BINAURAL INTERACTION COMPONENT OF AUDITORY BRAINSTEM RESPONSES IN CHILDREN USING CLICK AND SPEECH STIMULI

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June 2011

CERTIFICATE

This is to certify that this dissertation entitled ***“Binaural interaction component of auditory brainstem responses in children using click and speech stimuli”*** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No. : 09AUD031. 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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CERTIFICATE

This is to certify that the dissertation entitled ***"Binaural interaction component of auditory brainstem responses in children using click and speech stimuli"*** 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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June, 2011

DECLARATION

This dissertation entitled ***"Binaural interaction component of auditory brainstem responses in children using click and speech stimuli"*** is the result of my own study under the guidance of Mr. Sujeet Kumar Sinha, Lecturer, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore, Registration No.09AUD031

June, 2011

Dedicated to

My Dear …

Pappa & Amma

Saju chetan, Manuja chechi,

Eshan vava

&

Sujeet sir

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Introduction

In the real-world listening situations, auditory information is processed by two ears, often in the presence of background noise (Durrant & Lovrinic, 1995). The processing of auditory information through ears is known as binaural processing. Binaural processing is evaluated clinically by behavioural assessment of skills such as, auditory localization and the masking level difference. There have been attempt made by the researchers to use the measurement of binaural processing through binaural interaction component of the auditory brainstem responses. The development of such a physiological measurement is essential to provide objective information in difficult to test population.

Auditory brainstem response (ABR) is a useful diagnostic tool that provides both neurological and audiological information. ABR can be used for the identification of neurological abnormalities in the eighth nerve, auditory pathways of the brainstem and the estimation of hearing sensitivity. Auditory brainstem responses is the measure of neural synchrony of the time locked, single unit activity in the auditory nerve and brainstem. ABR basically consist of five peaks occurring between the latencies of 1-6 msec.

The auditory brainstem responses have been used for studying binaural interaction component elctrophysiologically. The Binaural interaction component (BIC) is derived by subtracting the ABR obtained with binaural stimulation from the waveform obtained by adding the responses from the left and right monaural stimulation. This concept is expressed as: Binaural difference waveform = (L + R) – BI; where, L + R is the sum of the left and right evoked potentials obtained with monaural stimulation, and BI is the response acquired from binaural stimulation. The BIC is most apparent in the binaural difference waveform obtained in humans at 4.5 to 7.0 ms after the stimulus onset for click stimulus, which is coincident with waves IV to VI (Wrege & Starr, 1981).

Binaural interaction is reflected in electrophysiological activity of neurons activated by binaural stimulation central to the cochlear nucleus (Jiang & Tierney, 1996). Binaural interaction is known to occur at three levels of the brainstem: the superior olivary complex, the nuclei of lateral lemniscus, and the inferior colliculus (Moore, 1991). Binaural interaction components (BIC) manifest binaural interaction (Debruyne, 1984; Dobie & Wilson, 1985; Hendler et al., 1990) and are valid and proven responses which reflect ongoing binaural processing (Fowler & Swanson, 1988; Jiang &Tierney, 1996).

Researchers have shown that summation of monaural ABRs do not predict the ABRs obtained with binaural stimulation (Dobie & Norton, 1980; Gardi & Berlin, 1981; Wrege & Starr, 1981; Brantberg, Fransson, Hansson, & Rosenhall, 1999). Binaural interaction in auditory evoked potential is observed when the sum of the monaural potentials responses is not equal to the binaural response (Wernick & Starr, 1968; Kelly-Ballweber & Dobie, 1984).

Recently the auditory brainstem responses have also been recorded using the speech stimulus. The speech evoked auditory brainstem response is considered to provide a direct electrophysiological measure of sensory processing in the auditory brainstem (Galbraith et al., 2000). Speech evoked auditory brainstem responses consist of a transient and a sustained portion that mimics the acoustic signal (Galbraith et al., 1995). The sustained portion is also known as frequency following response (FFR). Speech-evoked ABRs represent temporal features of speech stimuli with great fidelity and delays in the response on the order of fractions of milliseconds have been linked to abnormal perception and linguistic abilities. This makes it possible to derive from it considerable theoretical and clinically applicable information relevant to auditory processing of complex stimuli (Kraus & Nicol, 2005).

Speech ABR has been described to be a potential useful diagnostic tool. Several studies have linked stimuli pattern to speech ABR component characteristic and investigated the magnitude and one-to-one correspondence to spectral peaks (Wible, Nicol & Kraus, 2004; Russo, Nicol, Mussachia & Kraus, 2004). In addition several studies have pointed out the potential usefulness of speech ABR in the diagnosis of speech processing impairment (Russo et al., 2004; Johnson, Nicol & Kraus, 2005). In addition language experiences were also shown to have a significant effect on FFR synchronization (Krishnan et al., 2004, 2005, Chandrasekaran & Kraus, 2010). Furthermore it has also been reported that the musicians have enhanced FFR synchronization to CV syllable /da/ and to music stimuli than non-musicians (Mussacchia, Sams, Skoe & Kraus, 2007).

NEED OF THE STUDY:

1) Earlier the ABR has been recorded using simple stimuli such as a click or tone burst. Although clicks and tones have been instrumental in defining these basic response patterns, they are poor proximations of the behaviorally relevant sounds that we encounter in daily life. Therefore there is a need to study the encoding of speech sounds at the brainstem level.
2) There are several behavioural tests to evaluate the binaural processing in children. But the major problem with the behavioural test is it requires a behavioral co-operation from the children. Speech ABR is an electrophysiological test it doesn’t require any co- operation from the children and gives reliable information about brainstem encoding of speech sounds. It has been found as a useful tool in the diagnosis of learning disability and poor readers (Russo et al., 2004; Abrams, Nicol, Zeker & Kraus, 2009).
3) Deficits in binaural processing can lead to various degrees of auditory processing disorders. Assessing binaural interaction can serve as a diagnostic

tool especially in children with auditory processing disorders, as binaural interaction tasks are frequently affected in those children (Delb, Struss, Hohenberg & Plinkert, 2003). Hence there is a need to establish the binaural interaction component in normal hearing children, as to compare them with children having auditory processing problem.

4) Binaural interaction component of ABR has been studied using non speech stimulus like click stimuli, however, there is a dearth of information regarding the binaural interaction component of ABR using speech stimuli. So there is a need to understand the binaural interaction component using speech stimuli.
5) There is a different development pattern for auditory brainstem responses evoked using click and speech stimulus (Johnson, Nicole & Kraus, 2008). There is a need to study whether such difference occurs for binaural interaction component also.
6) Binaural interaction component for non-speech stimuli (Click) varies with maturation. Overall, it appears that binaural interaction task such as masking level difference, continue to improve from infancy up to 6 years of age. There is dearth of information regarding the maturational changes for binaural interaction component elicited by speech stimulus (Mc Pherson, Tures & Star, 1989).

