AUDITORY BRAINSTEM RESPONSE TO DICHOTIC SPEECH

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A dissertation submitted in Part Fulfillment for the Degree of

Master of Science (Audiology)

University of Mysore, Mysore

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MANASGANGOTHRI

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MAY 2013

CERTIFICATE

This is to certify that this dissertation entitled ***"Auditory Brainstem Responses to Dichotic Speech"*** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No. : 11AUD020. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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This is to certify that the dissertation entitled ***"Auditory Brainstem Responses to Dichotic Speech"*** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this Master's dissertation entitled ***"Auditory Brainstem Responses to Dichotic Speech"*** is the result of my own study under the guidance of Dr. Sandeep M., Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted in any other University for the award of any Diploma or Degree.

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ACKNOWLEDGEMENT

I am grateful to our beloved God. God you have been the guiding force for me in everything that I have done. Thank you

I would like to express my deep gratitude to Dr. Sandeep M., my dissertation guide, for his patient guidance, enthusiastic encouragement and useful critiques of this research work. Sir, you have been a wonderful guide, helping me throughout the research and making my work easier. Sir, a big thanks to you for your constant support, teaching and sharing your knowledge regarding Audiology and Research and inspiring for the research work. It was really enjoyable and learning experience working under your guidance ☺

I would also like to thank Dr. S. R. Savithri, Director, All India Institute of Speech and Hearing, for permitting me to complete the study.

My sincere thanks to Dr. Animesh Burman, HOD, Department of Audiology, for permitting me to carry out this research work and providing the facilities for the same.

A special thanks to Nike sir for helping me through data collection and statistical analysis. Sir, you had always been supporting.

I owe thanks to my parents. I am blessed to have you as my parents. For all the love, care, support & encouragement you have showered me with since the beginning of my life, I am very grateful. Words can't express my gratitude towards you. I thank my family members for always being supportive and encouraging throughout my study. I would also like to thanks my grandfather, who had always been my role model.

And my sincere thanks to Ganapathy sir, Hemanth sir, Jithin sir, Usha mam, Roshni mam, Reuben Sir, Prasanth sir, Kishore sir for making our data collection end within the time limit by opening the department on weekends and after 5.30 pm.

I would like to thank Sharath sir, Varun Sir for their timely help. Thanks a lot!

I thank all my teachers from the days of my primary schooling till my post graduation for all that they have taught me and for being good role models to me.

I would like to thank Vasanthalakshmi ma'am for her help in doing statistics.

I am also thankful to Sujeet Sir, Vijay sir, Prawin sir, Geetha mam, Ranjeet sir, Srikar sir, Antony sir, Vivek sir, Priya mam for always being helpful and providing me necessary information.

I am extremely thankful to all my participants for having patience with me and bearing a loud stimulus during recording. I would not have got more co-operative participants.

My sincere thanks to the entire library staff specially Shijith sir for answering my queries whenever I was in need.

Thanks to my best friend, though you were not here with me, you had always been inspiring, helping, caring, supportive, solving my problems so easily (especially those formulas) and bringing smile on my face ☺

Dear Nisha, Yashaswini, thanks a lot for all that you people have given. AIISH wouldn't have been so colorful without you. You both have been always there for me whenever I needed. ☺

I would also like to thank Vinni and Srishti for the wonderful time we spent together during data collection and writing dissertation ☺

Last but not the least, thanks to all my dear classmates specially Deepthi, Mitali, Suchi, Neha, Shrilakshmi, Prerna, Prajeesh, Abhishek , Sandeep and, you people had always been encouraging and helping whenever I needed. Special thanks to my classmates, who participated in my study inspite of having load of their own works.

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Chapter 1

INTRODUCTION

A remarkable feature of the human brain is that both are anatomically and functionally asymmetrical. These asymmetries exist in normal as well as in pathological conditions. It is seen for all the systems and can occur at any level of information processing beginning from peripheral to central level (Zaidel, Clarke & Suyenobu, 1990). The general impression is that there is special role played by left hemisphere in both production and understanding of the language whereas perception and synthesis of non-verbal information is the role of the right hemisphere (Kolb & Whishaw, 2003).

The asymmetries of the cerebral hemispheres can be studied either by using direct anatomical studies, imaging techniques (for example, MRI, fMRI), electrophysiological tests (like EEG, event related potentials), psychophysical tests or behavioral tests (laterality tests like Dichotic digit test, dichotic consonant vowel test).

Functional asymmetry of the auditory cortex is well documented on behavioral and perceptual tasks. Dichotic listening is probably one of the most common behavioral methods being used in the study of central auditory processing mechanism and the cerebral organization of speech processing (Hugdahl, 2000; Katz, 1994). The asymmetries in the dichotic listening have been reported in the form of right and left ear advantages on behavioral tests. The tests showing a Right-Ear Advantage (REA) involves tasks such as identification of words, digits, nonsense syllables, backward speech, formant transitions, morse code, tonal sequences with frequency transitions, difficult rhythms, tone used in linguistic decisions, and ordering temporal information. Whereas, the tests showing a Left-Ear Advantage include stimuli such as on musical chords, melodies, emotional sounds and hummed melodies, tones processed independently, complex pitch perception and environmental sounds (Kolb & Whishaw, 2003).

The term ‘dichotic listening’ refers to the auditory perception of the two different stimuli presented to both the ears simultaneously (Katz, 1994). Though it is known that each ear has an auditory pathway which connects it to both cerebral hemispheres, it has been reported that contralateral pathway have better representation at cortical level when compared to the ipsilateral pathway and therefore the ear opposite to dominant hemisphere has an advantage (Kimura, 1961; Clarke, McCann & Zaidel, 1998). In this perspective, it has been reported that the REA observed in studies using dichotic listening for verbal tasks should be interpreted as reflecting the dominance of the left hemisphere (Bryden, 1988).

There are several factors that affect the performance of a person on a dichotic listening task. These include stimulus related factors and subject related factors. Stimulus factors include intensity (Roeser, John & Price, 1972; Hugdahl, Westerhausen, Alho, Medvedev & Hämäläinen, 2008), frequency (Efron, Koss & Yund, 1983), temporal effects/lag effects (Berlin, Lowe-Bell, Cullen & Thompson, 1973), bandwidth (Berlin & Mc Neil, 1976), phonetic effects (Berlin et al., 1973), masking effects (Weiss & House, 1973), and stimulus material used (Kimura, 1967; Speaks & Jerger, 1965). Whereas the subject related factors include age effects (Gowri, 2001), gender effects (Jerger, Chmiel & Allen, 1994), attention effects (Martin, Jerger & Mehta, 2007), and ear effects (Kimura 1967).

One of the important stimulus factors that affect dichotic listening is ‘stimulus dominance effect’. This means higher scores or better representation of stimulus depends on the stimulus per se and not on the ear of presentation (Speaks, Carney, Niccum & Johnson, 1981). Literature reports the presence of stimulus dominance in dichotic listening, based on several acoustic features. With respect to voicing feature, voiceless consonant has been reported to be dominant over voiced consonant (Roser, Johns & Price, 1972; Rimol, Eichele & Hugdahal, 2006; Rajagopala & Yathiraj, 1996). This finding was replicated by Roeser, Johns and Price (1976) and, Niccum, Speaks and Carney (1976). In terms of place of articulation, studies have reported velars to be more dominating over bilabials and alveolar sounds (Speaks et al., 1981; Berlin et al., 1976; Rajagopala & Yathiraj, 1996).

The asymmetries in the auditory processing have also been documented on electrophysiological tests at cortical (Eichele, Specht, Moosmann, Jongsma, Quiroga, Nordby & Hugdahl, 2005) and at subcortical level (Hornickel, Skoe & Kraus, 2009; Sinha & Basvaraj, 2010). Eichele et al. (2005) reported presence of shorter latencies for speech in the left hemisphere (a right ear advantage) for auditory evoked late latency response, while Jones and Byrne (1998) reported larger cortical EP in T-complex produced by tones over the right temporal region.

The role of brainstem and subcortical auditory pathway in peripheral asymmetry of dichotic stimulus is not well understood yet. Studies of brainstem auditory evoked potentials, (Levine & McGaffigan, 1983; Levine, Liederman & Riley, 1988) have reported that for monaural click-train stimulation, a rightward asymmetry exists. Larger brainstem responses were elicited from the stimulation of the right ear than stimulation of the left ear which suggests that in the brainstem structures, there are an increased number of active neurons or increased firing synchrony along the afferent auditory path from the right ear to the left auditory cortex. The authors related this rightward asymmetry obtained in the brainstem responses to the dominance of left hemisphere for speech processing. Similarly, Sinha and Basvaraj (2010) recorded brainstem responses to speech in two monoaural conditions and reported that speech is processed faster through the right ear compared to left ear, supporting the existence of right ear advantage at subcortical level.

1.1 Need for the study

Dichotic listening tests has been a well established tool to study binaural integration and the hemispheric asymmetry of a perceptual schema. The phenomenon complementing specialization is evidenced by behavioral test like dichotic consonant vowel test (DCV), as well as in cortical evoked potential. However, there is limited information available in the literature to describe whether these processes also occur at subcortical level. Behavioral tests have limited usefulness in terms of giving a description of level of processing for such stimulus paradigm. Till date, it is not clear as to whether the hemispheric asymmetry observed in dichotic speech perception tests and the cortical auditory evoked potentials is purely a cortical-level phenomenon or does such asymmetry exist even at the brainstem level. This would also characterize the active versus passive nature of brainstem speech processing. Brainstem responses to speech precisely represent temporal coding of the consonantal and vowel portion of the stimulus. The latency, amplitude and spectral characteristics of these responses in the dichotic paradigm, therefore, can be useful in examining the ear effect in brainstem processing of dichotic speech.

Thus, the present study was undertaken to investigate the processing of speech stimuli at brainstem level through speech evoked auditory brainstem response in dichotic paradigm to signify whether the asymmetries in processing speech stimuli starts right at brainstem level or is just confined to higher centers. Such study will also provide electrophysiological evidence of processing asymmetry in terms of ear advantages.

1.2 Objectives of the Study

1. To examine the characteristics of auditory brainstem responses evoked by dichotic stimulation.
2. To examine the processing asymmetries (ear advantage and phonetic effects) for speech sounds, if any, in brainstem responses elicited for dichotic stimulation
3. To relate behavioral (DCV) and electrophysiological test results obtained (Speech evoked ABR) for dichotic stimulation.

Chapter 2

REVIEW OF LITERATURE

In the quest to unravel the complex nature of central auditory processing mechanisms in normal as well as subjects with brain damage, investigators have relied heavily on the use of dichotic stimuli. Dichotic listening is reported to be one of the most common methods used in the behavioral study of central auditory processing mechanism and the cerebral organization of speech processing (Hugdahl, 2000; Katz, 1994). When two different stimuli are presented to two ears simultaneously (dichotically), there is consistent ear difference in perception. The performance however depends on the nature of stimuli being used. The focus of present study being characterization of the brainstem response for dichotic stimulation, the following sections provide the relevant review of literature on the phenomenon of dichotic listening, its theoretical basis, important influencing factors, auditory evoked potentials for dichotic stimulus and nature of brainstem responses to speech stimulus. However, the clarity of the presentation, the contents are organized under following headings.

2.1 Dichotic listening and its theoretical models

2.2. Stimuli for dichotic speech recognition

2.3 Factors affecting dichotic listening

2.4 Hemispheric laterality for speech encoding

2.5 Subcortical laterality for speech encoding

2.6 Brainstem responses as a tool to study dichotic speech processing

2.7 Evidence to support neural origin of speech ABR

2.8 Evidence to support brainstem origin of FFR

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2.1 Dichotic Listening and its Theoretical Models

The term ‘dichotic listening’ refers to the auditory perception of the two different stimuli presented to the two ears simultaneously (Katz, 1994). Typically, right ear advantage is seen for verbal stimuli in right handed individuals.

Kimura (1967) provided an anatomical explanation of the right ear advantage. She showed that the right ear is connected to the left hemisphere which is language dominant through contralateral pathways. Similarly, the left ear is connected to the right hemisphere through the contralateral pathways. This was called structural theory. The structural theory attributes that the ear advantage occurs due to anatomic properties of the auditory system. With contralateral pathway being larger, the ear opposite to the dominant hemisphere was suggested to have an advantage.

Kinsbourne (1970) based on his experiments proposed an alternate theory through explanation of attention to account for the asymmetry. He suggested the lateralized cortical functions to be basis of laterality effect, but emphasized the role of attention in priming a particular hemisphere. For instance, when verbal stimuli are expected, it serves to prime the language dominant hemisphere i.e. left hemisphere and make it extra responsive to stimuli (Kinsbourne, 1970; Kinsbourne, 1973; Kinsbourne, 1975).

2.2 Stimuli for Dichotic Speech Recognition

Dichotic listening tasks uses words, digits, sentences, or consonant vowels (CVs), as stimuli. These stimuli can differ in two ways: in meaning and in length. If the stimuli convey less meaning to an individual, the dichotic listening task increases in difficulty and vice versa. Noffsinger, Martinez, and Andrews (1996) reported that CV tasks are challenging because the individual does not already have those stimuli present in their internal vocabulary. Without a place in one’s internal vocabulary, the syllables lack meaning, and this makes the dichotic listening task harder. Noffsinger et al. (1996) reported that the digits and sentences if used in a dichotic listening task are easier.

CVs are reported to be difficult not only due to their lack of meaning to a subject but also because of their short duration (Bowman, 2008). Noffsinger et al. (1996), stated that the use of CVs makes a task very difficult because the stimuli occur for the same duration with difference only in few characteristics. Wilson and Jaffe (1996) using digits as stimuli found that, as the stimuli increased in complexity and length from 1-pair digits to 4-pair digits, there was a decrease in correct recognition performance. The dichotic listening task became more difficult as the length of the stimuli increased. Also, as the stimuli became longer and more complex, the REA increased.

While either of the words, digits, sentences, or CVs could be used as stimuli for a dichotic listening task, the use of words (i.e., digits, monosyllabic PB words, and spondees) has its advantages. The most commonly used stimuli for dichotic listening tasks are digits. However, Roup, Wiley, and Wilson (2006) suggested the use of monosyllabic words due to their meaningfulness, limited syntactic cues and readily available norms.

2.3 Factors Affecting Dichotic Listening

There are various stimulus and subject related factors which affect individual's performance on dichotic listening task. However in the present review, only those factors which could affect the individual's responses for auditory evoked potential in dichotic listening conditions are being listed.

