dravidian languages of India like Kannada (Krishna & Manjula, 2004), Telugu (Srinivas, 1992), Tamil (Ashtamurthy, 2003), and Malayalam (Ashtamurthy, 2003). In languages like French and some Indian languages, such as Hindi and Gujarati, stress does not serve phonemic/distinctive function (Laver, 1994). In French, for example, stress is invariably on the final syllable in isolated words, but it is very different in connected speech. Whereas in English and many other languages such as German, Russian, Danish, and Dutch, stress assumes a phonological function. It varies according to the function of the word (Laver, 1994).

4.2 Sentence stress

Sentence stress plays an important role in prosody of narratives. The intonation contour is determined by the pattern of occurrence of stressed and unstressed syllables in a sentence. Thorsen (1983) was of the opinion that ‘sentence stress’, ‘primary stress’, ‘nuclear stress’, ‘tonic’, ‘focal accent’, ‘satzakzent’ are more or less synonymous terms which designate that one stressed syllable is more prominent than other stressed syllable in a stretch of speech. Sentence stress may occur either as emphatic or contrastive type.
4.2.1 Emphatic stress

The functions of emphatic sentence stress are to highlight, focus, contrast, comment, or indicate new information and it contributes to identification of intonation pattern of a sentence (Hirst, 1977). An important feature of English intonation is the use of an intonational accent (and extra stress) to mark the focus of a sentence. Normally this focus accent falls on the last major word of sentence, but it can occur earlier in the order to emphasize one of the earlier words or to contrast it with something else (Russell, 1997). In Tamil, which is a Dravidian language of India, the stress is reported to occur on the first syllable of a phrase (Ashtamurthy, 2003).

4.2.2 Contrastive stress

The contrastive stress marks comment or psychological predicate in an utterance (Hornby & Haas, 1970). It can occur on almost any element on an utterance. Its occurrence on a particular element is linked to specific situational and contextual aspects of discourse and to speaker-hearer presuppositions. It is related, in particular, to the element he/she wishes to place into focus. Bates and Macwhinney (1979) noted that contrastive stress is the device speakers’ use most often when the point of an utterance is to contradict or replace some aspect of the listener’s beliefs.

4.3 Cues to stress

An important topic of phonetic research has always been the acoustical and perceptual characterization of the properties by which the stressed syllable distinguishes itself from the unstressed syllables surrounding it (syntagmatic comparison) or, in a more
controlled approach, how a stressed realization of a syllable differs from an unstressed realization of the same syllable (paradigmatic comparison) (Sluijter & van Heuven, 1996). Four phonetic variables appear most significant as indicators of stress: Intensity, pitch, vowel quality, and duration (Collins & Mees, 2003). Intensity in physiological terms is the greater breath effort and muscular energy associated with stressed syllables, its perceptual correlate being loudness. F0 variation is perceptually correlated with pitch and plays a prominent role in determining stress. The stressed syllables may be characterized by increased F0 relative to the surrounding syllables. Duration is another important parameter in signaling stress. The syllables may be shorter in unstressed than in stressed syllables. In some languages, the syllable that carries stress in an utterance is in part determined by vowel quality i.e., the kind of vowel it consists in its structure. For instance, in English, the central vowels are unlikely to receive stress compared to the peripheral ones. For example, in the word 'present' (noun), the initial syllable contains the peripheral vowel and hence is stressed. While in its verb form, the stress is not placed on the initial syllable since it consists of a central vowel. The stress is shifted to the final vowel containing the peripheral vowel (Collins & Mees, 2003). Table 1 highlights the reported acoustic correlates of stress in some of the languages of the world.

4.4 Stress in Discourse

Prosodic prominence/stress has been claimed to be closely linked to the notion of "information structure" of an utterance, reflecting the flow of information and the ordering of new vs. given information (Nootenboom & Terken, 1982). A common observation is that given information, i.e. information that has already been mentioned or
is assumed by the speaker to be known, tends to precede new information. If, for some reason, this unmarked structure of information is deviated, it is usually signaled prosodically, for instance by a focal stress. Another, related generalization is that new information tends to be stressed, whereas given information tends to be destressed (Hirschberg, 2002). This particular prominence function of prosody signals the listener about new/important information (Nooteboom & Terken, 1982; Nooteboom & Kruyt, 1987; van Dozel & Koopmans-van Beinum, 2000). However, information structure alone is not the sole instigator of stress. Terken and Hirschberg (1994) investigated the relationship between stress and the new vs. given distinction in an experiment where the additional factors of syntactic function and sentence position were looked at. They found that when a given item has a certain syntactic function in the context of an utterance, it is just as likely to be accented as an element which is new to the discourse.

Table 1.

*Summary of Findings of Acoustic Cues to Stress in Different Languages*

<table>
<thead>
<tr>
<th>Investigator(s)</th>
<th>Language</th>
<th>Acoustic Cues to Stress</th>
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<tbody>
<tr>
<td>Non-Indian Languages:</td>
<td></td>
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<tr>
<td>Fry (1958)</td>
<td>English</td>
<td>F0</td>
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<tr>
<td>Morton and Jassem (1965)</td>
<td>English</td>
<td>Duration and F0</td>
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<tr>
<td>Liberman and Pierrehumbert (1984)</td>
<td>English</td>
<td>F0</td>
</tr>
<tr>
<td>Sluijter and van Heuven (1996)</td>
<td>Dutch</td>
<td>Duration and spectral balance</td>
</tr>
<tr>
<td>Sluijter, van Heuven, and Pacilly</td>
<td>Dutch</td>
<td>Duration and spectral balance</td>
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<td>(1997)</td>
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</tbody>
</table>
Suomi, Toivanen, and Ylitalo (2003) Finnish Duration
Suomi and Ylitalo (2004) Finnish Duration
Ortega-Llebaria and Prieto (2005) Spanish Duration and spectral tilt
Fant, Kruckenbg, and Liljencrants Swedish Duration and F0 (2000)
Botinis, Bannert, and Tatham (2000) Greek F0
Potisuk, Gandour, and Harper (1996) Thai Duration
Shen (1993) Chinese Duration
Shunde (1996) Chinese Duration and F0

Indian Languages:
Ohala (1977) Hindi F0
Balusu (2001) Telugu Duration and F0
Keane (2006) Tamil F0
Rathna, Nataraja, and Kannada Duration and intensity Subramanyaiah (1982)
Savithri (1987) Kannada Duration and F0
Manjula (1997) Kannada Duration and F0
Krishna (2002) Kannada Duration and F0
Krishna and Manjula (2004) Kannada Duration and F0

4.5 Summary of the aspects of intonation and stress

The review concerning intonation and its features signifies the intonation unit as
the basic analytical unit of intonation. The intonation unit consists of nuclear stressed syllable that carries a distinct pitch contour called nuclear tone. The nuclear tone along with terminal contour, which occurs at the end of intonation unit, constitutes an intonation contour. The systematic analysis of nuclear and terminal contours has witnessed steady transformations right from the era of Palmer (1922) to the current analytical frameworks including the ToBI system. The earliest system of analysis was based on subjective judgment of tonal configurations, without technological and instrumental support. The advent of instrumentation and speech analysis softwares facilitated visualization of tonal configurations leading to new methods of analysis.