OBJECTIVES OF THE STUDY

1) To determine the maturational changes of binaural interaction component using speech stimuli for different age groups.
2) To determine the maturational changes in binaural interaction component for click stimuli for different age groups.

Chapter- 2

Review of literature

A major advantage in having two ears is that differences in the sounds arriving at the two sides of the head can be detected. By comparing the information from the two ears, the brain can make judgments about sound sources such as their location in space. Anatomical studies have shown that the brainstem is one region of the nervous system where inputs from the two ears converge.

Wrege and Starr (1981) found that summation of monaural ABRs do not predict the ABRs obtained with binaural stimulation. The BIC is derived by subtracting the ABR obtained with binaural stimulation from the waveform obtained by adding the responses from the left and right monaural stimulation. This concept is expressed as: Binaural difference waveform = (L + R) - BI where, L + R is the sum of the left and right evoked potentials obtained with monaural stimulation, and BI is the response acquired from binaural stimulation. The BIC is most apparent in the binaural difference waveform obtained in humans at 4.5 to 7.0 ms after the stimulus onset, which is coincident with waves IV to VI (Wrege & Starr, 1981).

Binaural interaction is observed when the auditory evoked potentials (AEP) to binaural stimulation is not equal to the sum of the monaural AEPs (Wernick & Starr, 1968). Binaural interaction is observed in human brainstem auditory evoked potentials between 5 and 8 ms and accounts for approximately 14-23% of the expected amplitude of the binaural evoked potential (McPherson, Tures and Starr, 1989)

Factors affecting BIC

Stimulus rate

Shipley, Strecker, and Buchwald (1984) demonstrated that an increase in stimulus rate from 10 to 100 clicks per second reduced the BIC markedly in cats. Fullerton, Levine, Hosford-Dunn, and Kiang (1981) demonstrated a decrease in BIC amplitude as a function of increased stimulus rate in humans.

Slower stimulus rate revealed more components of the waveform, as well as an improvement in the morphology of the BIC compared to a faster stimulus rate. Hurley (2004) reported a study on 47 adults in the age range of 20 and 41 years (mean = 25) with hearing in the normal range revealed a great variability in BIC morphology between subjects and significant increase in absolute latency and decrease in absolute amplitude of both negative and positive peaks as click rate increased from 7.7per sec to 57.7 per sec.

Intensity and interaural time difference

Wrege and Starr (1981) showed that the amplitude of the BIC attenuated when click intensity was reduced from 70 to 60 dB SL. The attenuation of BIC was greater than the attenuation of the sum of the monaurally evoked potentials. In addition, the latency of the BIC increased as the interaural time difference increased from 0 to 500 msecs. The latency shift and the amount of interaural delay were proportionally related. Thus, BIC is affected by stimulus intensity and interaural time difference and is clearly affected by binaural neural processing.

Dobie and Berlin (1979) investigated stimulus intensity, interaural intensity and interaural time difference in the BIC of guinea pig. They found a BIC in the region of 3.5 to 4 msec region which is consistent with the wave IV. The BIC was still present with a 20 dB interaural intensity difference. They also varied the interaural time differences from +/-3000 μsec and reported significant changes on the amplitude and latency of the BIC when the interaural time difference was greater than 1000 μsec.

Furst, Levine and McGaffigan (1985) investigated the change in perception and the BIC for dichotic clicks with varying ITDs. They found that the first major peak of the BIC was present when the image was fused, this correlated with the perceptual task of lateralization. As the ITD increased, the first wave of the BIC, (β) was degraded.

Krishnan and McDaniel (1998) studied effect of interaural intensity difference in binaural interaction in human FFR. One of the aims of the study was to determine how the FFR-BIC is altered with changes in interaural intensity difference given that frequencies below about 1500 Hz do not carry appreciable IID cues. For this study they selected ten adult subject ranging 18-28 years. Results revealed that amplitude of summed monaural FFR as well as FFR-BIC decreases as the interaural intensity difference increases.

Frequency and rate

Parthasarathy and Moushegian (1993) studied binaural interaction component (BIC) of the auditory brainstem response (ABR) and BIC of the frequency-following response (FFR) to tonal stimuli in normal-hearing adults. All the subjects were in the age range of 20-30 years. The ABR and BIC latencies from all subjects were consistently shorter to the click-like sound than to the 2.0 kHz tone burst. As rate of stimulus presentation increases latency became longer and amplitude was diminished for ABR and BIC waveforms. The consequences of rate changes were independent of sound level. The FFR and BIC latencies to low-frequency tone bursts (0.5 and 1 .0 kHz) were minimally affected by rate, but their amplitudes were modified.

Ito, Hoke, Pantev and Lutkenhoner (1988) studied the frequency dependence of the binaural interaction in human binaural auditory evoked potentials (BAEP). Ten normal hearing subjects were selected for the investigation. Rarefaction click stimuli and tone burst with carrier frequencies of 1000, 2000, 4000, and 6000 Hz and a half value time of 0.5 msec was used as the stimuli. Results revealed that the major binaural interaction occurred in the latency range of brainstem auditory evoked potential waves V and VI, and there was no evidence of interaction in the earlier portion of the BAEP. Both latency and amplitude of the binaural difference potential components were evaluated. The latency of the binaural difference potential component - except of the latest one - showed an almost linear dependence both on stimulus intensity and stimulus frequency. The amplitude grew larger with decreasing frequency, and the visual detection threshold elevated as the stimulus frequency increased. Click stimuli, however, produced the largest amplitudes with lowest visual detection threshold.

Clinical application of BIC

BIC in infants and children

Mcpherson et al., (1989) compared binaural interaction component in normal hearing adults and normal term infants. They studied 18 normal hearing adults and 10 normal term infants. Binaural interactions at the times of ABR waves V and VI were comparable in term infants and adults. The latencies of the components of the ABR to monaural stimulation were significantly longer in term infants than in adults using rarefaction and condensation stimuli. Mean baseline-to-peak amplitude of waves III and V was significantly larger for the adults than for term infants. The absolute amplitude of binaural interaction component differed between term infants and adults due to amplitude differences of the monaural ABRs at this latency. Measurement of binaural interaction during maturation may be a useful tool in assessing neurologically affected infants.