2.3.1 Stimulus Related Factors

a) Temporal Aspect (lag effect)

When two different auditory signals are presented simultaneously one to each ear, one of them is perceived as having a greater perceptual salience than the other. This is known as 'ear advantage'. Apart from this, when one signal lags another signal then lagging signal will be perceived better. This is called 'lag effect'. The amount of time separation needed between message onsets to overcome the REA was investigated by

Berlin et al. (1972). They found that when one of the CV trailed the other by 30-60ms the trailing CV become more intelligible then when it was given simultaneously. This time advantage occurred to the lagging syllable and not to the leading syllable. This was also supported by Berlin et al. (1973). In their study they used 6 CV (pa, ta, ka, ba, da, ga) non-sense syllables. These stimuli were paired with onsets being 0, 15, 30, 60, and 90ms apart. Twelve adult females served as subjects. Results revealed REA when the syllables were given simultaneously. The leading syllable intelligibility dropped when leading by 15 and 30ms and the intelligibility of lag ear improved. Intelligibility of both lag and lead ear improved beyond 30ms.

Porter (1975) used a dichotic task, where signal were presented with onset asynchronies varying from 0 to 150ms, subjects identified lagging signal more accurately and reported them as clearer than the leading signal at 30 and 70ms delay between two ears. These differences were not found beyond 70 ms lag. Rajgopal and Yathiraj (1996) found an improvement in score from 0 to 90 ms lag. Gelfand, Hollman, Walkmen and Piper (1980) found aberration of lag effect for CV in elder subjects.

Berlin, Lows-Bell, Culkn, Chomson and Thompson (1973) attributed the lag effect to single left hemisphere speech processor being entered from two channels. This hypothetical processor require a finite time (around 30-60 ms) to handle a CV accurately provided it were not interrupted by different information arriving from the other channel. Darwin (1971) had demonstrated that REA and lag effect are independent of one another and there is evidence that lag effect might be a case of temporal masking, not limited to speech stimuli.

b) Phonetic Effects

Phonetic effect or stimulus dominance is a phenomenon where in higher scores are got for one of the 2 competing syllables, regardless of the ear to which it is presented. This effect is seen in natural CV syllables (Roeser, Johns & Price, 1972). In some respects, stimulus dominance is a more interesting phenomenon in dichotic listening, than is the ear advantage. It occurs with greater frequency and magnitude than the ear advantage.

Berlin et al. (1973) in his study reported that higher scores were obtained for voiceless stops (/pa/, /ta/, /ka/) when compared to voiced stops (/ba/, /da/, /ga/) in pairs of natural syllables contrasting in voicing. The voiceless stops were found ‘dominant’ than the voiced stops. The findings were in agreement with other reports (Roser, John & Price, 1972). Different studies have investigated various parameters that determine the voicing character of a sound. Repp (1976) studied the effect of varying voice onset time (VOT) on the perception of dichotic CV syllables which contrasted in voicing features. A systematic effect of variation in VOT was shown on the probability of hearing the fused stimuli as voiced or voiceless sounds. It is reported that varying the VOT of the voiceless stimuli had a larger effect than that of a voiced stimulus. Similar findings have been reported by other studies (Porter, Troendle and Berlin, 1976; Rajagopal & Yathiraj, 1996).

Another way to describe the pattern of stimulus is to focus on the place features. Porter, Troendle and Berlin (1976) used 6 CV (pa, ta, ka, ba, da, ga) paired randomly. Results revealed that velars were more often reported correctly than alveolars, which in turn are reported more correctly than labials (i.e. velar >alveolar>labials). Similarly results by Berlin et al. (1973) found that velars were reported more correctly followed by the bilabial and the alveolar (i.e. Velars > Bilabials > alveolars). Speaks et al. (1988) used 8 pairs in which velar competed with non velar (bilabials and alveolar). Result revealed that for 6 of these pairs, velars dominated the non velar. Rajgopal and Yathiraj (1996) found similar results in their study where velars were best perceived followed by labials and alveolars.

Most of the studies show little or no REA for vowel (Studdert-Kennedy & Shankweiler, 1970; Darwin, 1969; Shankweiler & Studdert-Kennedy, 1967). These studies howver revealed REA for vowels in a consonant context which was interpreted to mean that vowels surrounded by transition or acoustic correction of vocal tract adjustments towards a given target will have a REA. Berlin et al. (1973) suggested that the REA in speech like task may be related to the use of any acoustic event which is perceptually linkable to a rapid gliding motion of the vocal tract, as in a transition.

Even in vowels, some are better perceived than the others. Weiss and House (1973) dichotically presented 10 vowels (American) in CVC syllable where the consonant was kept constant and vowels were varied. The vowels were classified into long and short vowels. Results showed that larger REA for long vowels compared to short vowels. In long vowels, /a, ae/ were perceived better than /e, o/ which in turn were perceived better than /i, u/. In short vowels, /ɛ, ə/ were perceived better than /I, U/.

Darwin (1969) reported stronger REA for final position consonants when presented dichotically. Studdert-Kennedy and Shankweiler (1970) also reported strong REA to final consonant in natural speech stops.

Possible explanation for the stimulus dominance by Speaks et al. (1981) were Inherent intelligibility, Lag effect, Prototype matching hypothesis and Burst amplitude. Among this, the most accepted explanation is the Burst amplitude. It is concerned with the relative amplitude of the brief moment of articulatory release. The peak intensity of burst as well as its duration is generally greater in voiceless stops than the voiced (Klatt, 1975). Speaks et al. (1981) measured peak intensity of initial burst frication of 6 steps /p, t, k, b, d, g/. It was seen that the velar /k, g/ had greatest peak intensity followed by alveolar and labials. Hence, dominance of velar stimuli over alveolar stimuli is justified in the present study.

(c) Effect of Intensity

Effect of intensity on dichotic listening has not been studied extensively. Roeser, John and Prince (1972) tested 32 normals using Dichotic digit test at intensity level of 10, 30, 50, 70dB SL with respect to Speech Recognition Threshold. Results revealed fewer correct responses at lower intensity i.e. at 10dB SL. But the right-left difference did not vary as a function of intensity. So he concluded that SL is not a significant factor.

Speaks and Bissonette (1975) used 6 CV syllables and presented them in pairs dichotically using 4 intensities levels (80, 70, 60, 50dB SPL). The experiment was done in 2 phases. In the first phase, speech level in the right ear was attenuated in 8dB steps from each of four reference intensities. Whereas in the second phase, speech level in the left ear was increased in 8dB steps. Results showed that the REA was cancelled by attenuating the signal level in the right ear, but the attenuation amount required to cancel the REA varied with reference intensity (i.e. 22 dB for 80dB SPL to 5dB for 50dB SPL ref intensity).

Hugdahl, Westerhausen, Alho, Medvedev, and Hämäläinen (2008) in contrast showed that the right ear advantage was held constant when the left ear signal was 6 dB more intense than the right ear. Some investigators report that the intensity of the signal does influence the response received. Dobie and Simmons (1971) found that when two speech sounds are presented dichotically, the subjects were able to report accurately the input to either ear until the signal amplitude to the unattended ear exceeded that of the attended ear by 15dB.

(*d) Effect of Signal to Noise Ratio (SNR)*

Signal to noise ratio affects perception of dichotic listening. Weiss and House (1973) performed a dichotic competing vowels task at two SNR (0dB SNR & -10dB SNR) in 13 subjects. The presentation level was kept constant at 70dB SPL. Results revealed that as the SNR becomes poorer, the overall scores reduced and the REA became more pronounced. At favorable SNR ear preference were not apparent.

Cullen et al. (1974) also investigated the effect of SNR. In their experiments signal was presented at 60 dB SPL and band limiting noise was introduced with SNR varied from 0 to 30 dB in both channels simultaneously. They found performance decreased with low SNR, but right ear advantage was maintained as long as SNR was varied between two channels with 12 dB SNR difference between channels. This implies the need to balance SNR between 2 channels and a good absolute SNR so as not to obscure REA due to floor or ceiling effect.

(e) Effect of Stimulus Familiarity

Nachshon and Carmon (1975) studied the effect of speech lateralization, stimulus familiarity and their interaction on ear superiority for CV syllables. Six consonants (3 familiar), and four vowels (2 familiar) were used for the purpose. The test was done in 4 contexts; FF, FN, NF, NN (F-Familiar, N-Not familiar) e.g. in FN condition familiar stimulus (vowel or consonant) was given to left ear and the non-familiar stimulus was given to right ear. Results revealed that in FF or NN condition consonant showed REA and the recall of vowel are same for both the ears (as expected). NF consonant showed stronger right ear superiority and NF vowels showed right ear superiority (due to interaction of familiarity and language effect). This shows strong effect of stimulus familiarity.

(f) Effect of Bandwidth

Berlin and McNeil (1976) reported that the intelligibility of one channel can be decreased when the information transmitted to the other is increased by reducing frequency band width. Cullen et al. (1974) reported the dominance of right ear over left ear when there was a high frequency cut off set at 4kHz followed by an equal ear performance when high frequency cut off was 3kHz.They revealed a poor performance of the right ear when cut off frequency was 2kHz. The difference was found to be marked between channels when frequency was 1.5kHz.

2.3.1 Subject Related Factors

(a) Handedness

Asbornsen, Hudghal and Bryden (1994) reported that about 90% of the right handed population and 60% of left handed population would show a right ear advantage. The right ear superiority is seen for both meaningful and non-sense syllables and backward speech (Kimura, 1967). In contrast, left ear superiority has been reported for some non-speech stimulus such as music and sound effects (Curry, 1967).

(b) Effect of Age

The variation of age in dichotic listening can be referred as ‘developmental dichotic listening’. Ingram (1975) reported that a right ear advantage was indicated on dichotic listening task at the age as early as 3 years. This is suggestive of the left hemisphere dominance to certain extent for speech function by that age. This study supports the findings of Kimura (1961, 67) where she found that the right ear advantage appeared no later than the age of 6 years.

The magnitude of right ear advantage was studied using different stimuli. Bellis (1996) in her study revealed a greater right ear advantage in children when complex linguistically loaded dichotic stimuli were used than with the use of less complex stimuli. As the child matures, the right ear advantage will decrease, reaching adult values by approximately 11 to 12 years.

(c) Effect of Gender

Voyer and Voyer (2011) reported that males have larger laterality effects when compared to females. Papcun, Krashen, Terbeek, Remington and Harshman (1974) presented non-syllables dichotically and observed a significant REA for males. Jerger, Chmiel and Allen (1994) investigated effect of age and gender on dichotic sentence identification (DSI). The results suggested that there was a gender difference existing with the effect of age on the left ear deficit. In both ears, it was almost 30% for males and only 10% for female.

McCoy, Butler and Broekhoff (1977) studied the effect of age and gender on dichotic listening SSW. The test results revealed that older individual perform poorer than younger individuals. Males tended to perform significantly poorer than female. There was no significant difference between young males and females.

(d) Effect of Attention

Perceptual advantage in dichotic listening can be biased by attention. Bloch and Hellige (1989) investigated effect on instruction in terms of divided attention and focused attention. For the first task (attend both ears), more number of CV stimuli were identified from the right ear than from left ear. When subjects were asked to focus their attention only to left ear, identification of stimuli improved in that ear. Hiscock and Beckie (1993) in their experiment with 58 children (7-10 years) instructed them to attend to left ear and REA was over come for dichotic CV stimulus.

To conclude although dichotic listening tasks generally show right ear advantage, one needs to control for variables like age, gender, attention, stimulus type, lag before interpreting the results.

2.4 Hemispheric Laterality for Speech Encoding

Speech processing from the cochlea to auditory association cortices shows side-dependent specificities. Lazard, Collette and Perrot, (2011) using macro- and microanatomical observations studied the cerebral hemispheres and reported that the structural differences in the two cerebral hemisphere support asymmetry in favor of a left dominance for speech processing. Neuropsychological studies have shown that the posterior part of the superior temporal gyrus and the inferior frontal gyrus are larger in left hemisphere and are critical to the perception and production of speech. Similarly, both afferent and efferent pathway at peripheral level also shows asymmetric functioning (Lazard, Collette & Perrot, 2011; Schonwiesner et al., 2005) and can be contributing to the dominance of left hemispheric in language processing.

Therefore on a whole, it can be said that he right hemisphere specializes in the processing of auditory environmental nonlinguistic stimuli, such as, voice, music, or emotional prosody, whereas the left hemisphere has major role in processing the linguistic contents of speech.

2.5 Subcortical Laterality for Speech Encoding

The laterality in the subcortical auditory processing is not yet well understood. Levine, Liederman and Riley (1988) and Levine and McGaffigan, (1983) studied the brainstem auditory evoked potentials for monaural click-train stimulation, and reported a rightward asymmetry. Larger brainstem responses were elicited from the stimulation of the right ear than stimulation of the left ear which suggests that in the brain stem structures, there are an increased number of active neurons or increased firing synchrony along the afferent auditory path from the right ear to the left auditory cortex. The authors related this rightward asymmetry obtained in the brain stem responses to the dominance of left hemisphere for speech processing.

Hornickel, Skoe and Kraus (2009) recorded brainstem responses by presenting CV stimuli to the right and left ears. Results confirmed an REA for specific acoustic features that are characteristic of speech. These effects were exclusive to the speech stimulus as there were no interaural differences in click evoked responses. The finding suggested that the temporal and harmonic elements of the speech signal are preferentially encoded by the right-ear/left-hemisphere pathway, but that the fundamental frequency, perceived as pitch, is not.

2.6 Brainstem Responses as a Tool to Study Dichotic Speech Processing

Subcortical processing of complex acoustic features of speech can be studied objectively using ABR. Brainstem responses can provide better evidence on how the acoustic features of speech is encoded in the auditory system. The precise aspects of the speech signal are maintained and reflected in the neural coding. The brainstem response elicited by a speech syllable can be divided into transient and sustained portions which has similarity with stimuli itself. These are called as onset response and the frequency following response (FFR) which depicts the consonantal and vowel portion of a speech syllable (Song, Nicol & Kraus, 2011; Boston & Moller, 1985). In the case of CV syllables, the beginning portion of the consonant i.e. burst is represented as the transient onset response. The sustained FFR is synchronized to the periodicity of the sound, with each cycle reliably representing the temporal structure of the sound and thus the sustained FFR reflecting the neural phase-locking with an upper limit of about 1000 Hz (Chandrasekaran & Kraus, 2010).