Concerning the acoustic features of stress, duration and F0 were reported to be the primary correlates across most of the world’s languages (Morton & Jassem, 1965; Sluijter et al., 1997; Krishna & Manjula, 2004; Ortega-Llebaria & Prieto, 2005), with intensity assuming importance in very few languages (Rathna et al., 1982). The acoustic aspects of intonation and its function in discourse cohesion received adequate research attention. The acoustic features known to assume significance in structuring discourse are the onset and terminal F0, Peak F0, F0 range, and pause duration (Grosz & Hirschberg, 1992, Swerts & Geluykens, 1994; Swerts, 1997; Hirschberg & Nakatani, 1998).

The volume of prosody research carried out in Indian languages is significantly less compared to other languages of the world. The research involving acoustic correlates of stress in Dravidian languages received considerable attention and a few studies were carried out on this aspect of stress in Kannada language. The results of these studies in
Kannada language were equivocal. The duration and F0 were found to be the primary correlates of stress in Kannada language. With respect to intonation, the initial and terminal contours in interrogatives, narratives, and affective utterances were evaluated in Kannada language. However, the nuclear tones have not been often addressed in the studies in Kannada language. In addition, the acoustic measures of intonation such as onset F0 and terminal F0, F0 range, F0 reset across intonation unit boundaries, pause duration between successive intonation units, were not evaluated in spontaneous discourse in Kannada language. These measures are vital for discourse structure cohesion. In Telugu language, an inventory of nuclear and terminal contours were established (Girija & Neeraja, 2003) and in Hindi and Malayalam, 4 pitch levels and 3 types of terminal contours were found (Geethakumary, 2002). Ravisankar (1987) reported a low falling tone on declaratives and a low rising tone on interrogatives at the terminal portions of intonation contours.

The characteristic features of the prosodic constituents of intonation and stress are well documented and well received too. But the cortical regions involved in processing these features of prosody remain debatable. Review in further sections gives an account of the research carried out to delineate the neural correlates of prosody processing.

5.0 Neural basis of prosody

The two cerebral hemispheres are not identical in function and they differ in processing the information received. The language dominant left hemisphere is propositional, analytical, and serial in its processing while the right hemisphere is
holistic, synthetic and simultaneous (Springer & Deutsch, 1981). In communication, an interactive dual type of information processing occurs (Behrens, 1985). The left hemisphere functions to interpret linguistic aspects of the message (grammar, semantics, etc.) (Kimura, 1964); the right hemisphere interprets nonverbal, musical input (Milner, 1962; Curry, 1967). The notion of ‘dysprosody’ was first introduced by Monrad-Krohn (1947) to describe verbal behavior of certain brain-damaged clients (Joanette, Goulet, & Hannequin, 1990). He classified prosodic disorders resulting due to lesion of the nervous system into three types – hyperprosodia, dysprosodia, and aprosodia. A relatively large database has accumulated since then over the neural substrates of prosody. Yet, the findings remain largely undetermined and intriguing, leading to the proposition of several hypotheses (Baum, 1998).

e) The right hemisphere hypothesis (Klouda et al., 1988).

f) The functional lateralization hypothesis (Van Lancker, 1980).

g) The acoustic cues hypothesis (Van Lancker & Sidtis, 1992).

h) The subcortical processing (Cancelliere & Kertesz, 1990).

5.1.1 The right-hemisphere control of prosody

It is the most fundamental of the propositions concerning the neural correlates of prosody. The theory envisages a complete control of right hemisphere in processing prosody. It assumes that the right hemisphere is dominant for processing acoustic correlates of prosody while the left hemisphere simultaneously processes the segmental information contained within a sentence. The right hemisphere then transfers the prosodic information to the left hemisphere via the corpus callosum for further processing.
According to this hypothesis, the linguistic/non-linguistic functions of the intonation contours are irrelevant. Evidence for such observation was gathered from the studies involving both perception and production of prosody.

The dichotic listening experiments in normal subjects provided useful insights into processing of perceptual prosody. Blumstein and Cooper (1974) utilized a series of sentences spoken with intonation of question, command, or neutral declarative. The sentences were passed through low-pass filters to retain the intonation of the utterance, while rendering the words unintelligible. Significantly higher accuracy scores were observed for the left ear relative to the right ear. Goodglass and Calderon (1977) studied the simultaneous processing of verbal and tonal material in 16 trained musicians. The results revealed right ear advantage for verbal component and left ear advantage for tonal component of each stimulus. In another study involving dichotic listening paradigm, Shipley-Brown et al. (1988) examined laterality for affective (happy, angry, & sad) and linguistic (statement, question, & continuation) prosody stimuli. The results indicated left ear advantage for the identification of both affectively and linguistically intoned stimuli suggesting a right hemisphere advantage for processing prosody. In an effort to dissociate the verbal content and emotional tone of a sentence, Ley and Bryden (1982) dichotically presented affectively intoned sentences to normal subjects. The sentences with neutral content were read by two speakers in four different affective tones (happy, sad, angry, and neutral). The subjects responded by marking both the verbal or semantic content and the affective tone of each sentence they perceived. The results showed a left ear advantage for the identification of affective intonation and a right ear advantage for
the verbal content of the sentences. Such parallel hemispheric processing of segmental and prosodic information was also demonstrated by Behrens (1985). In a dichotic listening task consisting of real word stress pairs (hotdog vs hot dog), the subjects showed a greater right-ear preference. When the linguistic and phonetic content was substituted by non-sense words and filtered real-words, the left ear advantage was observed. The results suggest a cumulative effect to the lateral processing of prosody i.e., as the stimulus becomes more meaningful in terms of segmental composition, the left hemisphere becomes more adept at processing the stimuli. Similarly, Grimshaw (1998) employed the words “mad,” “glad,” “sad,” and “fad” spoken in four different emotional tones (mad, sad, glad, or neutral). He created a stroop-like effect to examine the potential for interference between linguistic and prosodic processing and measured ear advantages in terms of speed of response. A right ear advantage was observed when the participants listened to the target word whereas, a left ear advantage was observed when the subjects listened to the target affect. In summary, the findings suggest processing of linguistic content by the left hemisphere while the parallel processing of prosodic events occurs in the right hemisphere.