Dunn et al., (1981) recorded short-latency evoked potentials to monaural and binaural from scalp electrodes on healthy full-term neonates and on normally hearing adults. Binaural interaction (BI) was measured by summing the average monaural responses obtained from each ear (L+R) and subtracting the binaural response (B) from the monaural sum (BI=L+R-B). Results revealed that consistent BI was apparent following stimulation with moderate level clicks in all cooperative infants. In adults, binaural interaction occurred during waves IV, V and VI. There were systematic amplitude differences between the summed monaural and binaural waveforms. Peak latencies of the waves were not significantly affected. However, peak latencies were longer in neonates than in adults, which reflect maturational changes in the response. Similarly, peak latencies in the binaural interaction waveforms were also prolonged for the neonates. These results indicated that: (1) Binaural interaction is present at or soon after birth, (2) the gross response properties of binaural interaction are similar in infants and adults, (3) Binaural interaction occurs during specific waves in the response and it is independent of age, and (4) the assessment of binaural interaction may prove useful in estimating the functional integrity of brain stem structures in infants.

Sheykholeslami, Mohammad, Sebastein and Kaga (2003) recorded bilateral bone-conducted auditory brainstem responses (BC-ABRs) in children with atresia of the external auditory canal bilaterally (AECB) and compared the response characteristics to normal hearing adults. They reported that in adults, BC-BIC occurred in the latency region corresponding to waves IV-VI, whereas for children with atresia of the external auditory canal bilaterally corresponding peak latencies occurred earlier. Same as normal-hearing adults, BC-ABR IV-V complex peak amplitudes for sum of the BC-monaural right and BC-monaural left ears were different from binaural response amplitude. Individual peak latencies were similar in children with AECB when compared to normal-hearing adults except for shorter latencies for BIC. These results indicate that: (1) BC-BIC is present in children with AECB as well as normal-hearing adults, (2) the gross response properties of BIC are similar in children with AECB and normal-hearing adults, (3) fitting of a bilateral BC hearing aid might be a feasible method to optimize binaural hearing and sound lateralization.

Jiang and Tierney (1996) studied binaural interaction (BI) in brainstem auditory evoked response (BAER) in normal term neonates. The BI components coincided consistently with the latency range of BAER wave IV through wave VII. Most BI components seen in the adults could be identified in the neonates. Wave latencies and interpeak intervals were longer and amplitudes were smaller in neonates than in adults, which was associated with the differences between the neonates and adults in the BAER components. Changes in the BI components with stimulus intensity and rate in neonates were fundamentally similar to but more significant compared with those in adults. These findings suggest that neural connections in human auditory brainstem subserving the BI are established at birth but, particularly at higher levels of the brainstem, are immature.

BIC in children with (Central) Auditory Processing Disorder subjects

Gopal and Pierel (1999) studied BIC in (C)APD children between the ages of 7 and 13 years. It consisted of 9 children in experimental group and 9 children in control group who were diagnosed as (C)APD. They measured latency from onset of the stimulus to occurrence of peak V for right, left, binaural and summed ABRs, and for the BIC occurring at a latency corresponding to peak V and also Amplitude is measured from peak-to-trough for right, left, binaural and summed ABRs. Results indicated a significant reduction in the amplitude of the BIC occurring in the latency domain of ABR peak V, in the (C) APD group.

Delb, Struss, Hohenberg and Plinkert (2003) examined and to what extend BIC are capable of differentiating between normal children and children at risk of (C)APD. BIC were performed on 17 children at risk for CAPD and in age group of 25 normal children. Presence or absence of clearly demonstrable BIC waveform is an indication of whether (C)APD is present or not. Sensitivity and specificity of 76% was reported for the study. Thus BIC has diagnostic value in (C) APD.

BIC in specific Language Impairment

Clarke and Adams (2007) studied BIC in children with specific language impairment (SLI). Binaural interaction components (BICs) in the brainstem were compared in 19 children with SLI in the age range of 7year 4months–11year 10months and 31 comparison children with typical language development in the age range of 7year 1month–11year 4month. Results revealed that children with SLI had significantly smaller BIC amplitude than the comparison group. However, no clear relationship was found between BIC measures and severity of language impairment. The authors concluded that, for some children, SLI may be associated with reduced binaural interaction which may hinder the detection or localization of speech sounds from noisy contexts during critical periods of language acquisition.

BIC in cochlear implant users

Pelizzone, Kasper and Montandon (1990) studied BIC in cochlear implant subjects. Binaural interaction was demonstrated in electrically evoked brainstem responses (EBRs) of a bilaterally implanted patient. A clear binaural difference waveform (ED), consisting of a negative peak near 3.6 ms followed by a positive peak near 4.4 ms, was found by subtracting the recordings with diotic stimulation from the sum of the recordings with monotic stimulation. These results are consistent with those reported for normal subjects and suggest that neural processing in this patient might resemble those ordinarily used in binaural hearing. The authors suggested that the BIC in cochlear implant result from activity in auditory brainstem neurons and suggest a method for aligning the positions of the intracochlear electrodes.

Purdey et al., (2004) studied BIC in cochlear implant subjects. Data are presented for young normal hearing adults for the masking-level difference (MLD) and BIC paradigms. For normals, frequency was fixed at 1000 Hz in one ear and varied in the other ear (250–4000 Hz). N1-P2 BIC showed a tuning effect with the largest BIC when frequency was matched. BIC responses for an experienced implant user who has worn the cochlear implant bilaterally for several years showed a tuning effect similar to normal listeners, with largest BIC for pitch-matched electrodes. Results from normal listeners showed that cortical auditory-evoked responses obtained using these methods can be used to measure binaural processing.

Speech evoked Binaural Interaction Component

D’Costa, Raj, Kumar, Kumar and Bhat (2010) studied the binaural interaction component at the brainstem level using speech stimuli. 10 normal hearing participants with 17 to 40 years were included in the study. The binaural interaction components were observed at 3 places in speech evoked auditory brainstem response in 10 participants. These were named as BIC_1, BIC_2 and BIC_3. Prevalence of BIC_1 was 100%, BIC_2 and BIC_3 were 70%. The latency obtained for BIC_1 was approximately 14 ms, while BIC_2 was obtained around 28 ms and BIC_3 was obtained approximately round 50 ms. BIC_3 had maximum amplitude (0.42µv) and BIC_1 had lowest amplitude (0.22 µv).

Deepthi (2008) studied the click evoked BIC and speech evoked BIC among children who are experiencing academic problems in school. Subjects were divided into two groups 13 poor performers and 20 good performers based on the scores obtained in Reading Readiness Test in Kannada. Results revealed that within subjects BIC for good performers as well as for poor performers the mean latency difference between BIC for click and speech stimuli are statistically significant. Whereas, mean amplitude difference between BIC for click and speech stimulus were not statistically significant. Across the groups the mean amplitude and latency obtained for click stimuli were not significantly different but mean amplitude and latency obtained for speech stimuli were lower in poor performers than compared to good performers.