The speech evoked ABR also gives reliable information on encoding of harmonics. Hornickel, Skoe and Kraus (2009) recorded brainstem responses by presenting CV stimuli to the right and left ear and reported that the temporal and harmonic elements of the speech signal are preferentially encoded by the right-ear or left-hemisphere pathway, when compared fundamental frequency of the stimuli

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Abrams, Nicol, Zecker and Kraus (2006) and Johnson et al. (2005) reported that Speech-evoked ABRs represent temporal features of speech stimuli with great reliability and delays in the response on the order of fractions of milliseconds have been linked to abnormal perception and linguistic abilities.

Marsh, Brown, and Smith (1974) reported subcortical structures to be generator of speech evoked responses including cochlear nucleus (CN), trapezoid body, and superior olivary complex (SOC).

Also there are evidences that ABR using a speech stimulus could extend the audiological tests to include assessment of the conditions of central auditory neural pathways in children with language-based learning problems (Russo, et al., 2004; Greenberg, Popper, & Ainsworth, 2004a; Skoe & Kraus, 2010), evaluation of the encoding of speech in the intact and impaired auditory system (Johnson et al., 2005; Johnson et al., 2008), evaluation of speech intelligibility with hearing aid and cochlear implant usage (Aiken & Picton, 2006), and for monitoring auditory training progress (Russo et al., 2005).

Therefore, speech evoked brainstem responses can be used as a reliable tool to study the auditory processing asymmetry arising in dichotic listening task in the subcortical structure.

2.7 Evidence to Support Neural Origin of Speech Evoked Brainstem response

Worden and Marsh (1968) conducted experiments to delineate FFR from cochlear microphonics (CM) and provided evidence for a neural basis for the FFRs. They reported that the latency of FFR for even simple pure tones occurs beyond 5 ms, suggesting a site of generation beyond the cochlea and also proving that the FFR is not a reflection of stimulus related artifacts. Adding on, the authors reported that the FFR is not an exact reproduction of the input stimulus, since the response consists of considerable amplitude and phase fluctuation which is unlike the CM that perfectly replicates the input stimulus. The CM can be recorded even under anoxia. However, the FFR shows reduction in amplitude which is consistent with other neural potentials. Also, the CM is not susceptible to change in stimulation rate where as the FFR shows shifts in latency with increasing rates. Marsh, Brown, and Smith (1974) obtained FFRs in cats and reported of precise phase correspondence between the FFRs and electrical activity at the cochlear nucleus (CN), trapezoid body, and superior olivary complex (SOC), thus, indicating that the FFR is an ensemble response reflecting phase-locked activity from multiple generator sites within the auditory brainstem. Collectively, these studies support the neural origin of FFR.

2.8 Evidence to Support Brainstem Origin of FFR

In most studies, FFRs are recorded using vertical ipsilateral montage compared to the horizontal montage. Though the FFRs are recorded from the vertex, there are abundant reasons that suggest that the FFRs reflect activity of the brainstem rather than cortex. Most studies using speech syllables to evoke FFR, report of the response amplitude within 1 microvolt. Hoorman, Falkenstein, Hohnsbein and Blanke (1992), obtained FFRs across different stimulus frequencies and reported that the FFR amplitudes were largest between 320 and 380 Hz. 400 nanovolts was found to be the mean FFR amplitude in these frequency ranges. This is in contrast to the usual cortical responses, which are much larger in amplitude ranging over several microvolts. This difference in size between brainstem and cortical responses, leads to difference in the number of averages required to obtain the optimum morphology for each of these responses. FFRs need at least 1000 averages lo attain its distinctive morphology, whereas, only about 75-100 averages are sufficient for cortical responses.

The FFR amplitude is stable with increase in stimulus repetitions (Johnson, Nicol & Kraus, 2008), whereas reduction in amplitude with increase in repetition rate, a phenomenon known as neural adaptation occurs in cortjfr^l potentials (Grill-Specior, Henson, & Martin, 2006). These differences support the evidence which suggests that at the single neuronal level, stimulus specific adaptation is seen more in cortical neurons than sub cortical neurons (Ulanovsky, Las & Nelken, 2003).

It is evident from these studies that FFR is generated by brainstem. However acquisition of FFR is dependent on various factors.

2.9 Factors Affecting Speech Evoked ABR

Speech evoked ABR is affected by the factors related to the subject, stimulus parameters and recording parameters. Each of these factors would be discussed in the following subsections.

2.9.1 Subject Related Factors

Age is proven to effect the encoding of speech at the brainstem (Vander Werff & Burns, 2010; Johnson, Nicol & Kraus, 2008). Unlike clicks, a developmental pattern was observed in the brainstem response to speech across age groups between 3 to 12 years. The onset response and FFR was found to be significantly delayed in 3-4 years group relative to 5-12 years group (Johnson et al., 2008). This data suggests an effect of age in both temporal and frequency domains of speech evoked ABR and also suggest a possibility of experience-dependent plasticity in the human auditory brainstem. Similarly, when the mean latencies and amplitudes of speech evoked ABR was compared between young normal hearing adults group (age range of 20- 26 years) and an older normal hearing group (age range of 61-78 years), a significant delay was reported in the offset response along with reduction in the amplitude of onset and offset response in the older adult group relative to the younger adult group (Van-Werff & Burns. 2011). The authors reported that these effects were different from those of simply decreasing the overall stimulus level, which causes significant shifts in latencies of all waves evoked by speech stimulus.

Another biologically inherent factor reported to have an effect on brainstem encoding of speech is the native language of the subject. Experience with one's native language is reported to not only shape speech perception ability of the listener but auditory processing in general. Bent, Bradlow & Wright, (2006) in their study reported that the native speakers of Mandarin, which is a tonal language, could better process the pitch contours even in a nonlinguistic context, when compared to native speakers of English. At the physiological level, a more robust encoding of pitch was seen in Mandarin speakers when Mandarin sounds were used at the brainstem level, suggesting that language experience fundamentally changes the neural circuitry of the auditory pathway (Krishnan, Xu. Ciandour & Cariani, 2005).

2.9.2 Stimulus Related Factors

The stimulus factors which are proven to have an effect on speech evoked ABR are ear of stimulation, the type of transducer used for presentation of the stimulus, stimulus intensity, stimulus polarity, repetition rate and the number of stimulus. Hornickel, Skoe and Kraus (2009), recorded brainstem responses to /da/ syllable, which was presented monaurally to the right and left ears in adults with symmetrical interaural click-evoked responses. Right ear responses were reported to have earlier latencies for peaks D and F, than the left car. Further, robust encoding of Fl was observed when the stimulus was presented to right ear then left ear. The authors suggested possibility of the right ear advantage for speech stimulus. Thereby, showing that the right–ear advantage is evident at brainstem level. Additionally, majority of the studies recommend electromagnetically shielded insert earphones for presentation of stimulus relative to circumaural headphones. This is because there is an increased chance for stimulus artifact contamination while using circumaural headphone. Furthermore, the intensity of the speech stimulus was also found to have an effect on the onset and sustained response. In a study by Akhoun et al. (2008) when the syllable /ba/ was varied as a function of intensity from 0 to 60 dB SL in 10 dB increments, both response components showed orderly latency shifts with increasing intensity. The onset response and FFR latencies decreased with increasing stimulus intensity, with a greater rate for FFR (-1.4 ms/10 dB) than for onset response (-0.6 ms/10 dB).

Two different methods have been recommended while recording speech evoked ABR. The first method recommends recording of response to any one stimulus polarity (Krishnan. 2007). The second method suggests recording responses to both polarities and either adding (Russo et al.. 2004 & Akhoun et al.. 2008) or subtracting the responses (Krishnan, 2002) to the two stimulus polarities. The process of adding will emphasize the low frequency components of the response which includes phase locking to the amplitude envelope and minimizing stimulus artifact and the cochlear microphonics. Subtracting will increase the high frequency components by maximizing the spectral response, and also maximize artifact contamination. Hence, the Alternating polarity is most preferable. Adding on, the number of sweeps required for speech stimulus, to obtain robust and reliable responses are comparatively greater than that required for clicks and tones. One of the general principles of signal averaging in EP test is that the SNR is proportional to the square root of the number of sweeps (Hood, 1998; Hall 2006). Thus, initially overall SNR increases rapidly then slowly begins to stabilize with more number of sweeps. However, SNR progression may vary across each component of the speech evoked ABR Most studies use an approach of collecting responses to more than one stimulus trials, typically 2000 to 3000 per polarity and adding the responses.

Lastly, the length of the stimulus and the inter stimulus interval (ISI) are also important to decide the repetition rate. It is an established fact that, changing the ISI can modify the perception of sound. Also, if the ISI is short, the response to one stimulus may not fully conclude before the next stimulus is presented. Hence, the ISI and the analysis time should be sufficiently long enough to allow for the response to return to baseline.

Krizman, Skoe and Kraus (2010), conducted a study to determine the effects of stimulation rate on ABR. They recorded evoked responses for clicks and speech syllable /da/ presented at three rates (15.4, 10.9 and 6.9 Hz). The results showed that the latency of click evoked response was constant over the three repetition rates. But, latency of the onset response to /da/ varied systematically, increasing in peak latency as presentation rate increased. The FFR was also found to be rate dependent. It was found that the magnitude of the high frequency components of the response reduced with increasing rate. Similar results have been reported in other studies on children (Ranjan & Burman, 2011), young adults and old adults (Garvita & Sinha, 2012) in Indian population.

2.9.3 Response Acquisition Related Factors

The response acquisition factors that are proved to have an effect on speech evoked ABR are the analysis time, sampling rate, electrode montage, filter setting, and amplification. Among these, the analysis time window is recommended to be long enough to include a pre stimulus baseline period, a response period, and a post stimulus period. The post stimulus period is needed to account for the stimulus transmission delay and neural conduction time. Hence, a post stimulus period between 10 and 50ms is recommended to ensure that the response returns to baseline (Skoe & Kraus, 2010a). Another important factor is the sampling rate. Sampling rate determines the frequency of digitization of the neural signal by the recording system. According to the Nyquist theory, the sampling frequency should be twice that of the highest frequency in the stimulus. Hence, studies using speech as stimulus to evoke brainstem responses, have made use of sampling rates ranging from 7 to 50kHz (Musacchia, Sams, Skoe & Kraus, 2007; Akhoun et al, 2008; Banai, Hornickel, Skoe, Nicol, Zecker & Kraus, 2009). A higher sampling rate not only reduces sampling error but also increases the temporal precision of the recording and allows for finer differentiation of response peaks.

Additionally to record speech evoked ABR, majority of the studies have used the vertical, one channel montage. This configuration requires three electrodes corresponding to the active (non-inverting), reference (inverting), and ground electrode. The preferred electrode placements are Cz for active electrode, ipsilateral earlobe or nape of the neck for reference electrode, and forehead or contralateral earlobe as ground. A non cephalic site is preferred over the mastoid as reference because it leads to fewer artifacts from bone vibration (Hall, 2006). Furthermore, optimum filtering is essential to isolate activity evoked by the subcortical structures from cortical structures and to increase the SNR of the response. The band-pass filter for speech evoked ABR and FFR falls in the range of 100 to 3000Hz (Skoe & Kraus, 2010a). This frequency range has been reported to increase the detection of the high frequency transient peaks, such as wave V, which has a sharp slope. Lastly, since the response of interest originates from the brainstem, the response amplitude is in the order of several nanovolts. Hence, amplification of the response is essential and gain of 100000 has been found to be necessary.

To conclude, stimulus and acquisition parameters need to be carefully chosen to elicit the response. The protocol should be such that it minimizes the effects of other stimulus and acquisition parameters and clearly shows the effects of only the target variable on the brainstem responses to speech.

Chapter 3

METHOD

The present study was undertaken to investigate the presence of processing asymmetries, if any, at brainstem level for different stimuli, differing in terms of place of articulation. For this, normal hearing human participants were included in the study. They were tested with the two speech stimuli in monotic, diotic and dichotic conditions to study ear effect and phonetic effect if any, in brainstem responses. The results were analyzed for onset and sustained portion of the responses separately. Further the results of brainstem responses were related with the results of behavioral dichotic consonant vowel test, where such ear differences have been documented.

In the present study a true experimental research design was used to test the null hypothesis that there is no significant stimulus dominance or ear dominance effect represented in the brainstem responses elicited for dichotic stimulation. The following method was adopted to test the null hypothesis.

3.1 Participants

Twenty normal hearing human adults in the age range of 18 to 30 years participated in the study. All the participants had pure tone thresholds of less than 15dBHL at octave frequencies between 250Hz and 8000Hz. They had normal middle ear functioning as reflected by type-A tympanogram and presence of ipsilateral as well as contralateral reflexes on immittance evaluation. There was no history of otological or neurological problems.

They did not report of difficulty listening in adverse listening conditions and obtained more than 60 percent score in speech in noise test. The speech was presented at 40dBSL as referenced to Speech recognition threshold (SRT) and at 0dBSNR. They also showed normal binaural integration ability on Dichotic Consonant Vowel test at 0ms lag according to the normative of adults developed by Prachi and Yathiraj (2000).

The participants also obtained a high score of left hemisphere preference in laterality preference schedule (Venkatesan, 2010)[1]. An informed consent was taken prior to their inclusion in the study.

3.2 Instrumentation

Several technical equipments were used for the preliminary evaluations and in the actual experimental procedures. The equipments included a calibrated diagnostic audiometer (OB-922) with TDH-39 earphones, calibrated middle ear analyzer (GSI tympstar), a calibrated Intelligent Hearing system (IHS) evoked potential system with Smart EP (version 3.7) software and a computer used to deliver stimuli for Dichotic Consonant Vowel test at controlled intensity.

3.3 Test Environment

Testing was carried out in an electrically shielded and sound treated room with ambient noise levels within permissible limits (ANSI S3.1-1999). The room was also air conditioned.

3.4 Test Stimuli

Stimuli for speech perception in noise: Standardized monosyllabic word list in English for Indian population developed by Swarnalatha and Rathna (1972) was used for testing

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[1] Note: The schedule consists of 30 questions based on daily activities, checking individual's preference of usage of limbs, eyes and ears (right/ left) for the activities.

the speech identification ability of participants at 40dBSL and 0dB signal to noise ratio (SNR) in the presence of speech noise.