Shapiro and Danly (1985) were amongst the first to acoustically analyze and examine linguistic and affective prosody in RHD patients. A variety of F0 measures were derived from the speech of 11 RHD clients, 5 LHD clients, and 5 normal control subjects. Results revealed a lower mean F0 and restricted F0 range in clients with right anterior and central lesions. In contrast, clients with right posterior lesions exhibited higher than normal mean F0 and increased F0 range. The performance of clients with LHD was on
par with the normal controls. Klouda et al. (1988) examined F0 and duration cues to prosody in affective and linguistic contexts in a client with callosal damage. The results revealed that both affective and linguistic prosody distinctions were impaired in this client suggesting that the right hemisphere role is not just limited to processing affective prosody but includes the linguistic prosody processing too. Similar deficits in F0 measures to signal affective / linguistic prosody were noticed in individuals with RHD by Pell (1999).

5.1.2 Functional lateralization hypothesis

The Functional lateralization hypothesis assigns a functional significance to processing of prosodic cues. According to this hypothesis, the left hemisphere which is dominant for language, processes prosody that performs linguistic functions whereas, the right hemisphere, which is dominant for the processing of non-linguistic information, processes prosody that performs non-linguistic functions (Van Lancker, 1980).

To determine if prosodic cues subserving linguistic functions is processed by the left hemisphere, Baum (1998) evaluated the ability of LHD, RHD, and normal control subjects in perceptually identifying phonemic and emphatic stress. The clients with LHD presented significant deficits in phonemic stress judgements compared to the normal control subjects. Although the RHD patients demonstrated better performance than LHD group, it was below that of normal controls. Complex prosody functions such as syntactic boundary resolution (the contrast between parenthetical and subordinate clauses) (Perkins et al., 1996) and syntactic ambiguity resolution (Walker, Fongemie, &
Daigle, 2001; Walker, Daigle, & Buzzard, 2002) in LHD, RHD, and normal controls suggests the vital role of left hemisphere in linguistic prosody processing. Furthermore, the limited role of right hemisphere in the processing of linguistic prosody was shown experimentally in a production study by Walker, Pelletier, and Reif (2004). The RHD subjects were similar to normal control subjects in manipulating duration, F0, and intensity cues to convey lexical stress, mark syntactic boundaries, and differentiate questions from statements. The results suggested that the function of prosodic structure dictates hemispheric specialization.

Perception of affective prosody showed that clients with RHD presented significant impairment relative to LHD clients in the ability to categorize affective meaning of prosodic cues (Heilman, Scholes, & Watson, 1975). The results were replicated in an extended study by Tucker, Watson, and Heilman (1977) and Bowers, Coslett, Bauer, Speedie, and Heilman (1984). The processing deficits were not limited to the verbal domain. They included nonverbal affective communication signals too (Blonder, Bowers, & Heilman, 1991). However, in the event of an increase in cognitive demand of affective stimuli, the processing was reported to shift from the right hemisphere to both hemispheres (Tompkins & Flowers, 1985).

Research concerning the production of emotional attributes of speech contributed greatly to the notion of right hemisphere engagement in the processing of affective prosody. For instance, affect based utterances produced by RHD clients were judged by a panel of normal listeners as not carrying the intended emotion (Tucker et al., 1977). As
major proponents of this hypothesis, Ross and others (Ross, Edmondson, & Seibert, 1986; Edmondson, Chan, Seibert, & Ross, 1987; Ross, Edmondson, Seibert, & Homan, 1988) examined affective prosody in a task involving repetition of sentences carrying varied emotional tones while the epileptic subjects were undergoing right-sided Wada test. The mean F0 was found to be reduced following injection of sodium amytal solution. Ross et al. (1988) suggested that the flattened affect resulted due to deactivation of the right hemisphere. In another experiment, Ross, Thompson, and Yenkosky (1997) evaluated comprehension as well as production of emotion laden stimuli at varied verbal-articulatory levels (which included a sentence - “I am going to other movies”, a monosyllable- /ba ba ba ba/, and asyllabic utterance- /aaaaahhhh/). The performance of individuals with LHD witnessed steady improvement upon reduction of verbal-articulatory complexity. In contrast, the RHD clients continued to exhibit deficits in affective prosody in both comprehension and production at all articulatory complexities. Further, based on data from English-speaking brain-damaged patients, Ross (1981) proposed a classification system for affective prosodic deficits similar to that utilized for left hemisphere-damaged aphasic patients (Goodglass & Kaplan, 1983). Specific constellations of symptoms were hypothesized to be associated with particular lesion sites. For example, impairments of affective comprehension were supposedly due to temporal lobe lesions, parallel to auditory comprehension deficits from left temporal lobe lesions. Whereas, disorders of spontaneous affective production were thought to arise subsequent to inferior frontal lobe damage, similar to the speech production deficits associated with left Broca’s area lesion (Ross 1981).
Among the studies that incorporated examination of both linguistic and affective prosody in the same set of subjects, Elias, Bulman-Fleming, and Guylee (1999) employed affective and non-affective words from two standardized tests [Fused Rhymed Words Test (FRWT) (Wexler & Halwes, 1983) and Emotional Words Test (EWT) (Bryden & MacRae, 1989)]. The results revealed that 83% of subjects demonstrated right ear advantage on FRWT and 81% had left ear advantage on EWT. McNeely and Parlow (2001) followed a similar method to determine complementary function of the hemispheres. The investigators chose the Dichotic Emotion Recognition Test (DERT) (McNeely & Netley, 1998) to test the hypothesis. The DERT composed of phrases of nonsense words spoken in four different emotional tones (happy, sad, angry, or fearful) paired dichotically with similar nonsense phrases spoken with neutral prosody. The results showed that 78% of the subjects displayed complementarity of linguistic/affective hemispheric specialization while 22% demonstrated reversed complementarity for linguistic and prosodic functions. Extending the investigation to individuals with brain damage, Walker et al. (2002) conducted experiments to evaluate the ability of RHD and LHD subjects to utilize prosodic cues to identify lexical stress, differentiate syntactically ambiguous sentences, distinguish question versus statement, and to determine the affect associated with utterances. The results demonstrated that in tasks involving linguistic prosody, the LHD patients performed below par compared to the RHD group and normal subjects. While a reverse trend was true for processing tasks of affective prosody in which the RHD patients demonstrated significant deficits than the LHD and normal controls. Earlier work by Heilman, Bowers, Speedie, and Coslett (1983) and Geigenberger and Ziegler (1998) demonstrated similar complementary results for
linguistic/affective prosody in individuals with RHD and LHD. However, Baum and Pell (1997) in an experiment involving production of sentential affective and linguistic prosody demonstrated that RHD and LHD patients differentiated both linguistic and affective sentence types in a manner comparable to normal control speakers.