Speech evoked ABR

Russo, Nicole, Mussachia, and Kraus (2004) established normative values for speech evoked brainstem response. The stimulus waveform includes both transient peaks as well as sustained elements. The response to the onset of the speech stimulus is seen as the onset response as V peak (positive peak) followed by an immediate negative trough labeled as ‘A’. Also wave I and III are also visible. Following onset response is peak ‘C’ which corresponds to the onset of vowel portion or the beginning of transition from consonant to vowel. Peak D, E and F corresponds to the three glottal pulses in the stimuli and the interpeak latency (10 msec) of D, E and F corresponds to the F0 of the stimulus i.e., 100 Hz. The neural conduction delay is approximately 7 msec between stimulus and response. In stimulus the F0 is approximately at 15 msec, 24 msec and 33 msec. In the response it is seen as D, E and F at approximately 22 msec, 31 msec and 40 msec. The offset response labeled as O is seen approximately at 51 msec. The mean amplitude for the responses V, A, C, D, E and F were 0.31, -0.65, -0.36, -0.33, -0.39, -0.44 and -0.19 respectively.

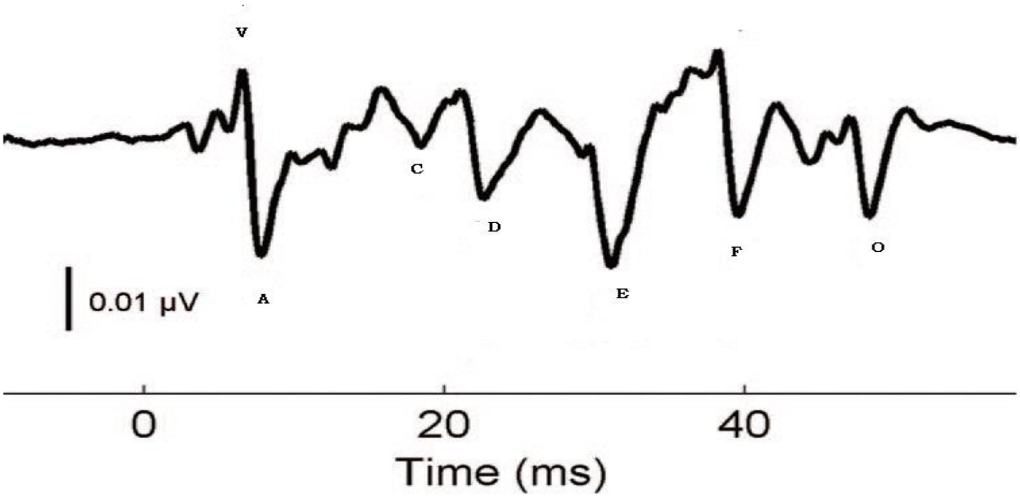

Figure 2.1 Pictorial representation of transient and sustained features in response to /da/.

The ABR has emerged as an experimental tool to assess the integrity of brainstem processing of speech and other complex stimuli in normal and impaired populations (Kraus & Nicol, 2005). Speech-evoked ABRs represent temporal features of speech stimuli with great fidelity and delays in the response on the order of fractions of milliseconds have been linked to abnormal perception and linguistic abilities.

Speech evoked ABR in learning disability

Russo et al. (2004) reported that brainstem responses were robust in quiet but background noise disrupted the transient responses whereas the sustained response was resistant to the deleterious effects of noise. Speech-evoked auditory brainstem responses (speech- ABR) provide a reliable marker of learning disability in a substantial subgroup of individuals with language based learning problems (LDs). 40% of LDs have abnormal speech-ABRs and that these individuals are also likely to exhibit abnormal cortical processing.

King, Warrier, Hayes and Kraus (2002) compared speech-evoked auditory brainstem responses (ABRs) in normal children and children diagnosed with a learning impairment to determine if there are neurophysiologic timing differences between these two populations. Measures of speech sound perception and neurophysiologic measures from the cortex were used to interpret differences in ABRs seen in the learning-impaired subjects. Subjects were 8–12 years old and included 33 normal children (NL) and 54 children diagnosed with learning impairment (LP). Results revealed that no latency differences between the NL and LP populations were seen in responses to the click stimuli, the syllable /da/ did elicit latency differences between these two groups. Deficits in cortical processing of signals in noise were seen for those LP subjects with delayed brainstem responses to the /da/, but not for LPs with normal brainstem measures.

Studies which compared normal hearing children and the children who diagnosed with learning disability has shown that children with learning disability present abnormalities of both the onset response and the magnitude of the FFR. King et al., (2002) demonstrated that wave A of the onset response was at least 1 S.D delayed in 20 of the 54 listeners with learning disability they studied, and that these listeners also had delayed waves C and F. Wible, Nicol and Kraus (2004) further studied the differences in brainstem encoding of speech between normal learning and children with learning disability. This study investigated how the human auditory brainstem represents constituent elements of speech sounds differently in children with language-based learning problems compared to normal children especially under stress of rapid stimulation. They selected 11 children who have language problem and 9 normal children. They concluded that children with learning disability had markedly shallower slopes of the transition between onset waves V and A, suggesting a more sluggish response in these children. They also showed that the amplitude of the FFR was significantly reduced among learning disability children in the frequency region corresponding to the first formant (F1) of the /da/ stimulus used. These data suggested that poor representation of crucial components of speech sounds could contribute to difficulties with higher-level language processes.

Speech evoked ABR in Autism Spectrum Disorder (ASD)

Russo, Zecker, Trommer, Chen and Kraus (2009) evaluated Speech-evoked responses (100–300 ms) in quiet and background noise in typically-developing (TD) children and children with ASD. ASD responses showed delayed timing (both conditions) and reduced amplitudes (quiet) compared to TD responses. As expected, TD responses in noise were delayed and reduced compared to quiet responses. Children with ASD exhibited deficits in both the neural synchrony (timing) and phase locking (frequency encoding) of speech sounds, despite normal click-evoked brainstem responses. They also exhibited reduced magnitude and fidelity of speech-evoked responses and inordinate degradation of responses by background noise in comparison to typically developing controls. Neural synchrony in noise was significantly related to measures of core and receptive language ability. These data support the idea that abnormalities in the brainstem processing of speech contribute to the language impairment in ASD. Because it is both passively-elicited and malleable, the speech-evoked brainstem response may serve as a clinical tool to assess auditory processing as well as the effects of auditory training in the ASD population.