Stimuli for speech perception in Dichotic condition: The stimuli developed by Yathiraj (1999) were used for testing the speech perception ability of participants on dichotic consonant-vowel test. The test material contains a total of 30 pairs of monosyllabic stimuli. Each pair of stimuli is presented simultaneously (with 0ms lag) to both ears. Here different monosyllables go to each ear at a single time, simultaneously.

Stimuli for Speech evoked ABR: Two different stimuli were used to elicit speech evoked brainstem responses. Both the stimuli were monosyllables made of voiceless stop consonants (/t/ and /k/) with vowel /a/. They differed in terms of place of articulation, wherein /ta/ is an alveolar stop and /ka/ is a velar stop.

The stimuli were spoken by adult male speaker and were digitally recorded using unidirectional microphone at a sampling frequency of 44100 Hz and 16 bit digitization, and recorded using PRAAT signal editing software (version 4.5.18). The duration of the two stimuli (/ta/ and /ka/) were 63.9ms and 67.9ms as shown in figure 3.1 and 3.2 respectively. Table 3.1 and 3.2 give the temporal and spectral characteristics respectively of /ta/ and /ka/.

Table 3.1*: Temporal characteristics of stimuli /ta/ and /ka/*

Parameters	Duration (ms)	
	/ta/	/ka/
Burst	3.5	8.2
Transition	17.1	12.94
Steady state vowel	39.5	21.2

Table 3.2: *Spectral characteristic of stimuli /ta/ and /ka/*

Parameters	Values(Hz)	
	/ta/	/ka/
F0	114	125
F1	634	540
F2	1456	1446
F3	2727	2644

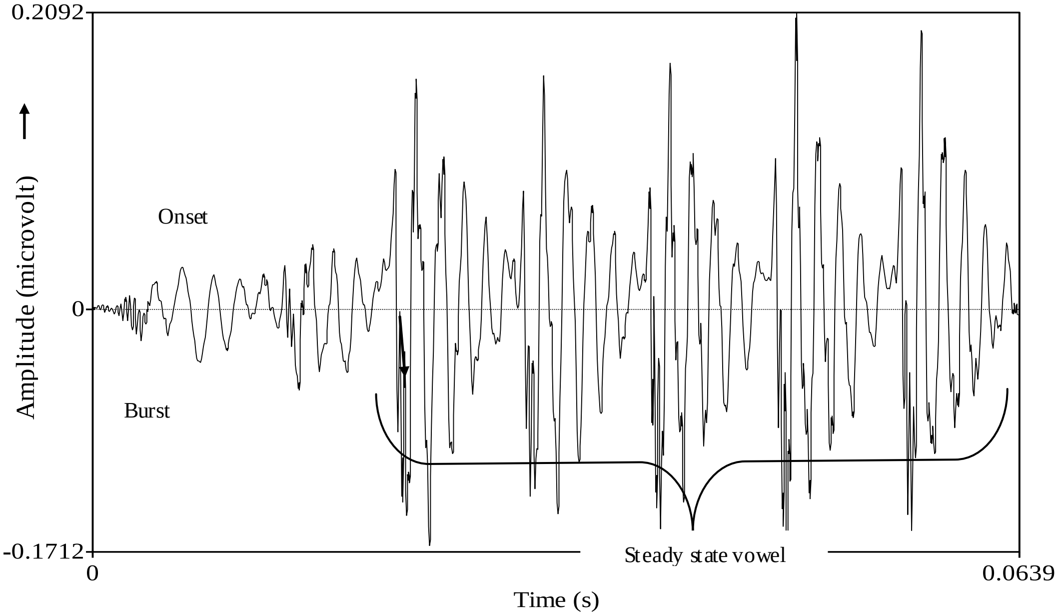

Figure 3.1: Time amplitude waveform of stimuli /ta/.

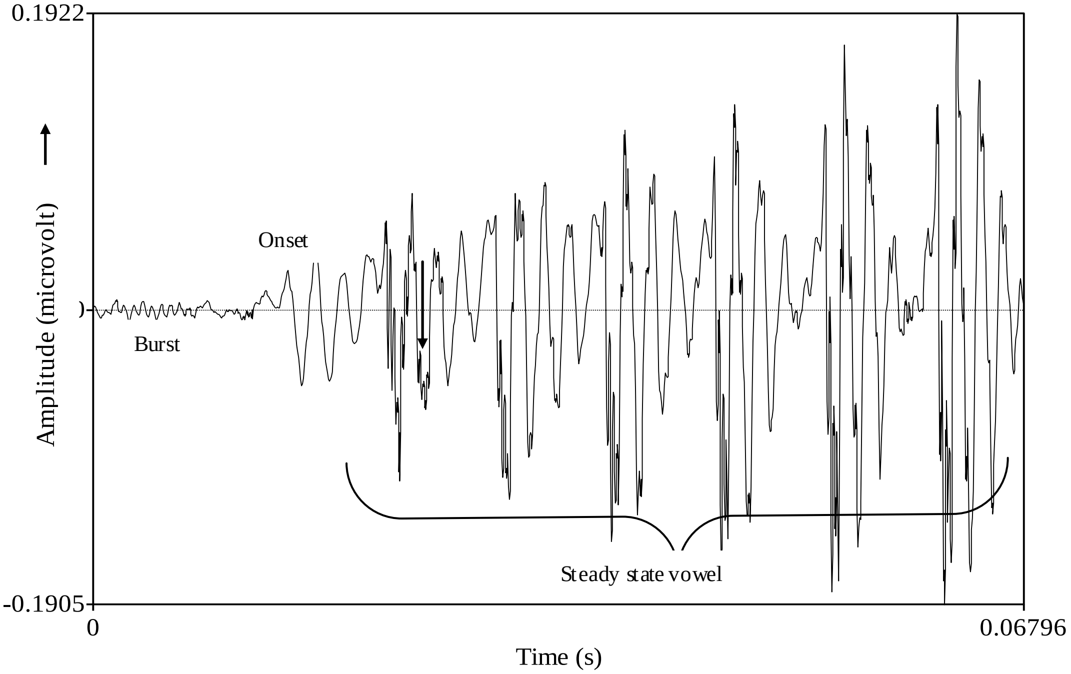

Figure 3.2: Time amplitude waveform of stimuli /ka/.

3.5 Test Procedure

3.5.1 Preliminary evaluations:

The purpose of the preliminary evaluations was to rule out presence of any hearing loss, middle ear pathology, screen for auditory processing disorders in the participants and to determine hemispheric dominance in them.

Behavioral air conduction thresholds were tracked using modified Hughson-Westlake procedure (Carhart & Jerger, 1959) using a calibrated clinical audiometer (OB-922) coupled to impedance matched TDH-39 ear phones with MX-41/ AR ear cushion. Air conduction thresholds were measured for frequencies between 250Hz and 8000Hz while bone conduction thresholds were measured between 250Hz and 4000Hz.

Speech identification scores (SIS) in quiet and in the presence of noise were obtained using monosyllabic words in English developed by Swarnalatha and Rathna (1972). The stimuli were routed through the OB 922 audiometer at 40dBSL. The speech noise was presented at 0dBSNR. The SIS was obtained monaurally for both the ears.

Immittance evaluation was carried out using a calibrated microprocessor- based automatic immitance meter (Grason- Stadler, Inc.,Tympstar). Middle ear admittance was measured using 226Hz probe tone, sweeping the pressure from + 200dapa to -400dapa. In acoustic reflex threshold measurement, both ipsilateral and contralateral reflexes were measured for 500Hz, 1000Hz, and 2000Hz and 4000Hz pure tone at peak pressure. The threshold was defined as the minimum level of signal presentation which leads to change in compliance by 0.03ml.

Laterality preference checklist (Venkatesan, 2010) was administered to check for hemispherical dominance where the participants were asked to indicate their preference for performing a group of tasks in the checklist between right/left limbs, eyes and ears.

Administration of dichotic test: The dichotic consonant vowel test was tested using stimuli developed by Yathiraj (1999). The participants were seated in a double room audiometric suite. The recorded track was played at 40dBSL (most comfortable level) using a PC connected to the audiometer (OB 922), and presented to the subject via headphones (TDH-39). The participants were instructed to write down the syllables they hear in the two ears.

Recording of AEPs: Auditory brainstem responses to speech stimulus were recorded for /ta/ and /ka/ in four stimulus conditions; Monotic right, Monotic left, Diotic (once each for /ta/ & /ka/) and Dichotic stimulation. The order of presentation was (a) Right monotic /ka/, (b) Left monotic /ka/, (c) Right monotic /ta/, (d) Left monotic /ta/, (e) Diotic /ka/, (f) Diotic /ta/, (g) Dichotic (/ka/-right ear, /ta/- left ear), (h) Dichotic (/ta/-right ear, /ka/- left ear).

Table 3.3: *Parameters used for recording speech evoked ABR*

Stimulus Parameters	
Stimulus	/ta/ & /ka/
Polarity	Alternate
Repetition rate	10.9/s
Intensity	80dBSPL
number of sweeps	2000
Acquisition Parameters	
Band-pass filter	30-3000Hz
Pre-stimulus time	-10.88ms
Analysis time	91.74ms
Notch	On
Gain	100000
No. of channels	1
Buffers	4
Number of points	1024 * 4
Montage	Vertical

Advance research module of Intelligent Hearing System was used to present the stimuli and record the responses, as more number of data point can be used to represent the response waveform. Prior to the recording, the site of electrode placement was prepared with skin preparation gel. Silver chloride electrode was used with conducting gel. Responses were differentially recorded from AgCl electrodes with absolute electrode impedance of less than 5 kΩ. Single channel recording was used wherein, non-inverting electrode was placed on forehead (Fz), inverting electrode was placed at nape of the neck and ground electrode was placed at nasion. The stimuli were delivered through insert earphones (ER-3A). The parameters listed in Table 3.3 were used to record the auditory brainstem responses to speech stimulus. Recording in each stimulus modality was replicated.

3.6 Response Analysis

The performance on dichotic CV test was analyzed for single correct score-right (SCS-R), single correct score-left (SCS-L) and double correct scores (DCS). The score then were compared to normative score for adults developed by Prachi and Yathiraj (2000). Analysis of phonetic effect in behavioral test for dichotic listening task was carried out by comparing the response of participants on those items of DCV test which had either /da/ & /ga/ or /ta/ & /ka/ paired with each other. There were four such pairs including /daga/ (/da/-right ear & /ga/- left ear), /gada/ (/ga/- right ear & /da/- left ear), /kata/ (/ka/-right ear & /ta/-left ear) and /taka/ (/ta/- right ear & /ka/- left ear). The responses of participants who had not identified both the stimulus of the pairs were analyzed.

Speech evoked ABR was analyzed both subjectively and objectively. Analysis of data was done separately for onset and steady state portions wherever possible. The subjective analysis was carried out by two experienced Audiologists. On subjective analysis, the peak latency, peak to peak amplitude of wave V-A and its slope were measured for each participant and considered for comparison. The right end of the wave with the largest amplitude approximately around 8ms following the stimulus onset was marked as wave V. The immediate negative trough following the wave V was marked as wave A. The V-A amplitude was obtained from the voltage difference between the wave

V and wave A. The slope was obtained diving amplitude difference between V and A by latency difference between V and A.

To obtain correlation between responses across different recording condition, the recorded waveforms were converted to ASCII file and all the analysis was done for the amplitude values in each data point. These amplitude values obtained from all the twenty subjects were averaged for each data point in each stimulus condition. The grand averages data obtained for each recording condition was further analyzed to obtain correlation. Correlation was separately obtained for onset and steady state responses. The data points were selected based on latency of A wave. Figure 3.3 shows a representative grand averaged waveform of brainstem response, elicited for one of the diotic conditions.

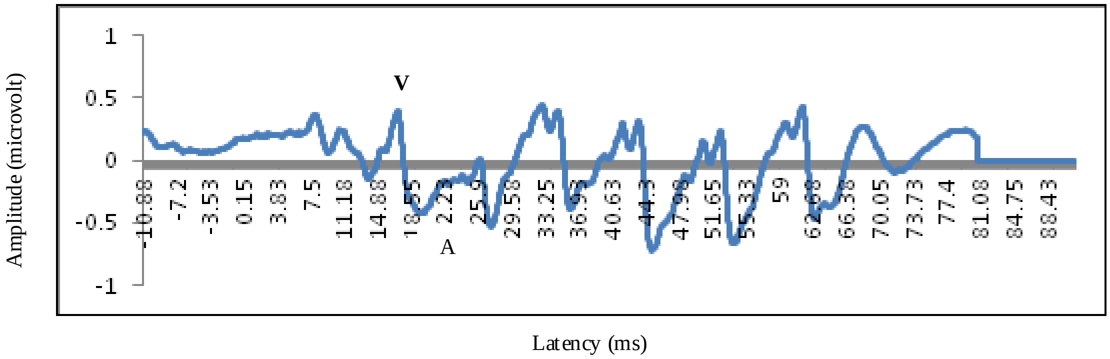

Figure 3.3 Representative Brainstem response elicited in one of the diotic condition.

Later to evaluate the spectral composition of speech evoked ABR in different condition Fast Fourier transformation (FFT) analysis was done for the epoch duration of 10 ms to 91.74ms to assess the amount of activity occurring over two frequency range i.e. 114Hz +/- 3Hz and 125Hz +/- 3 Hz and their corresponding three higher harmonics. This was executed using the MATLAB R 2009a platform. The amplitude of energy at fundamental frequency, the three harmonics was noted from the FFT results.

3.7 Data Analysis

The data thus obtained were used to test the hypothesis of the study through:

1. Results of dichotic Consonant vowel test

2. Comparison of stimulus and response waveform.
3. Correlation of the onset and steady state responses across different conditions
4. Comparison of latency, amplitude and slope of onset responses across stimulus condition.
5. Comparison of FFT output of steady state responses across stimulus conditions.

Chapter 4

RESULTS

The results of present study are reported in light of processing asymmetries in the brainstem responses to speech stimuli. The stimulus paradigm served as the independent variable, the effect of which was tested on the dependent variable, brainstem responses. This influence was statistically tested using Statistical package for social sciences (SPSS, version 16.0) software. Both the individual and averaged group data were used for statistical comparisons.