To address the question whether the neural substrate of prosody is similar in tone language speakers, Edmondson et al. (1987) involved 8 RHD Taiwanese speakers and 8 normal controls to repeat affectively intoned sentences and subjected them to perceptual judgement. Results indicated that normal listeners were less accurate in judging the intended emotions of RHD speakers compared to normal controls. Gandour et al. (1995) too noted impaired production of affective prosody by RHD clients in Thai language. On similar lines, tones carrying linguistic significance in Chinese (Naeser & Chan, 1980; Packard, 1986), Thai (Gandour et al. 1992) and Norwegian (Ryalls & Reinvang, 1986) were produced with less proficiency by individuals with LHD, while the RHD subjects had no difficulty in producing mandarin tones (Hughes, Chan, & Ming, 1983). The overall results imply that at least in tone languages, linguistic and affective prosody appear to be differentially lateralized (Gandour et al., 1995).

A critical variable that has been espoused to play a pivotal role in determining functional lateralization of prosody is the linguistic level at which prosody operates. Behrens (1988) explored the ability of right-hemisphere-damaged (RHD) clients to produce linguistic stress. The stimuli included phonemic stress tokens (Re'dcoat vs. red coa’t) as well as examples of contrastive stress, or sentential emphasis (e.g., Sam hated
the movie). The results of acoustic analysis showed that at the sentence level, RHD clients produced fewer acoustic cues to stress compared to the normal subjects. In the following experiment, Behrens (1989) examined the acoustic characteristics of sentence intonation in a story-completion task. Eight RHD clients and 7 normal controls produced declarative, imperative, yes/no, and WH-interrogative sentences. The RHD clients produced the intended sentence type in only 14 of 24 trials as judged by a panel of native listeners. He concluded that right hemisphere damage may lead to impairments in the production of sentence level intonation while it is preserved at the lexical level. In a replication and extension of Behrens' (1988) study, Ouellette and Baum (1994) found that both lexical and emphatic stresses were adequately produced by right-hemisphere-damaged patients. Similar results for lexical stress operation were obtained by Emmorey (1987). The RHD individuals were able to modify pitch and duration cues to distinguish compound noun versus noun phrase. In contrast, individuals with LHD had difficulties in manipulating these acoustic parameters. The results of these studies highlight that the domain over which prosody is programmed is an important factor in predicting whether or not a deficit would emerge in RHD patients. However, experiment by Ryalls, Joanette, and Feldman (1987) in 19 French-speaking RHD clients and normal subjects yielded contradicting results. The acoustic cues to prosody at sentential level did not show significant differences between the RHD and normal control subjects.

Additional support for the functional lateralization hypothesis is lent by the fMRI studies in normal subjects. Pihan et al. (1998) demonstrated increased activation of right hemisphere for the affective stimuli and reduced activation for neutral sentences. Even in
a follow up study, Pihan, Altenmuller, Hertrich, and Ackermann (2000) found predominant activation of the frontal regions of the right hemisphere for all types of affective intonation. But when the subjects repeated the stimulus through the inner speech (silent speech), a bilateral hemispheric involvement with pronounced activation of left hemisphere frontal regions was observed. The investigators suggested that the shift in activation of cerebral areas from the right to the bilateral hemispheres during inner speech reflects the inherent left hemisphere functional coupling of acoustic input and verbal output channels. Mayer, Wildgruber, Riecker, Dogil, Ackermann, and Grodd (2002) recruited 10 normal native German subjects to produce 5 syllables (dadadadada) in a sentence-like sequence varying in pitch-accent location and contours (the FOCUS condition), boundary tones (the MODUS condition), and emotional states (the AFFECT condition). In FOCUS condition, activation was found in anterior part of the superior temporal gyrus and in the inferior frontal gyrus with additional cluster of activation in left motor control area and anterior cingulum. While in the AFFECT condition, the focus of activation was found to be in the right inferior frontal gyrus. The results thus conform to the functional lateralization hypothesis. Also, no significant activation was noticed in the subcortical regions in processing prosody in any of the tasks, thus nullifying the participation of subcortical structures in processing of prosody. In accordance with the production study, fMRI findings followed the same pattern as in perception experiments. Wildgruber, Ackermann, Klein, Riecker, and Grodd (2000) compared identification of prosodically expressed emotions (happiness, anger, fear, sadness, disgust) with a non-prosodic, phonological control task (identification of the vowel following the first “a” in a sentence). Subtraction of the control task from the emotive identification elicited
activation in the right Superior Temporal Gyrus and bilateral activation of Inferior Frontal Gyrus, with the right hemisphere showing overall greater activation in terms of magnitude and spatial extent. In another experiment, Wildgruber, Hertrich, Ackermann, Riecker, and Grodd (2001) compared perception of affective prosody with perception of linguistic prosodic features. Activation patterns in both tasks involved Inferior Frontal Gyrus. The linguistic task elicited additional activation in the left Broca’s area 44/45. Focal activation in the orbito-basal frontal cortex during perceptual processing of prosody was also shown by Mayer (1999) in a series of fMRI studies using filtered speech and by Dapretto, Hariri, Bialik, and Bookheimer (1999) using meaningful sentences. The findings of these studies point to a crucial role of the deep frontal operculum in the processing of the basic phonetic-phonological aspects of prosody.

There are other sets of findings that suggest that right hemisphere too has a role in processing of linguistic prosody. For instance, Grant and Dingwall (1984) conducted 2 experiments to examine the perception of linguistic prosody in a group of LHD, RHD, and normal control subjects. In experiment I, comprehension of linguistic changes brought about by syllabic stress was examined while in experiment II, comprehension of linguistic changes due to variation in intonation contours was studied. The results indicated poor performance of RHD clients in both tasks compared to the LHD and normal control subjects. Similar dominance for linguistic prosody by the right hemisphere was reported by Bryan (1988). The RHD and LHD individuals were assessed on a series of tests designed to examine discrimination and production of different aspects of linguistic prosody which included lexical stress, intonation, emphatic stress,
lexical stress in sentence contexts, language identification using prosodic cues, and prosody in discourse. The RHD subjects were relatively more impaired compared to LHD and normal control subjects. The results also indicated that the right temporoparietal area appeared to be important in processing linguistic prosody. In yet another experiment, Bradvik, Dravins, Holtas, Rosen, Ryding, and Ingvar (1991) demonstrated the importance of right hemisphere in processing linguistic prosody. They compared the performance of 20 Swedish-speaking clients with RHD and 18 normal controls on tasks of both linguistic and affective prosody (e.g. emphatic stress perception, identification of linguistic and emotional intonation). The performance of RHD clients was inferior on both linguistic and emotional tasks compared to the control group subjects.