Speech evoked ABR in hearing loss population

Khaladkar, Kartik and Vanaja (2005) investigated the perceptual deficits in a population of sensorineural hearing loss (SNHL) patients. Auditory brainstem responses (ABRs) were obtained on 20 ears with mild to moderate SNHL for this preliminary study. Two stimuli were used to evoke the ABR; a standard acoustic click and the burst portion of the syllable |t|. The results of the study indicated that while click evoked ABRs exhibited latency values within normal limits, speech burst evoked ABRs showed more deviant results i.e. delayed latency of wave V suggesting that using speech sounds to elicit the ABR offers an opportunity to better isolate normal speech processing from abnormal speech processing, which might be useful for patients with possible auditory processing disorders.

Plyler and Krishnan (2001) investigated FFR to determine (1) if FFR can encode time varying second formant transition in synthetic stop consonant stimuli in normal hearing and hearing impaired listeners (2) if hearing impairment causes degradation of this neural representation and (3) if the degraded representation is correlated with reduced consonant identification in hearing impaired listeners. FFR were obtained from normal hearing and hearing impaired listeners in response to 15 step ba-da-ga continuum generated by varying the onset frequency of second formant from 900-2300 Hz. Their results showed that FFR did encode the second formant transition in normal hearing listeners and in hearing impaired listeners, it was severely degraded. This may be due to reduction in the identification performance.

Akhoun et al., (2008) included adult subjects with unilateral hearing loss in a study of the speech-evoked ABR using the CV stimulus /ba/. Speech-evoked ABRs were recorded separately from the better-hearing ear and the ear with hearing loss of 6 subjects. The ear with hearing loss (termed as the “non-functional auditory pathway”) was stimulated to confirm that the speech-evoked ABR was a true auditory response rather than an artifact-generated response. The root-mean square (RMS) value of responses from the better-hearing ear of unilateral hearing loss participants approximated responses from adults with normal hearing in both ears. Individual response components and timing were not examined, and no analyses were conducted to correlate the stimulus with the response.

Speech evoked ABR in poor readers

Children with reading impairments have deficits in phonological awareness, phonemic categorization, speech-in-noise perception, and psychophysical tasks such as frequency and temporal discrimination. Many of these children also exhibit abnormal encoding of speech stimuli in the auditory brainstem, even though responses to click stimuli are normal. Hornickel, Skoe, Nicol, Zeker and Kraus (2009) investigated whether sub-cortical differentiation of stop consonants was related to reading ability and speech-in-noise performance. They considered group of children with a wide range of reading ability, the sub cortical differentiation of 3 speech stimuli ([ba], [da], [ga]) was found to be correlated with phonological awareness, reading, and speech-in-noise perception. Good performers exhibiting greater differences among responses to the differentiation of 3 syllables. That is when the subjects were categorized based on phonological awareness and speech-in-noise performance; the good phonological awareness group had higher stop consonant differentiation score than the poor phonological awareness group. These results are consistent with the view that the neural processes underlying phonological awareness and speech-in-noise perception depend on reciprocal interactions between cognitive and perceptual processes.

Poor readers have impaired representation of the speech envelope, the acoustical cue that provides syllable pattern information in speech. Abrams, Nicol, Zeker and Kraus (2009) measured cortical-evoked potentials in response to sentence stimuli in children with the age range of 9-15 years. They found that good readers indicated consistent right-hemisphere dominance in auditory cortex for all measures of speech envelope representation, including the precision, timing, and magnitude of cortical responses. Poor readers showed abnormal patterns of cerebral asymmetry for all measures of speech envelope representation. This study supported a relationship between acoustic-level processing and higher-level language abilities, and are the first to link reading ability with cortical processing of low-frequency acoustic features in the speech signal. These results also supported the hypothesis that asymmetric routing between cerebral hemispheres represents an important mechanism for temporal encoding in the human auditory system.

Speech evoked ABR in older adults

Werff, Kathy, Burns and Kristen (2011) evaluated whether neural encoding of speech features at the brain stem level is altered in the aging auditory system. In addition, the effect of minimal peripheral hearing loss on the auditory brain stem response (ABR) evoked by speech stimuli and interactions with aging were examined. They recorded Speech-evoked ABRs using a synthetic 40-msec /da/ stimulus from both ears of participants in two groups. 19 normal-hearing younger adults and 18 normal-hearing older adults. Latencies and amplitude for Speech evoked-ABR peaks representing neural responses to the onset and offset of the speech syllable as well as a sustained frequency following response to the vowel content were analyzed. Results determined that older adults had significantly smaller onset and offset responses for the S-ABR, with significantly delayed offset latencies in response to this synthetic consonant–vowel syllable. Many of the S-ABR variables were found to significantly correlate with high-frequency audiometric thresholds, and few of the group differences remained significant when this was taken into account. The remaining significant S-ABR effects were decreased amplitude at the onset and significantly delayed offset responses in the older group. These effects were different from those of simply decreasing the overall stimulus level, which caused significant shifts in latency across the entire S-ABR. There were significant delays in the timing of the offset portion of the S-ABR in older listeners compared with their younger counterparts, even after accounting for the differences in peripheral hearing threshold between groups. There were also significant reductions in amplitude of the S-ABR at the onset. These results are consistent with a reduction in neural synchrony in older adults to transient components of both speech and non-speech sounds.

Training related improvement in speech evoked ABR

Auditory training can alter the preconscious neural encoding of complex sounds by improving neural synchrony in the auditory brainstem. Russo, Nicol, Hayes, Zecker and Kraus (2005) investigated whether auditory training targeted to remediate perceptually-based learning problems would change the neural brainstem encoding of the acoustic sound structure of speech in such children with learning problems. In this study auditory perceptual training was given for nine subjects who were clinically diagnosed with a language-based learning problem (e.g., dyslexia). Ten control subjects, who did not participate in any remediation program, underwent the same battery of tests as equivalent to the trained subjects. In the beginning and within three months after completing the training program, brainstem responses to the syllable /da/ were recorded in quiet and background noise in both normal as well as children with learning problem. Transient and sustained (frequency-following response) components of the brainstem response were evaluated. They concluded that the primary pathway afferent volley – neural events occurring earlier than 11 ms after stimulus onset – did not demonstrate plasticity. However, in the trained children quiet-to-noise inter-response correlations of the sustained response (11–50 ms) increased significantly. This reflects improved stimulus encoding precision, whereas control subjects did not exhibit this change.

To, summarise the review of literature; there are a lot of studies which has reported binaural interaction component using the non speech stimulus such as click. The binaural interaction component using click stimulus has been found useful in the diagnosis of the clinical population especially in children with CAPD and SLI. Recently speech evoked ABR has been reported to be superior in the diagnosis of clinical population such as learning disability. There are only a few studies which have reported a BIC using the speech stimulus. BIC component of the ABR using speech stimulus may be more useful in the diagnosis of clinical population.

Chapter- 3

METHOD

The study was carried out with an aim of studying the maturational changes of binaural interaction component in children in the age range of 6-12 years using speech stimuli. In addition, the study also aims to compare the maturational changes in binaural interaction component for speech and non speech stimuli.