To begin with, the distribution of the data was tested using Kolmogorov-Smirnov test of normality for each dependent variable. This was to decide the nature of the statistical test (parametric vs. non-parametric) to be used. The results obtained indicated that all data were normally distributed ($p > 0.05$) and supported the use of parametric test. Descriptive statistics, repeated-measure analysis of variance, paired-samples t test and Pearson's correlation tests were the statistical tests used to verify the objectives of the study. The results are reported under two major headings;

1. Results of dichotic consonant vowel test
2. Results of speech evoked auditory brainstem responses

4.1 Results of Dichotic Consonant Vowel Test.

Table 4.1 gives the mean, standard deviation, maximum and minimum of single and double correct scores obtained by the twenty participants of the study on DCV test.

Table 4.1: *The Mean and standard deviation (SD) of single correct scores and double correct scores obtained in dichotic CV test*

Measures	Mean	SD	Maximum	Minimum
Double Correct	19.2	4.5	28	15
Single Correct-Right	24.5	3.6	29	20
Single Correct-Left	21.2	3.6	28	18

Note: Maximum Score = 30

The individual double-correct score of all the participants was within the normative range (15-30; normative given by Prachi & Yathiraj, 2000). The mean right single-correct score was found to be higher than mean left single-correct score. Even the individual data showed the same trend (refer Appendix 1).

To derive the phonetic influences on dichotic speech perception, the responses of each participant for /ta/-/ka/, /da/-/ga/, /ka/-/ta/ and /ga/-/da/ were analyzed. The analysis of the dichotic perception for /ta/-/ka/, /da/-/ga/, /ka/-/ta/ and /ga/-/da/ stimuli revealed that five of the twenty participants, perceived both the stimuli correct. However among the ones who perceived only one stimulus, twelve of them perceived /ka/ and thirteen participants perceived /ga/ while only two and one subject perceived /ta/ and /da/ respectively. In other words, results showed that /ka/ and /ga/ were recognized more number of times in dichotic listening than /ta/ and /da/. This is true with ear of presentation been counterbalanced.

4.2 Results of Speech Evoked Auditory Brainstem Responses

In the electrophysiological responses obtained for speech stimuli, both onset and steady state portion were seen for each condition in all the participants. The results of speech evoked ABR has been reported under the following headings;

1. *Comparisons of stimulus and response waveform*
2. *Comparison of brainstem responses elicited for /ta/ with that of /ka/*
3. *Correlation of the responses elicited in different stimulus conditions*
4. *Effect of stimulus conditions on onset responses*
5. *Effects of stimulus condition on steady state responses*

4.2.1 Comparison of Stimulus and Response Waveforms

Figure 4.1 shows the stimulus waveform for /ta/ and /ka/ and averaged brainstem responses for stimulus /ta/ and /ka/ in right monotic condition.

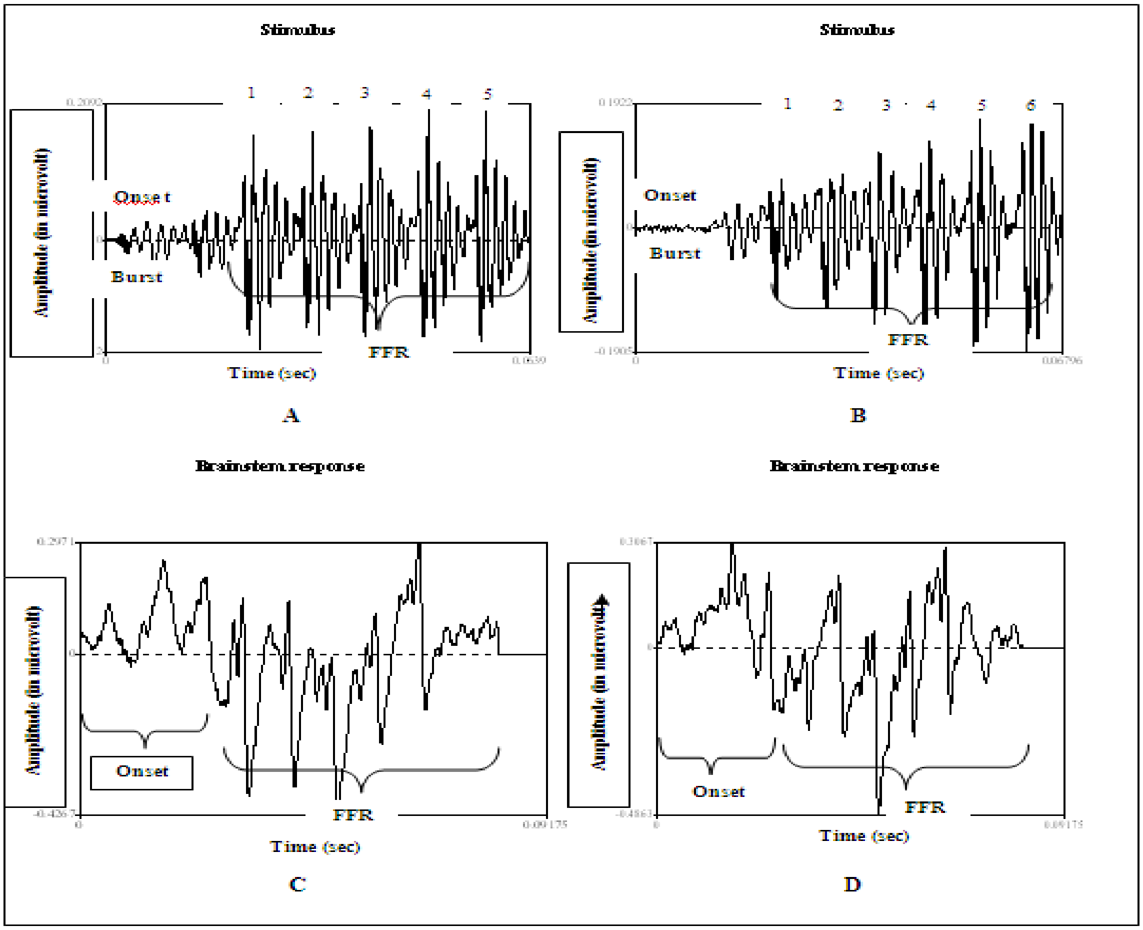

Figure 4.1: Time amplitude waveform of stimulus /ta/ (A) stimulus /ka/ (B) and grand averaged neurophysiological response for ta/ monotic Right condition (C)/ and /ka/ monotic right (D).

The stimulus and response waveforms were compared morphologically as well as in terms of their onset latency and latency for peaks in the steady state portion. The same is represented in Table 4.2.

In the response for /ta/, onset is being evidenced by approximately 8.14 ms after stimulus onset. Phase locking to fundamental frequency of stimulus is represented by negative peaks from 19ms to 58ms and stimulus offset is represented by a negative peak at approximately 72ms.

In the response for /ka/, onset is being evidenced by approximately 8.11ms after stimulus onset represented by 'V peak'. Phase locking to fundamental frequency of stimulus is represented by negative peaks from 18ms to 64ms and stimulus offset is represented by a negative peak at approximately 71ms. The cycle in steady state portions had occurred in every 9 ms approximately in the response waveforms for /ta/ stimuli and in every 8ms for /ka/ stimuli which corresponded to their fundamental frequency. Regardless of common morphology of responses, slight variations in timing of peak latencies are seen across the participants.

Table 4.2: *The latency obtained in response waveforms for the onset wave and peaks in steady state portion*

Peaks	Latency (in ms)	
	/ta/	/ka/
V	8.14	8.11
1	22.07	23.23
2	31.02	30.94
3	39.56	38.73
4	48.18	46.77
5	56.63	54.89
6	-	61.1

4.2.2. Comparison of Brainstem Responses Elicited for /ta/ with that of /ka/

While comparing the stimulus waveforms obtained through monotic presentation of /ka/ and /ta/ stimuli, a sharper peak is seen in response to /ta/ than /ka/ in the onset

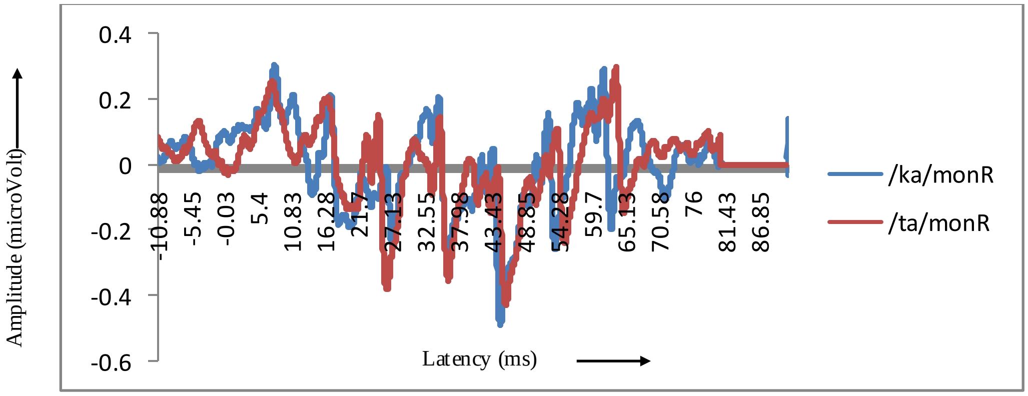

Figure 4.2: Response waveforms for monotic presentation of /ka/ and /ta/ stimuli in the monotic presentation.

portion as seen in Figure 4.2. In the steady state portion, it is seen that both the responses almost overlaps with small variations in amplitude and latency at different points of time.

4.2.3 Correlation of the Responses Elicited in Different Stimulus Conditions

The amplitudes of all the twenty participants in each data points were averaged and the averaged data was used for correlation. Pearson's correlation test on the SPSS platform was used for the purpose. The correlation coefficient and significance of correlation were found separately for the onset (0-20 ms) and steady state portions (post 20- 91.74ms) of the waveforms. The comparisons were made among two monotics, monotics and diotics, and dichotic with rest of the conditions.

A. Correlation of the Two Monotic Conditions

Table 4.3 gives the results of correlation between right monotic and left monotic conditions. The results are given for both onset and steady state portions.

Table 4.3: *Results of correlation between the right and left monotic condition in the onset and steady state responses*

Stimulus Conditions	/ka/ monotic left		/ta/ monotic left	
	Onset	Steady state	Onset	Steady state
/ka/ monotic right	0.914*	0.935*	-	-
/ta/ monotic right	-	-	0.819*	0.909*

Note: * $p < 0.05$. A value of $0 < |r| < 0.3$ = low correlation, $0.3 < |r| < 0.7$ = moderate correlation, $|r| > 0.7$= high correlation, where r= correlation coefficient.

The results showed a significant high correlation between right monotic and left monotic condition for /ka/ as well as /ta/ stimuli. This was true for both onset and steady state portions. Figure 4.3 shows the right and the left monotic responses overlapped separately for the /ka/ (left panel) and /ta/ (right panel) stimuli.

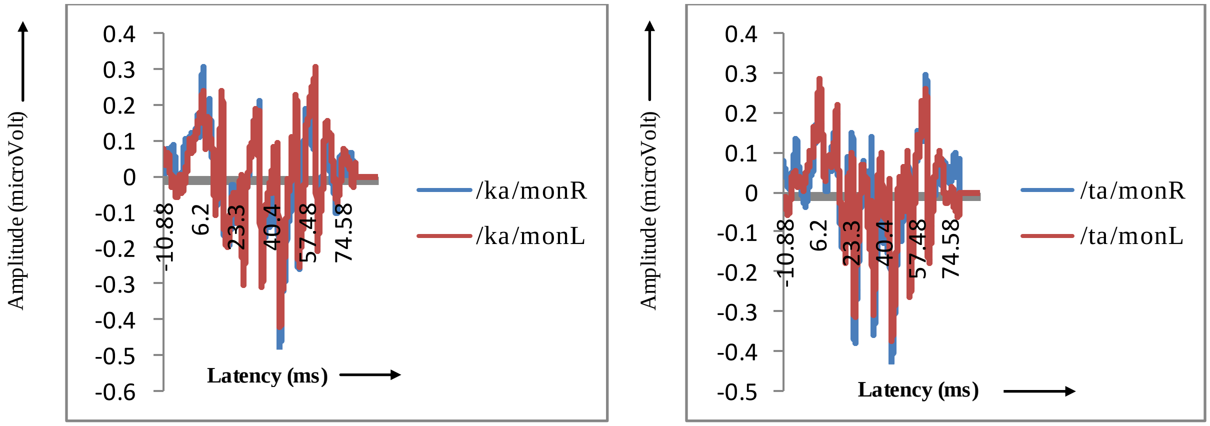

Figure 4.3: Overlapped averaged waveforms of right and left ears in monotic conditions for /ka/ (left panel) and /ta/ (right panel) stimuli.

B. Correlation of Monotic and Diotic Conditions

The responses of monotic and diotic conditions were correlated to verify if the monoaural versus binaural stimulations, lead to differences in the characteristic of the brainstem responses. Table 4.4 gives the correlation coefficient and significance of correlation obtained between monotic and diotic conditions for onset responses and steady state responses.

Table 4.4: *Results of correlation between diotic and, the right and left monotic conditions in the onset and steady state responses*

Stimulus Conditions	/ka/ diotic		/ta/ diotic	
	Onset	Steady state	Onset	Steady state
/ka/ monotic right	0.888*	0.809*	-	-
/ka/ monotic left	0.889*	0.884*	-	-
/ta/ monotic right	-	-	0.877*	0.885*
/ta/ monotic Left	-	-	0.814*	0.926*

Note: $*p < 0.05$

A significant high correlation coefficient was obtained for both the stimuli in onset as well as steady state responses. Figure 4.4 shows the monotic and diotic waveforms overlapped for /ka/ and /ta/ stimuli. It is apparent from the figure that diotic conditions showed a higher amplitude waveform than the monotic conditions although a temporal charaterstic of the responses remained same.