Experiments involving production too suggested the right hemisphere involvement in processing of linguistic prosody. Weintraub, Mesulam, and Kramer (1981) elicited utterances containing contrastive stress patterns from individuals with RHD. Subjects participated in tasks requiring repetition of emphatic stress patterns and sentences with varied intonation contours. The utterances of the subjects were presented to normal listeners for perceptual identification of stress. The listeners did not perceive the stress contrasts and intonation produced by RHD clients. Dykstra, Gandour, and Stark (1995) examined the perception and production of linguistic and affective prosody at the word, phrase, and sentence levels in a single client with history of seizures in the nondominant frontal lobe i.e the right hemisphere. The results of comprehension task revealed that the client was less proficient in comprehending either linguistic or affective
prosody relative to the normal controls. On the production front, the client was unable to modulate speech prosody in either emotional or non-emotional contexts.

5.1.3 Cue dependent hypothesis

Psychophysical experiments indicated that the right hemisphere has an advantage over the left hemisphere in extracting pitch information from complex auditory stimuli. The Double Filtering by Frequency (DFF) Theory (Ivry & Robertson, 1998) proposes a cue dependent representation of prosodic information in the brain. According to this theory, low frequencies are mainly processed by the right hemisphere, whereas high frequencies are processed by the left hemisphere. Since the prosodic parameter F0 is contained in the low-frequency portion of the speech signal, it is assumed to be lateralized to the right hemisphere. Support for such a differential lateralization of acoustic prosodic cues comes from various studies. For instance, Robin et al. (1990) observed that right temporo-parietal lesions affected the discrimination of tones, but not the perception of time patterns, while lesions in the homologous regions of the left hemisphere had opposite effects. Van Lancker and Sidtis (1992) based on the discriminant analysis of affective prosody processing suggested that clients with LHD seem to rely on F0 variations, whereas clients with RHD seem to base their judgements on durational cues. Pell and Baum (1997) attempted to replicate the results of Van Lancker and Sidtis (1992) by following similar method. The results however did not demonstrate systematic differences in the use of F0, duration, or amplitude in comprehending affective/linguistic tones by the brain damaged individuals.
Left hemisphere superiority for timing was demonstrated in experiments by Cooper et al. (1984), Gandour et al. (1994), and Schirmer et al. (2001). They found that clients with unilateral left hemisphere lesions exhibited greater deviations in sentence timing than clients with unilateral right hemisphere lesions. Among the LHD aphasics, variability was found in the pattern of temporal deficits in fluent and non-fluent aphasic clients. The fluent aphasics showed deviant speech timing in larger linguistic units only (Baum, 1992) while the nonfluent aphasics exhibited timing deficits at segment, word, and sentence level (Baum & Boyczuk, 1999). The differential pattern of dissolution suggested that the timing deficit emanated from different underlying mechanisms (Gandour et al., 1992a, 1992b; Gandour et al., 1993). The investigators suggested that in nonfluent aphasics, the timing deficit is a consequence of an impaired phonetic-motoric component and in fluent aphasics, the deficit is due to shorter-than normal domains of speech planning. Baum and Boyczuk (1999) carried out a controlled study to examine the temporal control in simple and complex sentences in clients with LHD-fluent, LHD-nonfluent, and RHD. The performance of RHD clients and fluent aphasics was on par with normal controls. The findings in fluent aphasics were contrary to the belief that these clients are susceptible to timing deficits in larger segments. The nonfluent aphasics exhibited consistent deficits in phrase final lengthening across all linguistic levels.

Similar to these findings, the role of right hemisphere in F0 processing was highlighted by Shapiro and Danly (1985). A variety of F0 measures were derived from the speech of 11 RHD clients, 5 LHD clients, and 5 normal control subjects. Results revealed a lower mean F0 and restricted F0 range in clients with right anterior and central
lesions. In contrast, clients with right posterior lesions exhibited higher than normal mean F0 and increased F0 range. The performance of clients with LHD was on par with the normal controls. Klouda et al. (1988) examined F0 and duration cues to prosody in a client with callosal damage. The results revealed apparent impairment in F0 while the duration cues were preserved. It was suggested that F0 information processed in the right hemisphere is integrated with information processed in the speech centers of the left hemisphere via the corpus callosum. Hird and Kirsner (1993) examined duration cues to signal various prosodic distinctions in a group of RHD patients and normal controls. The results revealed that the RHD patients were able to utilize duration cues to bring-forth distinctions in linguistic and affective prosody. Blonder, Pickering, Heath, Smith, and Butler (1995) examined F0 and duration cues to prosody in spontaneous speech at pre and post right hemisphere stroke. Comparison of acoustic data revealed restricted F0 range, changes in initial F0, peak F0 in the post-stroke condition when compared to pre-stroke condition. The duration measures however, did not vary as a function of stroke. Baum and Pell (1997) and Pell (1999) too reported aberrations in F0 in RHD clients compared to the normal controls. The results of these studies suggest that right hemisphere impairment may lead to deficits in execution of F0 patterns which require continuity.

It may be inferred that right hemisphere is specialized in processing F0 while the left hemisphere dominates in timing control.
5.2 Representation of prosody in bilateral hemispheres

There have been instances when none of the existing hypotheses suffice to explain the processing impairments for prosody in brain-damaged clients. Clients with LHD and RHD were not accurate in their judgments of either linguistic or affective intonation according to some investigators (Schlanger, 1973; Schlanger, Schlanger, & Gerstmann, 1976; Heilman et al., 1983; Pell 1998). The results of fMRI investigations suggest bilateral, left accentuated activation of temporal, subcortical (putamen and thalamus), and left inferior frontal regions for lexical speech carrying emotional load. On the other hand, for non-lexical/filtered speech, bilateral inferior frontal, and subcortical (caudate) activation was noticed (Kotz, Meyer, Alter, Besson, von Cramon, & Friederici, 2003). Plante, Holland, and Schmithorst (2006) reported a network of activation including frontal, temporal, and parietal regions in response to linguistic prosody stimuli, specifically in the areas of bilateral superior temporal gyrus, bilateral inferior frontal gyrus, bilateral precentral sulcus and right middle frontal sulcus. The bilateral activation of superior temporal region was especially found to be more critical for prosodic features of speech (Plante, Creusere, & Sabin, 2002; Plante et al., 2006) regardless of linguistic (Meyer, Alter, Friederici, Lohmann, & von Cramon, 2002; Plante et al., 2002; Meyer et al., 2004) or affect (Buchanan, Lutz, Mirzazade, Specht, Shah, Zilles, & Jancke, 2000; Kotz, Meyer, Alter, Besson, von Cramon, & Friederici, 2003; Mitchell, Elliot, Barry, Cruttenden, & Woodruff, 2003) based stimuli. Earlier, based on the results of an EEG study of left and right hemisphere, responses to neutral and emotionally significant words, Kostandov (1987) remarked that all mental functions, particularly emotions are
organized and regulated through close and mutually complementary collaboration of the two hemispheres.