Participants

A total of 60 children with normal hearing in the age range of 6 to 12 years participated in the study. They were basically categorized into 6 groups (10 subjects per age group) as follows.

Group I: 6 to 6.11 years.

Group II: 7 to 7.11 years.

Group III: 8 to 8.11 years.

Group IV: 9 to 9.11 years.

Group V: 10 to 10.11 years.

Group VI: 11 to 11.11 years.

The following table provides the demographic information about the 60 children's who participated in the study.

Table 3.1.

Mean age of the children participated in the study

			Age (in years)
		No of children	**Mean**
Group I	Males	3	6.20
	Females	7	6.50
	Total	10	6.35
Group II	Males	4	7.90
	Female	6	7.30
	Total	10	7.60
Group III	Males	5	8.20
	Females	5	8.40
	Total	10	8.30
Group IV	Males	2	9.60
	Females	8	9.90
	Total	10	9.75
Group V	Males	4	10.10
	Females	6	10.60
	Total	10	10.35
Group VI	Males	5	11.70
	Females	5	11.20
	Total	10	11.45

Participant selection criteria

All the subjects who participated in the study were selected based on the following criteria:

- Their air conduction thresholds were less than or equal to 15 dB HL in the octave frequency range of 250 Hz to 8000 Hz and bone conduction thresholds less than or equal to 15 dB HL in the octave frequency range of 250 Hz to 4000 Hz.
- All the participants had ‘A’ type tympanogram and presence of acoustic reflexes.
- None of them had any history of otological symptoms (ear ache, ear discharge, and tinnitus or hearing loss)
- None of the children had any neurological problems or any other general weakness.
- They had no history of poor academic performance as reported by the parents and/or teachers.
- All the children had to pass SCAP (Screening Checklist for Auditory Processing developed by Yathiraj & Mascarenhas, 2004).
- All of them had normal click ABR. i.e. identifiable auditory brainstem response peaks (wave I, III & V) within normal latency.

Instrumentation

Following equipments were used for the study:

1) Pure Tone Audiometer

A two channel OB922 audiometer with TDH-39 head phone coupled to impedance matched TDH 39 earphones with MX-41/ AR ear cushions and a bone vibrator (Radio ear B-71) was used. It was used to obtain pure tone threshold at different frequencies for both air conduction and bone conduction.

2) Immittance meter

A calibrated automatic Immittance meter with a visual display (Grason - Stadler GSI-TS) was used to rule out middle ear abnormalities. Each ear of the participant was tested for the type of tympanogram and presence or absence of acoustic reflexes.

3) Evoked potential system

An evoked potential system (Intelligent Hearing System version 3) was used to record both click evoked and speech evoked ABR.

Test environment

All the Audiological evaluation and recording were be carried out in a sound treated room. The ambient noise was within the permissible limits as recommended by ANSI (S3.1; 1991).

Test Stimulus for speech ABR:

The test stimulus which was used for speech evoked ABR in the present study was a synthesized /da/ syllable. The stimulus is available in evoked potential system with the BioMARK protocol. The /da/ stimulus is a 40 ms synthesized speech syllable produced using KLATT synthesizer (Klatt, 1980). This stimulus simultaneously contains broad spectral and fast temporal information characteristics of stop consonants, and spectrally rich formant transitions between the consonant and the steady-state vowel. Although the steady-state portion is not present, the stimulus is still perceived as being a consonant-vowel syllable. The fundamental frequency (F0) linearly rises from 103 to 125 Hz with voicing beginning at 5 ms and an onset noise burst during the first 10 msec. The first formant (F1) rises from 220 to 720 Hz, while the second formant (F2) decreases from 1700 to 1240 Hz over the duration of the stimulus. The third formant (F3) falls slightly from 2580 to 2500 Hz, while the fourth (F4) and fifth formants (F5) remain constant at 3600 and 4500 Hz, respectively. Figure -1 shows both the time and spectral domain of the stimulus used in the present study.

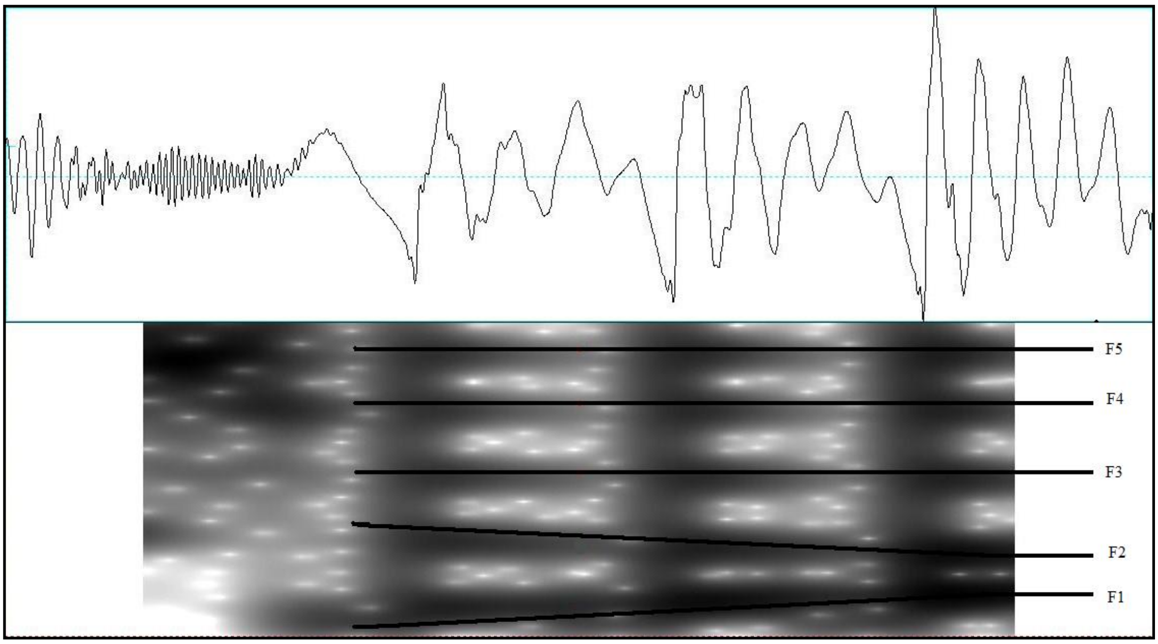

Figure 3.1 Spectral and temporal aspects of the Speech stimulus /da/ used in the present study. The top one represents the temporal details of the waveform whereas the bottom one depicts the spectral details.

Procedure

All the childrens were screened for hearing loss and middle ear dysfunction. Participants who met the criteria specified earlier were selected for the study.