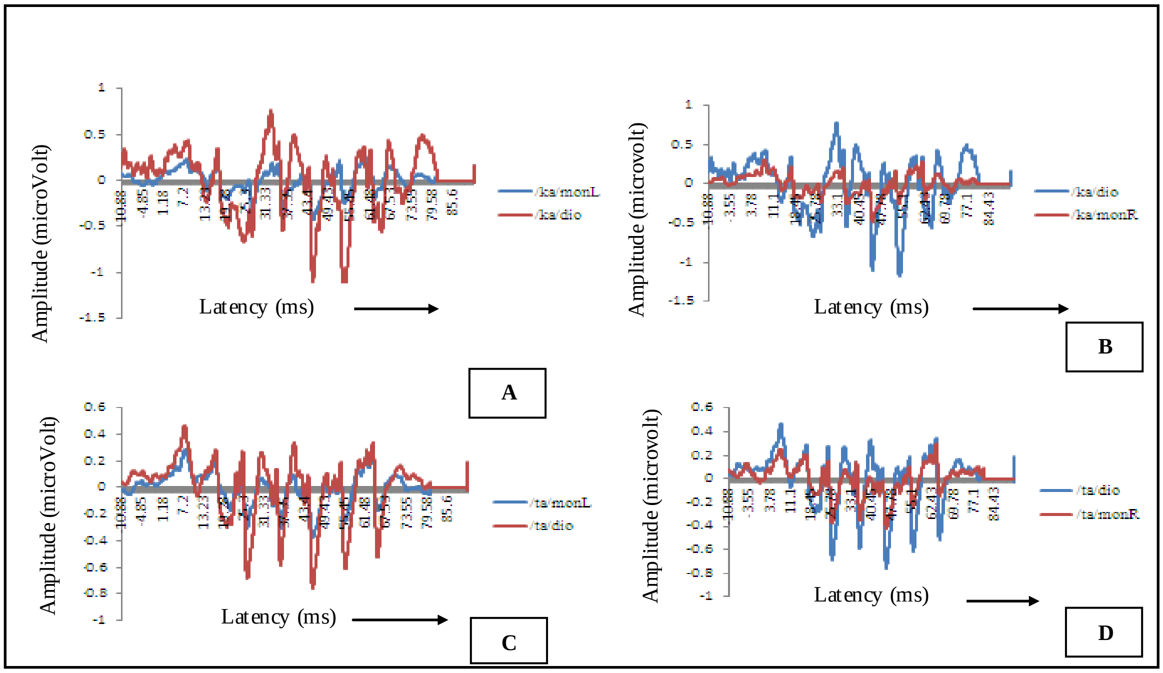

Figure 4.4: Overlapped response waveforms of monotic condition and diotic conditions for /ka/ and /ta/ stimuli across right and left ear (A)/ka/ monotic left and /ka/ diotic, (B) /ka/ monotic right and /ka/ diotic, (C) /ta/ monotic left and /ta/ diotic and (D)/ta/ monotic right and /ta/ diotic.

C. Results of Correlation of Dichotic Condition with Rest of the Conditions.

Table 4.5 gives the result of correlation obtained for the comparisons between dichotic condition and rest of the conditions. The correlation was done for each stimulus separately in the onset and steady state response regions. While correlating monotic condition with dichotic conditions, the /kata/ dichotic response was correlated only with that of /ka/ monotic right and /ta/ monotic left. On the other hand, /taka/ dichotic response was correlated with /ta/ monotic right and /ka/ monotic left i.e. stimuli in a particular ear remained same.

It is seen from the Table 4.5 that a significant high correlation was obtained between diotic conditions and both dichotic conditions (/kata/ and /taka/). This was true for both the stimuli /ka/ and /ta/, in onset and steady state portions. When monotic conditions were correlated with dichotic conditions, dichotic condition showed a significant high correlation with all monotic conditions, except for /ta/ monotic left with /kata/ dichotic condition where a moderate correlation was obtained in onset response.

Table 4.5: *Results of correlation between dichotic and rest of the stimulus conditions in the onset and steady state responses*

Stimulus Conditions	/kata/ dichotic		/taka/ dichotic	
	Onset	Steady state	Onset	Steady state
/ka/ diotic	0.943*	0.869*	0.878*	0.863*
/ta/ diotic	0.844*	0.855*	0.921*	0.861*
/ka/ monotic right	0.873*	0.724*	-	-
/ka/ monotic left	-	-	0.905*	0.797*
/ta/ monotic right	-	-	0.813*	0.764*
/ta/ monotic left	0.667*	0.772*	-	-

Note: $*p < 0.05$

Comparison of diotic and dichotic condition showed that dichotic responses correlated better with the diotic responses elicited for the stimulus presented to the right ear in the dichotic condition, i.e. /kata/ correlated better with /ka/ diotic and /taka/ correlated better with /ta/ diotic. This was true for both onset and steady state responses. However, when the dichotic responses were correlated with monotic responses, in most circumstances higher correlation was obtained with /ka/ monotic responses, irrespective of the ear to which /ka/ was being presented. However, in steady state response for /kata/ dichotic condition, a higher correlation was obtained for /ta/ monotic left when compared to /ka/ monotic right. The correspondence of the dichotic responses with the different monotic and diotic responses is pictorially represented in Figure 4.5 and 4.6 respectively.

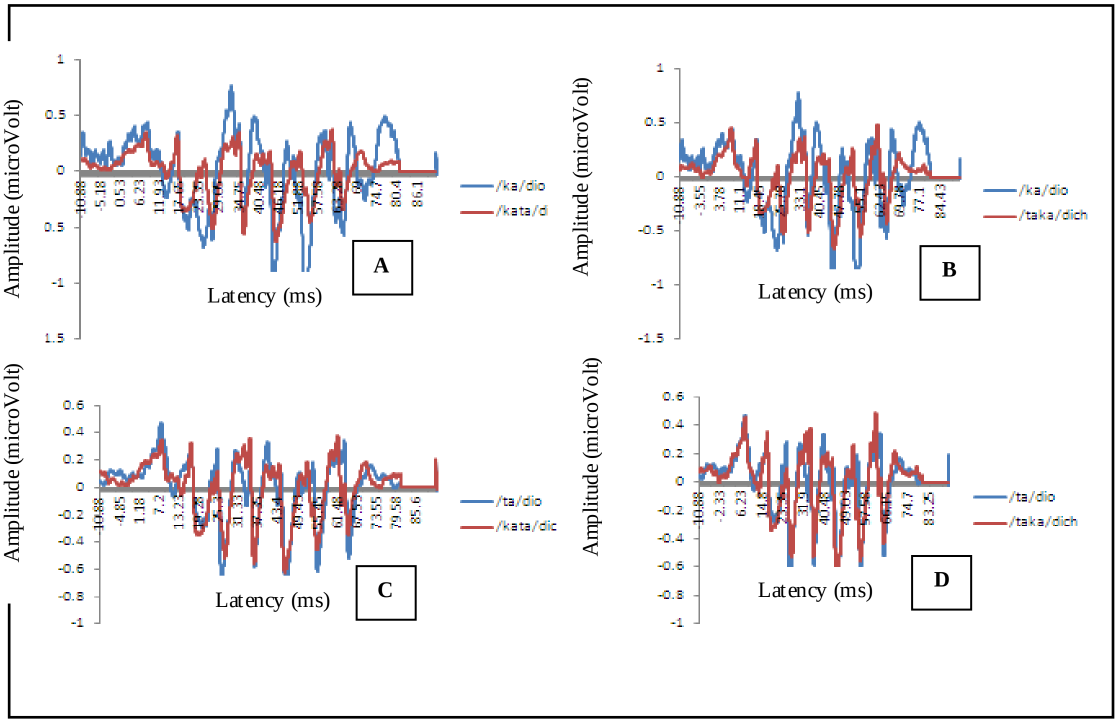

Figure 4.5: Overlapped response waveforms of diotic condition and dichotic conditions for /ka/ and /ta/ stimuli (A) /ka/ diotic and /kata/ dichotic, (B) /ka/ diotic and /taka/ dichotic, (C) /ta/ diotic and /kata/ dichotic (D) /ta/ diotic and /taka/ dichotic.

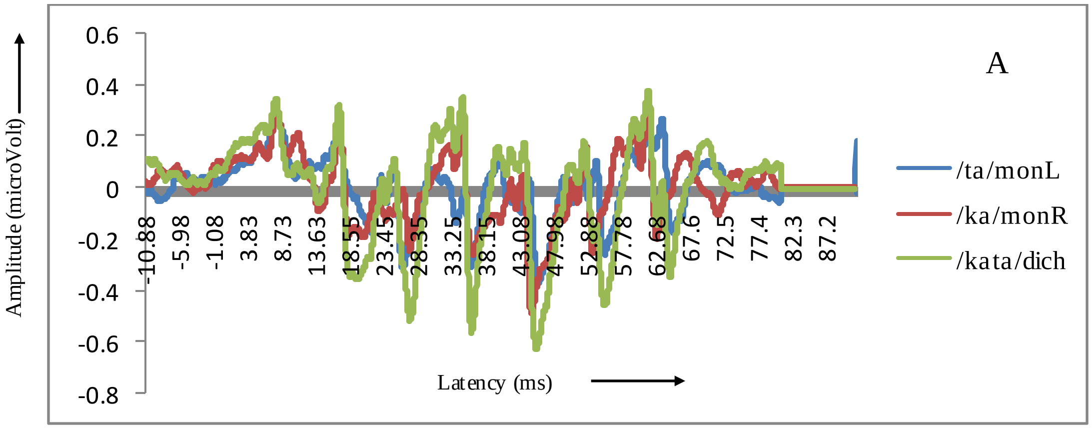

Figure 4.6a: Overlapped response waveforms for /ka/ monotic right, /ta/ monotic left and /kata/ dichotic.

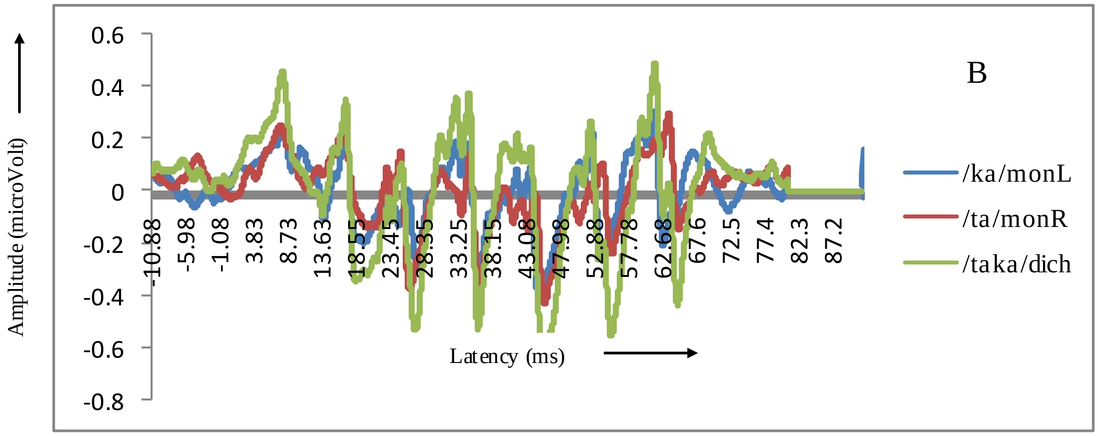

Figure 4.6b: Overlapped response waveforms of for /ta/ monotic right, /ka/ monotic left and /taka/ dichotic.

4.2.4: Effect of Stimulus Conditions on Onset responses

The onset responses in different stimulus conditions were compared for their latency, amplitude, and slope parameters. Table 4.6 gives mean and standard deviation for peak latencies, peak-peak amplitude (V-A) and slope in different stimulus conditions.

It is evident from Table 4.6 that the results obtained for mean peak latency, peak to peak amplitude and slope, differed across various stimulus conditions. Results of mean latency showed that right ear responses were earlier compared to left ear responses, but for which there was no specific trend in the way latency varied across different stimulus conditions.

The mean amplitude and the mean slope of onset responses also varied in specific way across stimulus condition. The amplitude was higher and slope steeper in the left ear responses compared to that of right ear responses. Irrespective of the stimulus, dichotic and diotic conditions showed higher amplitude and steeper slope than the monotic conditions.

Table 4.6: *The mean and standard deviation (SD) of peak latency and peak –peak amplitude and V-A slope in different stimulus conditions*

Stimuli	Condition	Ear	Measures							
			V latency		A latency		V- A amplitude		Slope	
			Mean (ms)	SD	Mean (ms)	SD	Mean (µV)	SD	Mean µV /ms	SD
/ka/	monotic	R	8.14	0.36	9.43	0.63	0.24	0.12	-0.21	0.13
/ka/	monotic	L	8.28	0.38	9.42	0.60	0.29	0.15	-0.27	0.13
/ta/	monotic	R	8.11	0.47	9.35	0.69	0.24	0.12	-0.20	0.10
/ta/	monotic	L	8.25	0.37	9.49	0.64	0.28	0.17	-0.23	0.12
/ka/	Diotic	B	8.33	0.41	9.46	0.59	0.44	0.19	-0.42	0.19
/ta/	Diotic	B	8.17	0.41	9.50	0.63	0.41	0.19	-0.32	0.14
/kata/*	dichotic	B	8.17	0.36	9.37	0.53	0.42	0.23	-0.36	0.17
/taka/*	dichotic	B	8.22	0.36	9.35	0.47	0.44	0.17	-0.38	0.14

Note: R= right, L= left, B=Both

**In /kata/ dichotic, /ka/ goes to right ear and /ta/ to left ear, whereas in /taka/ dichotic, /ta/ goes to right ear and /ka/ to left ear.*

To test whether the observed mean differences were statistically significant, the data was subjected to Repeated measure ANOVA. Results revealed a significant main effect of condition on mean amplitude [F (7,133) = 7.658, p<0.01] and mean slope [F (7, 133) = 9.585, p<0.01] of onset responses. The mean differences in latency of wave V [F (7, 133) = 1.421, p>0.05] and A [F (7, 133) = 0.475, p>0.05] however were not statistically significant.

As there was a significant main effect of the stimulus condition on amplitudes and slope of the onset response, the data was further subjected to Bonferroni test for pair wise comparisons. The results of pair wise comparison in peak to peak amplitude (Table 4.7) and slope (Table 4.8) across monotic and diotic conditions are represented in following tables.

Table 4.7: *Pairwise comparison of mean amplitude across different stimulus conditions*

Conditions	/ka/ monotic left	/ta/ monotic left	/ka/ diotic	/ta/ diotic	/kata/ dichotic	/taka/ dichotic
/ka/ monotic right	NS	-	S	-	NS	S
/ka/ monotic left	-	-	NS	-	NS	S
/ta/ monotic right	-	NS	-	S	NS	S
/ta/ monotic left	-	-	-	S	NS	NS
/ka/ diotic	-	-	-	-	NS	NS
/ta/ diotic	-	-	-	-	NS	NS

Note: S= p<0.05; NS= p>0.05

Results of Bonferroni showed that the diotic conditions were significantly different compared to monotic conditions except for /ka/ monotic left and /ka/ diotic. Also, /taka/ dichotic was significantly different from all monotic conditions but for /ta/ monotic left. There was no significant difference in any of the other stimulus conditions.