Contrary to the theory of differential lateralization of acoustic parameters (Van Lancker & Sidtis, 1992), the LHD and RHD clients displayed impairments in the control of both temporal and spectral properties (Gandour & Baum, 2001). The deficits were noted across tasks such as signaling phonemic stress pairs (e.g., HOTdog versus hot DOG) (Balan & Gandour, 1999), marking phrasal boundaries in syntactically ambiguous sentences (Baum & Pell, 1997; Baum, Pell, Leonard, & Gordon, 1997), or resolving stress-clash in double-stressed words (e.g., thirTEEN vs THIRteen MEN) (Grela and Gandour, 1998).

The pattern of impairments advances the notion that distributed mechanisms in both cerebral hemispheres may be responsible for processing of prosody.

5.3 Stress and intonation in LHD aphasics

The sections 5.1 and 5.2 constituted findings of research that attempted to determine the seat of neural control of prosody. Evident contradiction in these hypotheses seem to suggest that perhaps the processing of prosody is distributed bilaterally i.e. both hemispheres are vital in processing prosody and that damage to any of the structures involved in comprehension and expression of speech-language may adversely affect prosody. The following section outlines the deficits in stress and intonation in different types of LHD aphasics.
5.3.1 Stress in LHD aphasics

Assigning stress to different parts of an utterance is a vital part of prosodic application. Incorrect placement of stress may distort the meaning of the message and distort the input provided to listener. Research findings suggest that LHD aphasic individuals are often inconsistent in the assignment of stress. For example, the LHD-nonfluent and LHD-fluent speakers were found to be less proficient in signaling phonemic stress contrasts (HOTdog versus hot DOG) (Vijayan & Gandour, 1997) and irrespective of sentence length, the LHD- nonfluent group was significantly poorer in performance, while the LHD- fluent clients exhibited reduced performance in medium-length sentences compared to short-length sentences (Balan & Gandour, 1999). The stress assignment however, was preserved in words consisting predictable stress pattern. The errors occurred more frequently on words with irregular stress than those with regular stress (Cappa et al., 1997; Laganaro et al., 2002). The error patterns consisted of shifting the stress to regular position in case of irregular words and vice versa (Laganaro et al., 2002). The results suggested that regular lexical stress was assigned by default, where as irregular stress was stored along with other phonological information (Levelt, Roelofs, & Meyer, 1999). Further, the performance varied as a function of severity level. The more severe the aphasia symptoms, the greater was the probability of error scores on the specified tasks (Baum et al., 1982).

One of the well-known examples of stress effects at the sentence level was a phenomenon in English referred to as the ‘Rhythm Rule (RR)’ (Liberman & Prince 1977; Hayes, 1984). According to this rule, there is a general tendency towards spacing of
stressed syllables so that utterances exhibit a preferred periodicity. The rule is applied to prevent 'stress clash phenomenon'. It occurs when two syllables carrying primary stress are adjacent with no intervening phrase boundary (e.g. thirTEEN WOmen). In this case, speakers must adjust their utterance to resolve the clash situation. This is accomplished by applying the RR (e.g. THIRteen WOmen). In isolation, primary stress on the word, thirteen, is placed on the final syllable. In a stress clash situation, primary stress is shifted to the initial syllable. This aspect of stress phonology was examined by Grela and Gandour (1999) in different aphasic syndromes. Individuals with LHD-nonfluent failed to shift stress in a clash context to a degree comparable to that of the normal controls where as LHD-fluent individuals faltered on less occasions. Gandour and Baum (2001) observed that the LHD aphasic subjects were able to implement phonological rhythm rule, although, its phonetic implementation was significantly deviant from that of normal controls. Specifically, the LHD aphasics exhibited deficits in both F0 and duration cues to signal stress. The findings suggested that prosodic disorders in clients with left brain damage are due to phonetic-motoric deficits rather than an inability to apply the phonological rule.

5.3.2 Intonation / F0 deficits in LHD aphasics

The term intonation refers to pitch that conveys verbal information at the sentence or phrase level. Its correlate at the physical or acoustic level is primarily the fundamental frequency (F0). Extensive research has been carried out in the past two decades to understand the intonation or F0 usage by individuals with aphasia.
5.3.2.1 F0 deficits in aphasics speaking tone languages

In tonal languages, the tones assume a phonemic function. A small variation in tonal contour brings about a change in meaning of the utterance. Thus, there is an increased probability that the LHD aphasics are prone to tone production deficits. T’ sou (1978) in a case study of Cantonese-English bilingual conduction aphasic, reported that the client had difficulty in producing the low falling tone. Tonal productions were reportedly compromised in aphasic individuals in Mandarin (Naeser & Chan, 1980; Packard, 1986) and Norwegian languages (Moen & Sundet, 1996). In order to determine the nature and extent of tonal deficits in aphasia, Gandour et al. (1988) carried out an acoustic perceptual study of lexical tone in Thai. In all types of aphasics, the tonal confusion was predominant between the mid and low tone, which was possibly due to similarities in height and shape of F0 contours. In a severe Broca’s aphasic client, the low tone was virtually indistinguishable from mid tone. Overall, the results suggested a positive relationship between severity of aphasia and tone production. In a subsequent study, Gandour et al. (1992) recruited additional number of brain-damaged subjects (11 right-brain-damaged nonaphasics, 9 fluent aphasics, 8 non-fluent aphasics, and 4 aphasics with subcortical lesions) to evaluate the tonal contrasts. The results were similar to the previous findings, in the sense that tonal productions of brain-damaged individuals demonstrated accuracy rate in excess of 93% except for the non-fluent aphasics whose scores recorded 85% accuracy. Contrasting findings by Gandour et al. (1997) implied that some aspects of intonation are preserved in brain-damaged clients regardless of site of lesion. In their study, individuals with RHD and LHD aphasia could produce lexical tone contrasts at different positions in a sentence in Thai language. Besides, the brain-
damaged individuals produced final lowering effect similar to the normal controls. While in Norwegian language, restricted F0 range was exhibited by LHD anterior aphasics (Ryalls & Reinvang, 1986).

5.3.2.2 F0 deficits in aphasics speaking non-tone languages

Research in non-tone languages too indicated F0 impairments in aphasic population. A higher average F0 and aberrations in jitter were noted in LHD fluent and non-fluent aphasics (Ryalls, 1984). The higher F0 observed in these brain-damaged clients were attributed to greater emotional stress, which led to greater tension in the vocal cords and hence increased F0 (Ryalls, 1984).