1)Pure tone audiometry

Behavioral air conduction and bone conduction thresholds were tracked using modified Hughson and Westlake procedure (Carhart & Jerger, 1959). Air conduction thresholds were obtained from 250Hz to 8 KHz and bone conduction thresholds were obtained from 250Hz to 4 KHz. Participants who had thresholds within 15 dB HL has further undergone immittance assessment in both the ears.

2) Tympanometry

Tympanometry was done to rule out pathology of middle ear using 226Hz probe tone. Immittance test was carried out by sweeping the pressure from +200 to -400 dapa. In reflexometry both ipsilateral and contralateral acoustic reflexes thresholds were measured for 500 Hz, 1000 Hz, 2000 Hz, and 4000Hz pure tone at the peak pressure.

3) Screening Checklist for Auditory Processing

SCAP developed by Yathiraj and Mascarenhas, (2004) was administered to all the children to rule out any auditory processing problem. This checklist consisted of 12 questions. The checklist was scored on a two point rating scale as ‘Yes’ or ‘no’. Each answer marked yes was scored 1 and each no was scored 0. Children who scored more than 50% is considered to be at risk for (C) APD. Pass criteria of SCAP is children who scored less than 50% (6/12).The detail of the questionnaire is given in the appendix-1

4) Electrophysiological recording

Electrodes were placed on the sites with conduction paste and secured with skin tape. It was made sure that each electrode impedance was within <5 k Ω and inter electrode impedance was within <2 k Ω. Impedance for each electrode was also checked during testing, to make sure that patient movement did not cause any variation in the impedance. Participants were instructed to sit comfortably on a reclining chair and relax during the testing. They were instructed to close their eyes during the testing to avoid any artifacts. ABR were recorded twice for the reproducibility for both speech and non-speech stimuli.

5) Click ABR and Speech ABR was recorded using the following protocol (Table 3.2)-

Table 3.2.

Parameters for recording click evoked ABR and speech evoked ABR

	Click evoked ABR	**Speech evoked ABR**
Stimulus, duration	Click, 100µs	CV syllable /da/, 40 ms
Level	80 dB SPL	80 dB SPL
Filter band	100 to 3000 Hz	100 to 3000 Hz
Rate	10.1/s	10.1/s
No of sweeps	1500	3000
Transducer	ER-3A Insert ear phone	ER-3A Insert ear phone
Polarity	Alternating	Alternating
Time window	12 ms	12 ms
Electrode montage	Non-inverting electrode: Vertex. Inverting electrode: the nape of the neck. Ground electrode: forehead.	Non-inverting electrode: Vertex. Inverting electrode: the nape of the neck. Ground electrode: forehead.

Analysis

Click ABR and speech evoked ABR was recorded monaurally for both the ears and binaurally. Response was obtained by giving the stimulus monaurally (right and left ear) separately and then binaurally. The binaural interaction component (BIC) was determined by subtracting the binaurally evoked auditory potentials from the sum of the monaural auditory evoked potentials:

BIC = [(left monaural + right monaural)-Binaural].

The latency and amplitude of click evoked and speech evoked ABR was estimated for monaural and binaural recordings. Latency and amplitude of V^{th} peak in particular was estimated in both speech and click evoked ABR. For both click and speech evoked ABR amplitude was estimated by taking the peak which has got maximum energy within 10ms.For click evoked ABR the peak which comes under 5-6 ms was estimated for obtaining the latency of the V^{th} peak. And for speech evoked ABR the peak which comes under 5-7ms was estimated for obtaining the latency of the V^{th} peak. Finally the amplitude and latency of BIC was also estimated. Following parameters were calculated.

a. Latency and amplitude of wave V of click evoked ABR summed monaurally.
b. Latency and amplitude of wave V of click evoked ABR recorded binaurally.
c. Latency and amplitude of wave V of speech evoked ABR summed monaurally.
d. Latency and amplitude of wave V of speech evoked ABR recorded binaurally.
e. Latency of binaural interaction component for click and speech stimuli.

Chapter-4

RESULTS

The study aimed to determine the maturational changes of binaural interaction component using click and speech stimuli. To study the maturational changes of the BIC the latency and amplitude of binaural interaction component was analysed for the click and the speech stimuli, separately for the different age groups.

1) Descriptive statistics was carried out to find out the mean and standard deviation of

a) Latency of wave V of click and speech evoked ABR for summed monaural, binaural and binaural interaction component across different age groups.
b) Amplitude of wave V of click and speech evoked ABR for summed monaural, binaural and binaural interaction component across different age groups.

2) Multiple analyses of variance was done to compare the significant difference across the six age groups for

a) Latency and amplitude of wave V of click evoked ABR summed monaurally (i,e responses of the right and left ear added together).
b) Latency and amplitude of wave V of click evoked ABR recorded binaurally.
c) Latency and amplitude of wave V of speech evoked ABR summed monaurally (i,e responses of the right and left ear added together).
d) Latency and amplitude of wave V of speech evoked ABR recorded binaurally.
e) Latency of binaural interaction component for click and speech stimuli.
f) Amplitude of binaural interaction component for click and speech stimuli.

Latency of BIC using click stimulus

ABR for click stimulus was recorded for right ear and left ear separately first, then the two responses were added together to get a summed monaural responses. Binaural ABR was recorded using simultaneous presentation of click stimulus to both the ears. BIC for click was derived by subtracting binaural responses from summed monaural responses.

The representative waveform of summed monaural, binaural and binaural interaction component has been given in the figure 4.1.