Table 4.8: *Pair wise comparison of mean slope across different conditions*

Conditions	/ka/ monotic left	/ta/ monotic left	/ka/ diotic	/ta/ diotic	/kata/ dichotic	/taka/ dichotic
/ka/ monotic right	NS	-	S	-	NS	S
/ka/ monotic left	-	-	NS	-	NS	NS
/ta/ monotic right	-	NS	-	S	S	S
/ta/ monotic left	-	-	-	NS	NS	NS
/ka/ diotic	-	-	-	-	NS	NS
/ta/ diotic	-	-	-	-	NS	NS

Note: S= p<0.05; NS= p>0.05

Results of pair-wise comparison of V-A slope showed that the /ka/ monotic right was significantly different from /ka/ diotic and /taka/ dichotic. Also, /ta/ monotic left was significantly different from /ta/ diotic and both dichotic conditions. There was no significant difference found among any other stimulus conditions. The onset response elicited by both /ta/ and /ka/ stimuli in different stimulus conditions are shown in Figure 4.7 (A & B).

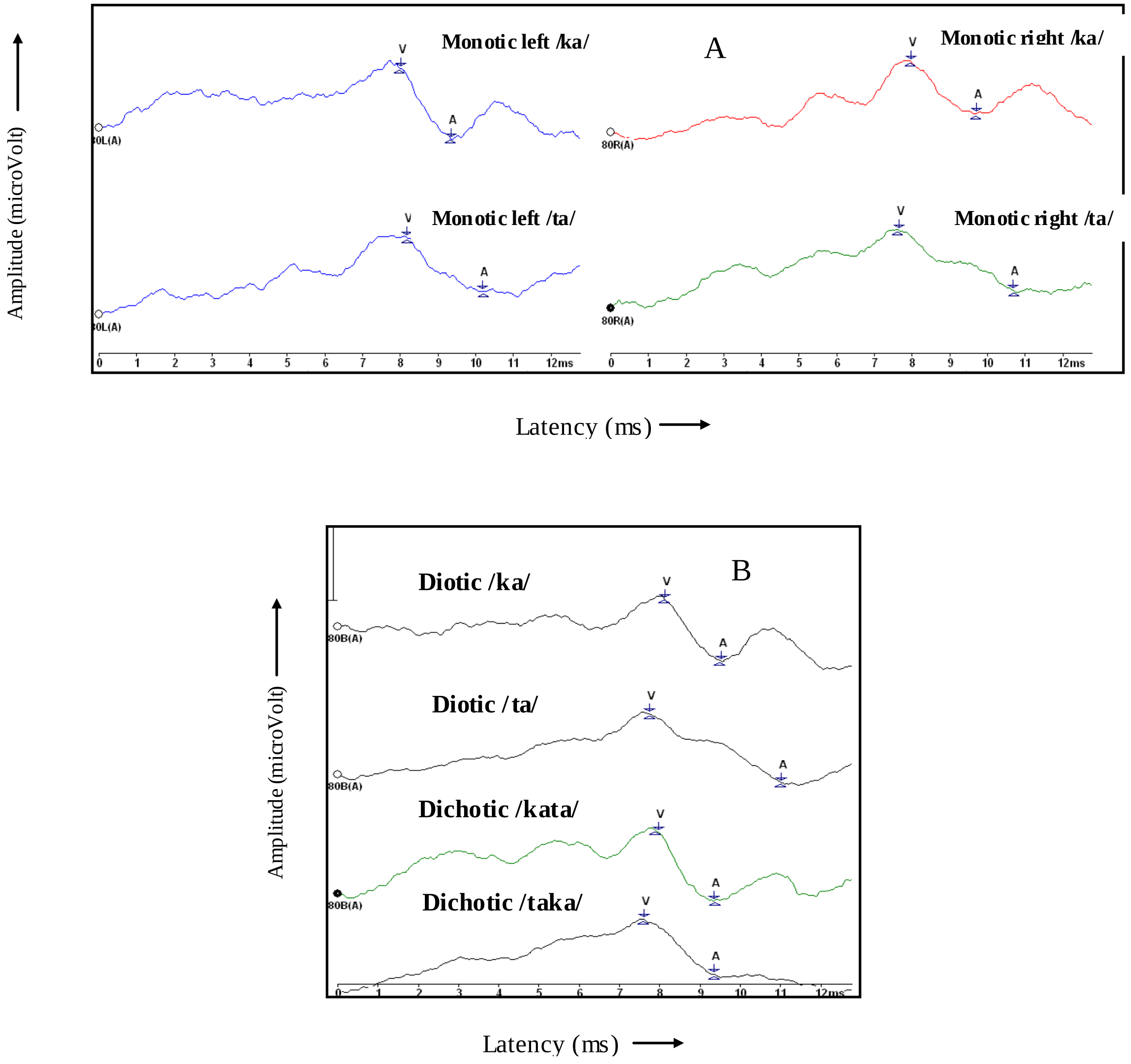

Fig 4.7: The onset responses elicited in different stimulus condition: monotic left /ka/, monotic left /ta/, monotic right /ka/, monotic right /ta/(A), diotic /ka/, diotic /ta/, dichotic /kata/, and dichotic /taka/(B).

4.2.5 Effect of Stimulus Condition on Steady State Responses

The steady state response was analyzed objectively using Fast Fourier transform (FFT). The FFT of steady state response was carried out using the MATLAB R 2009a platform. The peak amplitude at frequencies corresponding to fundamental frequency (F0), and higher harmonics (H2, H3 & H4) of the response was derived from FFT analysis. As the F0 and corresponding harmonics were slightly different in /ta/ and /ka/ stimuli, the dichotic conditions were separately compared for /ka/ and /ta/ stimuli. The mean and standard deviation of amplitude of F0, H2, H3 and H4 obtained from twenty participants are given in Table 4.9 and 4.11 respectively.

A. Analysis of the Harmonics corresponding to stimulus /ka/

Stimulus /ka/ had a F0 of 125Hz. Therefore the data reported in Table 4.9 gives the FFT output in the frequency range of 125Hz +/- 3 Hz and its corresponding three higher harmonics.

Table 4.9: *The mean and standard deviation (SD) of amplitude of fundamental frequency (F0), second harmonic (H2), third harmonic (H3), and fourth harmonic (H4) for the different conditions including presentation of /ka/ stimuli*

Conditions	Measures (µV)							
	F0 amplitude		H2 amplitude		H3 amplitude		H4 amplitude	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
/ka/ monotic right	0.06	0.04	0.03	0.01	0.02	0.01	0.02	0.01
/ka/ diotic	0.13	0.05	0.04	0.02	0.03	0.01	0.04	0.02
/kata/ dichotic	0.12	0.05	0.04	0.01	0.02	0.01	0.03	0.01
/taka/ dichotic	0.13	0.05	0.04	0.01	0.02	0.01	0.02	0.01

The mean data showed that the harmonics were of higher amplitude in diotic and dichotic conditions when compared to monotic conditions. In the higher harmonics diotic had higher amplitudes compared to dichotic and monotic conditions.

The statistical significance of observed mean differences were tested using Repeated measure ANOVA. Results showed a significant main effect of conditions on the mean amplitude of F0 [F (4, 76) =21.28, $p <0.01$], H2 [F (4, 76) =6.46, $p <0.01$], H3 [F (4, 76) =12.44, $p <0.01$], and H4 [F (4, 76) =17.05, $p <0.01$]. Consequent to the main effect, the pair wise differences were tested on Bonferroni test. The results of the test for amplitude of F0 and harmonics (H2, H3, H4) are represented in Table 4.10.

Table 4.10: *Pair-wise comparison of mean amplitude of F0, H2, H3, H4 across different conditions*

Conditions	/ka/ diotic				/kata/ dichotic				/taka/ dichotic			
	F0	H2	H3	H4	F0	H2	H3	H4	F0	H2	H3	H4
/ka/ monotic right	S	S	S	S	S	NS	NS	NS	S	NS	NS	NS
/ka/ diotic	-	-	-	-	NS	NS	S	S	NS	NS	S	S
/kata/ dichotic	-	-	-	-	-	-	-	-	NS	NS	NS	NS

Note: S= $p<0.05$; NS= $p>0.05$

The results in Table 4.10 can be summarized as follows.The /ka/ monotic condition had significantly low amplitude in all four harmonics compared to /ka/ diotic condition. The /ka/ monotic condition further had significantly low F0 amplitude compared to both the dichotic conditions. H3 and H4 amplitudes were significantly lower in both the dichotic conditions compared to diotic condition.

B. *Analysis of Harmonics Corresponding to Stimulus /ta/*

In contrast to stimulus /ka/, stimulus /ta/ had a F0 of 114Hz. Therefore the data reported in Table 4.11 shows the FFT output in the frequency range of 114Hz +/- 3 Hz and its corresponding three higher harmonics.

Table 4.11*: The mean and standard deviation (SD) of amplitude of fundamental frequency (F0), second harmonic (H2), third harmonic (H3), and fourth harmonic (H4) for the different stimulus conditions including presentation of /ta/ stimuli*

Conditions	Measures (µV)							
	F0 amplitude		H2 amplitude		H3 amplitude		H4 amplitude	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
/ta/monotic right	0.05	0.02	0.03	0.01	0.01	0.01	0.02	0.01
/ta/ diotic	0.13	0.06	0.06	0.02	0.02	0.01	0.03	0.01
/kata/ dichotic	0.116	0.04	0.03	0.01	0.01	0.01	0.02	0.001
/taka/ dichotic	0.12	0.05	0.03	0.02	0.01	0.01	0.02	0.01

The mean data showed trends similar to that in stimulus /ka/. That is, the harmonics were of higher amplitude in diotic and dichotic conditions when compared to monotic conditions. In the higher harmonics, diotic had higher amplitudes compared to dichotic and monotic conditions. The two dichotic conditions and the monotic conditions had same mean amplitudes in higher harmonics (H2, H3 & H4). To test if these mean differences were statistically significant, Repeated measure ANOVA was done. Result showed a significant main effect of condition on the mean amplitude of F0 [F (4, 76) =22.37, p <0.01], H2 [F (4, 76) =17.83, p <0.01], H3 [F (4, 76) =13.39, p <0.01], and H4 [F (4, 76) =23.5, p <0.01]. Consequent to the main effect, the pair-wise differences were tested on Bonferroni test. The result of the test for amplitude of F0 and harmonics H2, H3, H4 are represented in Table 4.12.

Table 4.12*: Pair wise comparison of mean amplitude of F0, H2, H3, H4 in different conditions*

Conditions	/ta/ diotic				/kata/ dichotic				/taka/ dichotic			
	F0	H2	H3	H4	F0	H2	H3	H4	F0	H2	H3	H4
/ta/ monotic right	S	S	S	S	S	NS	NS	NS	S	NS	NS	NS
/ta/ diotic	-	-	-	-	NS	S	S	S	NS	S	S	S
/kata/ dichotic	-	-	-	-	-	-	-	-	NS	NS	NS	NS

Note: S= p<0.05; NS= p>0.05

The results in Table 4.12 can be summarized as follows. The /ta/ monotic condition had significantly low amplitude in all four harmonics compared to /ta/ diotic condition. Further, the /ta/ monotic condition had significantly low F0 amplitude compared to both the dichotic conditions. H2, H3 and H4 amplitudes were significantly lower in both the dichotic conditions compared to that in diotic condition.

To further test the presence of phonetic and ear effects if any, in the dichotic conditions, the mean amplitudes in the /ka/ frequency range and /ta/ frequency range were compared separately for the /kata/ and /taka/ stimulus conditions. It was assumed that if the amplitudes, for example, in /ka/ frequency range was significantly higher than that of the /ta/ frequency range for the /kata/ condition, it would indicate dominance of /ka/ over /ta/ in the FFR region. On the contrary, if the /ta/ is dominant in /taka/ and /ka/ is dominant in /kata/, it would indicate right ear advantage.

In the present study, both for kata/ and /taka/ higher amplitudes were obtained in /ka/ frequency range compared to /ta/ frequency range. While in /kata/, higher mean amplitude was obtained for F0 and all its higher harmonics, in /taka/ dichotic condition, higher mean amplitude was obtained for F0, H2 and H3 only. To test whether these mean differences in amplitude were significant; a paired-samples t test was performed. Results showed that there was a significant difference in mean amplitude of H2 [t (-2.523, 19), p <0.05], H3 [t (-3.327, 19), p <0.05] and H4 [t (-2.657, 19), p <0.05] for /kata/ dichotic between the two frequency ranges. However, for /taka/ dichotic condition a significant difference for amplitude was found for F0 [t (-2.539, 19), p <0.05], H2 [t (-2.657, 19), p <0.05] as well as H3 [t (-2.477, 19) p <0.05].

Overall, the results of the present study can be summarized as follows:

- Both right ear advantage and phonetic effects were seen in DCV test.
- Brainstem response to /ta/ and /ka/ mimicked the acoustics of stimulus waveform.
- Responses obtained in monotic conditions between the ears were similar.
- Dichotic and diotic responses were temporally similar to monotic conditions. However amplitude was higher in dichotic and diotic conditions.
- Speech evoked brainstem responses showed evidence of asymmetry in terms of ear advantage and phonetic effects.
- Asymmetry was seen only in dichotic condition and not in the monotic condition.

Chapter 5

DISCUSSION

Dichotic listening task elicits an asymmetrical response between the two ears. Such asymmetries are seen in terms of ear advantage and phonetic effects. In the present study it was hypothesized that dichotic condition does not have any ear effect or phonetic effect on speech evoked brainstem responses. However, results obtained in the present study did not support the hypothesis. Differences were observed in both onset and steady state responses across, monotic, diotic and dichotic conditions. These differences were analysed to examine for the presence of asymmetries if any, in the brainstem processing of speech. In instances where asymmetries were present, further analysis was carried out to categorize the asymmetry in terms of ear advantage and phonetic. In the subsequent subsections, the reasons that could be attributed to the results obtained in the present study will be discussed.