5.3.2.3 F0 deficits in clients with Wernicke’s aphasia

The speech prosody in Wernicke’s aphasia is considered to remain intact (Hecaen & Albert, 1978). Few impairments were observed in certain parameters of intonation brought about by F0 fluctuations (Danly et al., 1983). In particular, the Wernicke’s aphasics presented frequent F0 resetting especially in medium-length sentences and in many instances, the resetting occurred at inappropriate boundaries within sentences. Apart from this, they exhibited increased number of continuation rises that occurred at minor syntactic boundaries suggesting that the Wernicke’s aphasics exhibit discontinuous intonation contours which are more frequent. In addition, they demonstrated greater F0 variability and often failed to use F0 to distinguish syntactic boundaries whose constituent structures were different. However, the performance of Wernicke’s aphasics’
on certain aspects of F0 such as declination, sentence-final fall, and onset peak F0, was comparable to that of the normal control group (Danly et al., 1983).

5.3.2.4 F0 deficits in clients with Broca’s aphasia

Individuals with Broca’s aphasia make prominent errors in intonation patterns. The F0 range was reported to be restricted in French and English-speaking Broca’s aphasics (Ryalls, 1982; Cooper et al., 1984). Danly and Shapiro (1982) demonstrated that the Broca’s aphasics displayed intact declination pattern in short sentences while little or no declination was found in longer stretch of utterances. In addition, they presented increased variability in F0 and abnormal patterns of final lengthening effects. The results also showed that regardless of the degree of impairment or sentence length, the Broca’s aphasics exhibited sentence final F0 fall. Overall, the results pointed towards syntax-prosody interface error. In normal subjects, the F0 resetting coincided with the syntactic boundaries such as the subject-predicate boundary. Where as, F0 resetting in Broca’s aphasia was more frequent and often occurred within the phrases. In other words, the syntactic control of F0 resetting was not as precise as that in normal speech. Thus, the increased number of continuation rises in Broca’s aphasics along with deficits in prosodic measures that were signaled at linguistic boundaries, reflected narrower-than-normal scope for linguistic planning (Danly & Shapiro, 1982).

The underutilization of F0 cues at sentence level by the LHD aphasic individuals was demonstrated by Baum and Pell (1997) and Baum, Pell, Leonard, and Gordon (1997). Peppe, Bryan, Maxim, and Wells (1998) suggested that prosody deteriorates with
utterance length due to the consequence of greater processing load. The intonation
deficits in LHD aphasics were not limited to sentence level utterances. They were
also noticed in conversation samples of Spanish-speaking aphasics with left
unilateral brain damage (Pietrosemoli & Mora, 2002). Especially, a client with lesion in
the left temporo-parietal region exhibited frequent terminal rises in declarative sentences
instead of a falling contour associated with these types of sentences.

5.3.2.5 Basis of intonation deficits in LHD aphasics

Based on the reported findings by various investigators, it can be presumed that
aphasic clients with LHD are prone to deficits in F0 either in tone or non-tone languages.
Nonetheless, the bases for the intonation production deficits in aphasic population have
been largely speculative. One assumption is that it is related to the phonetic-motoric
impairment. The hypothesis has evolved from research findings of investigators such as
Danly and Shapiro (1982), who in their study of LHD aphasics found that declination in
short sentences were preserved, while it was impaired in longer stretch of utterances.
Various types of F0 abnormalities have been reported in LHD aphasics and they have
varied from unusually large initial F0 peaks and peak-to-valley variations in F0 (Cooper,
Danly, & Hamby, 1979), restricted F0 range (Ryalls, 1982), greater than normal F0
variability (Ryalls, 1984), abnormally high F0 values (Cooper et al., 1984). These
variable F0 aberrations suggest an underlying deficit that might be phonetic or motoric in
nature (Seddoh, 2000). The idea is consistent with data on normal subjects which
indicates that some components of the F0 contours associated with intonation may be
determined physiologically (Ladd, 1983a, 1983b; Arvaniti, Ladd, & Mennen, 1998;
Ladd, Faulkner, Faulkner, & Schepman, 1999). Ryalls (1982) suggested that besides phonetic deficit, the reduction in F0 range in aphasic clients may be due to either impaired ability to readjust breathing patterns that regulate phonation or to disturbed ability to control laryngeal muscles.

Other studies suggest an underlying linguistic processing deficit leading to abnormal production of intonation in LHD aphasic clients (Seddoh, 2000). For instance, deficits in the production of lexical tone in tone languages such as Mandarin, Norwegian, and Thai reveals an underlying phonological impairment in individuals with aphasia (Tsou, 1978; Naeser & Chan, 1980; Packard, 1986; Gandour et al., 1988; Moen & Sundet, 1996). Besides this, at the sentence level, Danly and Shapiro (1982) reported that certain aspects of intonation such as F0 resetting were abnormal in LHD aphasics. They also presented frequent continuation rises which often did not occur at appropriate syntactic boundaries. The results suggested the inability of aphasic individuals to integrate syntax and prosody. Further, deficits in F0 to mark syntactically ambiguous boundaries represent another level of linguistic processing problems which are often evidenced in aphasic individuals (Baum et al., 1997; Walker et al., 2002). The conversation sample analysis too signifies the F0 modulation deficits in declarative sentences in these patients (Pietrosemoli & Mora, 2002). The findings are consistent with the results of a growing number of studies that indicate a close relationship between intonation and syntax in normal speech (O'Shaughnessy, 1979; Eady & Cooper, 1986; Nagel, Shapiro, & Nawy, 1994; Shapiro & Nagel, 1995; Taff & Wegelin, 1998).
There are other views which suggest that the critical variable on which F0 production depends is the length of the utterance, and that abnormalities in F0 associated with intonation deficits in aphasics’ speech result primarily from problems related to temporal control at the sentence level (Gandour et al., 1988; Gandour et al., 1989; Gandour et al., 1992). In other words, there seems to be an intimate relationship between F0 control and timing. Based on acoustic-phonetic measures of intonation and rhythm in aphasics’ speech, Danly and Shapiro (1982) and Danly et al. (1983) demonstrated that the programming of F0 crucially depends on sentence length, and that F0 programming may be less disrupted than temporal programming. They suggested that the programming of F0 necessarily intersects temporal programming in sentence production. Thus, disruption of F0 contours does not necessarily indicate malfunction in F0 mechanisms, but instead a secondary effect due to malfunction in timing (Gandour et al., 1988).

In an obvious attempt to delineate the nature of intonation deficits and their likely causative factors in left-brain-damaged aphasic individuals, Seddoh (2000) examined various components of F0 contours produced by 15 patients with fluent and nonfluent aphasia. The relatively preserved length-sensitive F0 measures in aphasic subjects suggested that F0 programming is not dependent on timing control ability. Since duration measures were not a part of the earlier experiment, Seddoh (2004) included temporal measurements in order to determine if F0 production was dependent on temporal control or they were dissociated in the brain. The results showed that non-fluent aphasics exhibited quantitative and qualitative differences on several duration measures. Specific impairments in temporal control with well preserved F0 control were earlier observed by
Seddoh (1999). Taken together, the results of studies carried out by Seddoh (1999, 2000, & 2004) and those of Danly, de Villiers, and Cooper (1979), Klouda et al. (1988), and Niemi (1998), suggests that there may be dissociation in production of F0 and speech timing in individuals with aphasia.

5.3.2.6 Temporal deficits in LHD aphasics

It has been posited that duration parameters convey abundant linguistic information. Two such linguistic parameters that have been shown to affect syllable duration are the size of the word or phonemic sequence of which the syllable is a constituent (Lehiste, 1972) and the overall position of the syllable within an utterance (Oller, 1973). Lehiste (1972) reported that the duration of a monosyllabic base word becomes progressively shorter as derivational suffixes are added to create bisyllabic and trisyllabic words. In a related study, which investigated syllable durations in larger contexts, Oller (1973) reported that the duration of a syllable in phrase-final position increases in duration. This phrase-final lengthening effect has been found in many languages (Oller, 1973) and is a salient perceptual cue to the location of phrase and sentence boundaries (Klatt & Cooper, 1975). Duration was also found to serve as a prominent cue to word boundaries (Cutler & Butterfield, 1990).

Timing aberrations have been the hallmark of individuals with LHD aphasics - particularly damage localized to anterior brain structures. Emmorey (1987) reported impaired utilization of duration in signaling stress contrasts by the LHD aphasic clients. Gandour et al. (1989) found temporal control to be spared in isolated monosyllabic words
but impaired in syllables that occur in series within words, phrases, and sentences in a client with Broca’s aphasia. The timing was found to be impaired while the F0 was preserved in both lexical and emphatic stress in Broca’s aphasics (Ouellette & Baum, 1994). Gandour et al. (1994) examined a host of absolute and relative duration parameters including syllable duration, intersyllable duration, sentence duration, and phrase-final lengthening. The LHD clients consisting Broca’s, fluent, and conduction aphasics presented deviant timing patterns compared to the normal subjects. Schirmer et al. (2001) observed significant temporal deficits in left hemisphere damaged aphasic speakers under conditions of wide and narrow focus. Specifically, substantially longer pause preceding the conjunctions along with relatively shorter word duration were noted. Furthermore, the pre-final lengthening in these clients was not strong enough to be called normal.

One characteristic feature of temporal control was a steady decline of root syllable duration with the increase in utterance length of carrier phrase. The individuals with non-fluent aphasia presented specific difficulty in adequate syllable shortening of root syllable as a function of utterance length (Baum, 1992; Gandour et al., 1993). The individuals with fluent aphasia displayed a more normal pattern of syllable shortening for both bisyllabic and trisyllabic words. However, the productions of fluent aphasics were not entirely within normal limits, particularly in trisyllabic words in which the stress pattern differed from their bisyllabic analogues (Gandour et al., 1993). In contrast, experiment by Baum and Boyczuk (1999) reported normal patterns of relative syllable shortening in individuals with non-fluent and fluent aphasia. But the non-fluent aphasics presented
deficits in phrase final lengthening, while the fluent aphasics' performance was intact at all syllable lengths.

The literature on temporal control in non-fluent aphasics suggests that these individuals exhibit impaired timing at all levels of linguistic structure. On the other hand, the fluent aphasics retain timing control in shorter units of speech while displaying sentence level temporal control abnormalities (Cooper et al., 1984; McNeil et al., 1990; Gandour et al., 1992, a, 1992b; Gandour et al., 1994). These patterns of temporal deficits in fluent and non-fluent LHD aphasics suggests different underlying mechanisms. In non-fluent aphasics it is thought to be due to impaired phonetic implementation (Gandour et al., 1994), while in fluent aphasics, Gandour et al. (1993) suggested that it may be due to limited domain of speech planning, yielding breakdowns in temporal control in longer utterances.

In essence, Gandour et al. (1989) suggested that slow speaking rate, shorter phrases, uniform syllable durations regardless of stress or sentence position, and exclusive use of one-syllable inter-stress intervals, all contributed to the dysrhythmic quality of Broca’s aphasics speech. It is also possible that deficits in production of linguistic prosody attributed to left hemisphere damaged patients may be secondary consequence of a more basic impairment on speech timing (Danly & Shapiro, 1982).

Summary of review of past literature

The review of literature points to certain key interpretations as outlined below:
1) Intonation and stress are the key elements of prosody (Delattre, 1972; Cruttenden 1997).

2) The primary acoustic correlate of intonation is F0 (Botinis, Granstrom, & Mobius, 2001), while for stress, F0 and duration are the important correlates (Sluijter et al., 1997; Krishna & Manjula, 2004).

3) Intonation and stress play an important role in discourse. They function to distinguish new/given information (Nooteboom & Terken, 1982; Nooteboom & Kruyt, 1987; van Dozel, & Koopmans-van Beinum, 2000), aid in segmentation of discourse by indicating boundaries of phrases (Swerts & Geluykens, 1993), discourse coherence indicating which parts of utterance belong together (Schiffrin, 1987), among others.

4) The findings of various researches (including neuro-psychological and neuro-imaging evidence) in support of numerous hypotheses have posed a dilemma as to which regions of the brain are involved in prosody processing (Baum, 1998). The research till date has not concretely defined with gusto the neurological seat of prosody processing.

5) The LHD aphasic individuals including Broca’s aphasics experience difficulties in stress assignment (Vijayan & Gandour, 1997; Cappa et al., 1997; Laganaro et al., 2002).

6) The intonation disruptions are also predominant in individuals with LHD aphasia including Broca’s aphasics (Ryalls, 1982; Danly & Shapiro, 1982; Cooper et al., 1984). The severe aphasics demonstrate both qualitative and quantitative deficits.
While in the less severe ones, deficits may be limited to degree than kind (Gandour et al., 1988)

7) The F0 (Gandour et al., 1992; Baum & Pell, 1997) and duration (Ouellette & Baum, 1994; Gandour et al., 1994; Schirmer et al., 2001) cues to prosody are prone to be impaired in LHD aphasic individuals including Broca’s aphasics.

8) The F0 and duration may be impaired independently in LHD aphasics including Broca’s aphasics (Seddon, 1999, 2000, & 2004).

9) The phonetic-motoric impairment is presumed to be responsible for prosodic deficits in LHD aphasics including Broca’s aphasics (Danly & Shapiro, 1982), although the linguistic basis may also be possible (T’ sou, 1978; Naeser & Chan, 1980; Packard, 1986; Gandour et al., 1988; Moen & Sundet, 1996; Baum et al., 1997; Walker et al., 2002).