Since the dichotic consonant vowel tests are one of the most common methods used in the behavioral study of central auditory processing mechanism and the cerebral organization of speech processing (Hugdahl, 2000; Katz, 1994), the participants underwent DCV testing. The scores obtained in Dichotic listening task for each participant were within normal limits (based on normative for adults by Prachi & Yathiraj (2000), and therefore ensured that binaural integration was normal in all the participants and qualified them to be participants for recording dichotic speech evoked auditory brainstem response on them.

All the participants selected had right dominance for their motor function (based on handedness, earedness, legedness, & eyedness). This would imply that they are likely to be left hemisphere would be dominant for speech processing. Further, other factors presentation level, stimulus lag, stimulus familiarity, age, attention, and phonetics of the stimulus which can influence the symmetric versus asymmetric function on a dichotic listening tasks were also controlled.

The behavioral studies on dichotic listening task provide limited usefulness in terms of giving a description of level of processing for such stimulus paradigm. It is not clear till date, as to whether the hemispheric asymmetry observed in dichotic speech perception tests and the cortical auditory evoked potentials is purely a cortical-level phenomenon or does such asymmetry exist even at the brainstem level. Brainstem responses to speech precisely represent temporal coding of the consonantal and vowel portion of the stimulus. The precise aspects of the speech signal are maintained and reflected in the neural coding (Song, Nicol & Kraus, 2011; Boston & Moller, 1985), and hence are good tools to be used to study the processing asymmetries at the subcortical level. Therefore speech evoked ABR was chosen as an objective tool in the present study to assess subcortical processing of complex acoustic features of speech in dichotic stimulation condition with two stimuli i.e. /ka/ and /ta/.

In the present study the precise nature of speech evoked brainstem response was ensured by comparing stimulus and response waveforms. While comparing the stimulus and response waveform for both the stimuli /ka/ and /ta/, it was found that response waveforms mimicked the periodicity the stimulus waveform. The large negative V- A peak approximately at 8ms in response waveform marked the stimulus onset. This was followed by phase locked negative peaks in steady state responses which were periodic in nature.

The onset response for /ta/ stimulus was found to be steeper when compared to /ka/ stimulus. This can be attributed to the differences in acoustic properties of the consonantal portions of the two stimuli, where typical alveolar stops have diffuse-rising spectrum while velar stops have a compact, mid frequency spectrum (Repp & Lin, 1988; Blumstein & Stevens, 1979; Hoffman, 1958). Even the duration of burst is different between velars and alveolars. Zue (1976) found duration to be more for velars. This is likely to be the case considering velars involve back of the tongue which is bulkier compared to the tip of the tongue which is used to produce alveolars. Given that, the alveolar (/ta/ in this study) has a rising spectra and shorter burst duration when compared to a velar stop, it would elicit a better synchronous firing of the nerves and therefore is represented as sharper wave V.

The steady state portion of stimulus /ta/ consisted of five vowel cycles and correspondingly five negative peaks were mimicked in the FFR region. Similarly /ka/ stimulus consisted of six vowel cycles in steady state portion and response obtained for the same stimuli accordingly had six negative peaks in FFR portion thus indicating that response waveform exactly mimicked the stimulus waveform. These negative peaks in steady state portions had occurred in approximately every 9 ms in the response waveforms of /ta/ stimuli and in 8ms in the response waveform of the /ka/ stimuli. This corresponded approximately to their fundamental frequencies i.e. 114Hz for /ta/ stimulus and 125Hz for /ka/ stimulus. Additionally, the spacing of the small, higher frequency fluctuations between periodic waves corresponds to Formant one (F1). Several studies on brainstem responses to speech syllable /da/ have reported such parallels in stimulus and response morphology (Johnson, Nicol & Kraus, 2005; Abrams, Nicol, Zecker & Kraus, 2006). With such good correspondence of the response with the stimulus, it was expected that these responses would accurately represent asymmetries, if any, in the dichotic stimulation at the level of brainstem.

The results of dichotic speech perception as assessed on DCV test and dichotic speech processing as on brainstem responses to dichotic stimulation are discussed in light of asymmetries, ear advantages and phonetic effects in perception and processing under following headings.

5.1 Findings in dichotic CV Test

5.2 Findings in brainstem responses to speech

5.1 Findings in Dichotic CV Test

Results of the behavioral dichotic CV test indicated asymmetry in the perception. Right ear scores were better than left ear scores indicating the presence of right ear advantage (REA). The phenomenon of REA in dichotic listening task has been unanimously accepted for the verbal stimuli (Hugdahl, 2000; Katz, 1994; Kimura, 1967). The verbal stimuli are predominantly processed in the left hemisphere. According to structural theory given by Kimura (1967), contralateral pathway connecting between right ear and the left hemisphere is advocated to be the dominant path and therefore the REA.

Right ear advantage has also been reported by Berlin et al. (1973) and Studdert-Kennedy et al. (1970), on western population. Prachi (2000), Rajgopal and Yathiraj (1996) and, Ganguly and Yathiraj, (1996) have reported similar results in Indian population. Rajgopal and Yathiraj (1996) studied dichotic listening performance of 50 normal hearing human adults for CV syllable pairs in 0ms lag condition and evidenced a significant high score in right ear when compared to scores for left ear. A study by Foundas, Corey, Hurley and Heilman (2006) on 51 adults for dichotic listening performance on CV syllable reported a significant REA of handedness with a stronger asymmetry in right-handers for the non-directed condition. Considering that all the individual shows right ear advantage, a similar ear advantage was expected in the brainstem responses if the asymmetry in the processing was to be observed.

A closer insight into the dichotic performance, specifically for /ta-ka/, /ka-ta/, /ga-da/ and /da-ga/ pairs, revealed influence of phonetic aspects of speech on dichotic perception. Findings showed that velars were predominantly perceived compared to alveolars irrespective to the ear to which they were presented. Such phonetic effects in dichotic listening is in agreement with the studies in the literature (Speaks et al., 1981; Berlin et al., 1976; Rajagopal & Yathiraj, 1996). In all these studies velars were found to be more dominating over bilabials and alveolar sounds in dichotic listening task. Several studies have suggested the role of spectral aspects of speech, reflecting the place of articulation (O’Brien, 1997; Shinn & Blumstein, 1983).

One of the possible reasons of better representation of velars over alveolars can be burst amplitude of velars. Speaks et al. (1981) measured peak intensity of initial burst frication of 6 steps /p, t, k, b, d, g/. It was seen that the velar /k, g/ has greatest peak intensity followed by alveolars and labials. The velar sounds also have been reported to have compact spectrum and therefore are easily recognizable when compared to alveolar speech sounds having diffused spectrum which require more processing to be perceived (O’Brien, 1997). These evidences support the dominance of velars over alveolar stimuli obtained in the present study.

5.2 Findings in Brainstem Responses to Speech

Correlation of brainstem responses evoked in different stimulation conditions showed a very high agreement in the temporal structure of the responses. That means the direction of amplitude variation remained similar irrespective of the stimulus condition. However, the differences were observed in the amplitude parameters. The diotic and dichotic conditions had higher amplitude responses compared to monotic conditions. This is because of the number of ears involved at a time. The diotic and dichotic conditions enjoy binaural advantage unlike the monotic condition. Binaural presentation of stimulus leads to an increased perception of loudness when compared to single ear presentation, a phenomenon known as binaural loudness summation (Reynolds & Stevens, 1960). In general, threshold-based estimates of binaural loudness summation yield increase in loudness perception of approximately 3 dB (Keys, 1947). In contrast, loudness perception for supra-threshold signals is higher than that observed with near-threshold signals, with typical values ranging from approximately 6 to 10 dB (Haggard & Hall, 1982). Therefore, it is logical to obtain higher amplitude in diotic condition compared to monotic condition.

Earlier studies (Hosford- Dunn, Mendelson & Salamy, 1981; Ainslie & Boston, 1980; Dobie & Norton, 1980) on auditory brainstem responses in normal hearing individuals are in agreement with the preset findings. They report that binaurally elicited brainstem response have higher amplitude when compared to monoaural stimulation, and attributed it to presence of binaural summation and binaural interaction component (neural interaction that occurs between the signal received in two ears as they progress through auditory system) leads to increase loudness perception (Durlach, Thompson & Colburn, 1981).

The brainstem responses in the diotic conditions were of higher amplitude compared to dichotic condition, in spite of both involving binaural stimulation. This difference suggests that it is not just the absolute intensity of the two stimuli in the two ears that counts for the enhancement of the brainstem responses. The spectral characteristic of the stimuli would influence in some way to determine the amplitude of the responses. From the differences between the diotic and dichotic conditions one can infer that if the two stimuli have the same spectral characteristics, it would facilitate brainstem responses more than the ones that differ in their spectral characteristics.

Dichotic responses showed evidence of asymmetry both in the onset as well as sustained portions. The asymmetry could be characterized as ear advantage and phonetic advantage. In most instances, REA and dominance of velars was found. Right ear advantage was apparent when diotic responses were correlated with dichotic conditions as higher correlation was seen with the diotic responses elicited for the stimulus presented to right ear in dichotic conditions. Phonetic effect of velar was evident while correlating monotic responses with dichotic response where irrespective of ear of presentation /ka/ monotic condition had a higher correlation. The results were same in onset and steady state responses.

These results were similar to the findings obtained in DCV test. The performance on DCV test had shown REA and dominance of velars in the same groups of participants. Similarities between a perceptual test and brainstem responses would mean that brainstem responses represent neurophysiological basis of dichotic listening at the brainstem level. Findings at the preliminary level show that even at the brainstem level before reaching the cortex, there exist preferential processing based on the ear of stimulation and phonetic characteristics of the stimulus.

In one instance, when the /kata/ dichotic was correlated with /ka/ monotic right and /ta/ monotic left responses in steady state responses, a higher correlation was obtained for /ta/ monotic left. This reveals left ear advantage and probably right hemisphere dominance in the steady state portions. This notion has been supported by findings of Day and Vigorito (1972). Day and Vigorito investigated ear advantage elicited by stops and vowels. They found that stops elicit a REA whereas vowels elicit a left ear advantage in dichotic listening conditions.

The asymmetries observed in brainstem responses are unique to dichotic paradigm and not observed in the monotic conditions. In the present study, the two monotic conditions were no different in their waveform, latency, amplitude and spectral information.

Overall, from the present results it can be concluded that brainstem responses represents underlying physiological mechanisms of dichotic speech processing at the brainstem level. However, one should consider it to be a preliminary investigation and conduct more research to standardize the stimulus paradigm and identify sensitive response parameters that are useful at the individual level.

Chapter 6

SUMMARY AND CONCLUSIONS

Dichotic listening tests has been a well established tool to study binaural integration and the hemispheric asymmetry of a perceptual schema. The phenomenon complementing specialization is evidenced by behavioral test like dichotic consonant vowel test (DCV), as well as in cortical evoked potential. However, there is limited information available in the literature about the existence of similar phenomena at subcortical level. Therefore, the present study was undertaken to investigate the brainstem response in dichotic paradigm. The present study was carried out to signify whether the asymmetries in processing speech stimuli starts right at brainstem level or is just confined to higher centers.

Twenty, right handed, normal hearing, human adults, in the age range of 18 to 30 years participated in the study. Their performance on behavioral dichotic consonant vowel test was assessed. Brainstem responses were elicited from the participants for /ka/ and /ta/ stimulus in eight different stimulus conditions, which included four monotic, two diotic and two dichotic conditions. The responses were recorded using Advance research module of Intelligent Hearing Systems.

The performance on dichotic CV test was analyzed in terms of single correct score-right (SCS-R), single correct score-left (SCS-L) and double correct scores (DCS). Speech evoked ABR was analyzed both subjectively and objectively. Analysis of data was done separately for onset and steady state portions wherever possible, for the parameters such as peak latency, amplitude of wave V-A, its slope and spectral amplitude. The responses elicited across different stimulus conditions were also correlated.

The result of DCV test revealed a higher mean single correct score for Right ear, indicating the presence of right ear advantage. The results also revealed presence of phonetic effect of velars over alveolar on further analysis.

In speech evoked brainstem response, a comparison of the stimulus and response waveform showed that, for both the stimuli /ta/ and /ka/ response waveforms mimicked the acoustic characteristic of the stimuli in the onset as well as steady state portions. Temporally, the response obtained across different conditions showed a high correlation, however diotic and dichotic conditions were found to have higher amplitude when compared to monotic responses. Results also showed that among the diotic and dichotic conditions, diotic response were of higher amplitude.

Dichotic responses showed evidence of asymmetry in onset as well as sustained portions. A higher representation of /ka/ monotic responses in both onset and steady state portions, in most of the conditions was indicative of phonetic dominance of velars over alveolars. Further, a higher correlation of responses of diotic conditions with dichotic corresponding to the stimuli presented to right ear in the dichotic condition was suggestive of presence of right ear advantage for dichotic processing.

Thus, to conclude, the auditory brainstem response elicited for dichotic speech reveal similar results to that obtained in behavioral DCV test. Both right ear advantage and phonetic effects were evident in the brainstem responses. Therefore one can use brainstem responses to dichotic stimulation as a neurophysiological correlates of dichotic speech perception. The study shows that the processing asymmetry starts right at brainstem level.

Implications of the study

The present study advances the theoretical knowledge on neurophysiological mechanism of dichotic speech perception, the role of brainstem in processing asymmetry and utility of brainstem responses in evaluating dichotic speech processing.

The paradigm needs to be validated for its utility at the individual level. If proved to be valid, it can be used to detect auditory processing deficits at the brainstem level.

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APPENDIX 1

Individual single correct scores and double correct scores obtained in dichotic CV test

Participants	Double Correct Score	Single correct score-Right	Single correct score-Left
1	15.0	20.0	18.0
2	20.0	23.0	21.0
3	28.0	29.0	29.0
4	15.0	20.0	19.0
5	16.0	20.0	18.0
6	20.0	21.0	21.0
7	15.0	28.0	18.0
8	19.0	28.0	21.0
9	15.0	20.0	18.0
10	17.0	26.0	19.0
11	21.0	27.0	23.0
12	17.0	26.0	19.0
13	17.0	23.0	20.0
14	28.0	30.0	28.0
15	19.0	28.0	21.0
16	20.0	25.0	18.0
17	15.0	20.0	18.0
18	27.0	29.0	28.0
19	15.0	21.0	21.0
20	25.0	27.0	26.0

Note: maximum score = 30