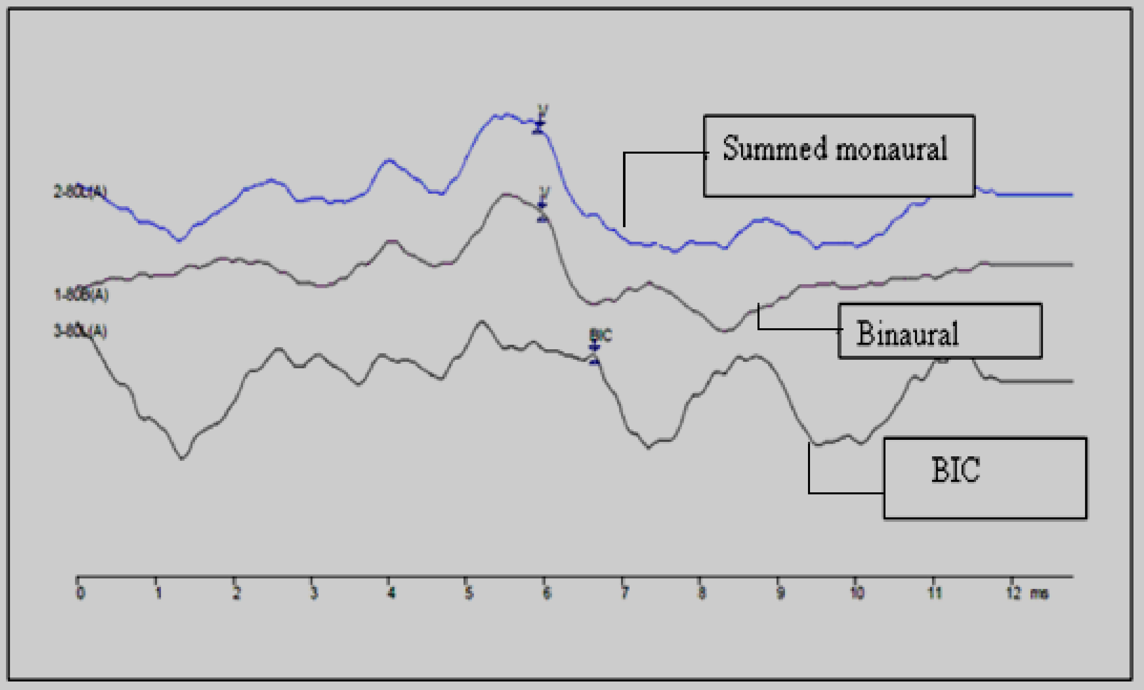

Figure 4.1 Sample waveform of summed monaural Binaural and Binaural interaction component using click stimuli recorded in one subject.

Click evoked ABR for the right and the left ear separately as well as binaurally could be recorded for all the subjects. Binaural interaction component of wave V was present for all the subjects. Latency of wave V of the summed monaural waveform, binaural waveform and binaural interaction component was measured.

Descriptive statistics was done to find out the mean and standard deviation of latency for summed monaural, binaural and binaural interaction component of ABR for the click stimulus. The details of the mean and standard deviation are given below in table 4.1

Table 4.1:

Mean and standard deviation of latency for click stimuli across the group

	Groups →	**I**	**II**	**III**	**IV**	**V**	**VI**
Summed Monaural Wave V latency	Mean(ms)	5.87	5.91	5.80	6.20	5.94	6.14
	S.D(ms)	0.23	0.31	0.24	0.32	0.25	0.39
Binaural Wave V latency	Mean(ms)	5.89	5.94	5.97	5.96	5.95	6.08
	S.D(ms)	0.27	0.27	0.37	0.32	0.27	0.34
BIC	Mean(ms)	6.83	6.80	6.91	6.99	6.98	6.98
	S.D(ms)	0.32	0..42	0.51	0.63	0.46	0.60

As we can see in table 4.1 that the mean latency of wave V of summed monoaural response, binaural response and the BIC elicited using click waveforms is similar across different age groups except for group IV and VI in summed monoaural response and group VI in binaural response. The latency of wave V in these two groups (group IV and VI) is slightly higher compared to the other groups for summed monaural responses. The mean latency of wave V of binaurally recorded ABR was higher for group VI compared to the other groups.

It can also be seen from table that the mean latency of BIC is almost similar for I and the II group whereas the mean latency of BIC for the III, IV, V and VI group is almost similar and around 0.1 msec higher compared to the I and II group. The same can be seen in figure 4.2.

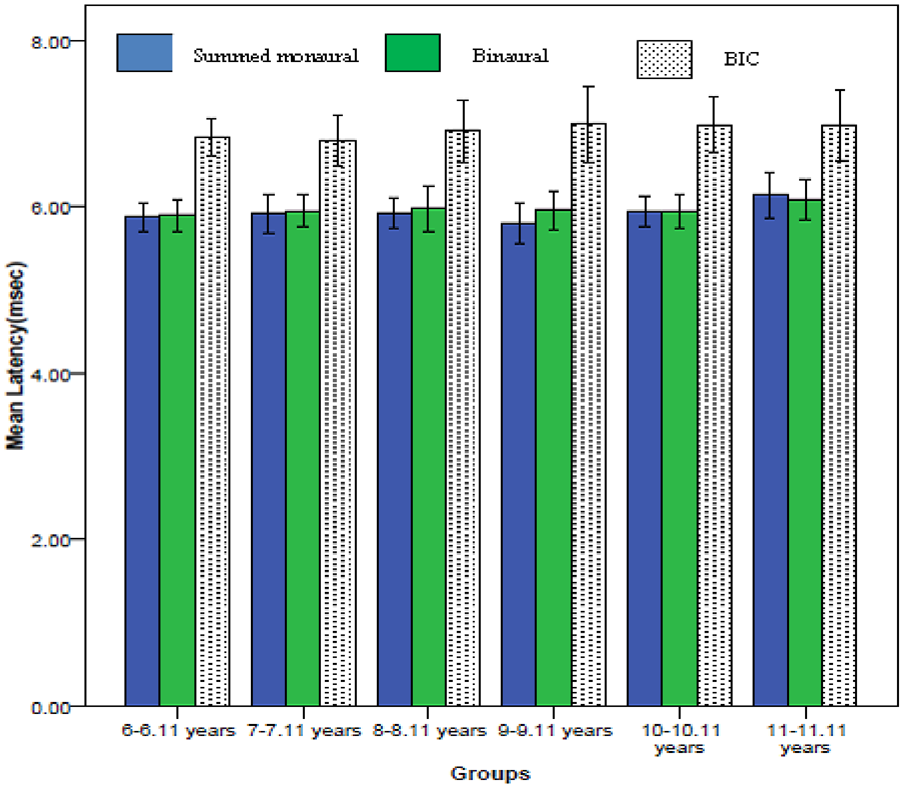

Figure 4.2. Bar graph of the latency of BIC and wave V of summed monaural and binaural ABR for different age groups.

Multiple analysis of variances (MANOVA) test was carried out to check the significant difference in the mean values of the latency obtained for click stimuli across all the groups. MANOVA analysis revealed no significant difference for wave V latency of summed monaural recording for click stimuli across all the age groups [F (5, 54= 1.42, P> 0.05] and also for the latency of wave V of binaural recording for click stimuli across age groups [F (5, 54 = 0.38, P> 0.05]. MANOVA also failed to show any significant difference for latency of binaural interaction component for click stimuli across different age groups [F (5, 54 = .27, P> 0.05].

Latency of BIC using Speech stimulus

ABR for speech stimulus was recorded for right ear and left ear separately first, then the two responses were added together to get a summed monaural responses. Binaural speech ABR was recorded using simultaneous presentation of speech stimulus /da/ to both the ears. BIC for speech was derived by subtracting binaural responses from summed monaural responses. The representative waveforms of summed monaural, binaural and binaural interaction component has been given in the figure 4.3

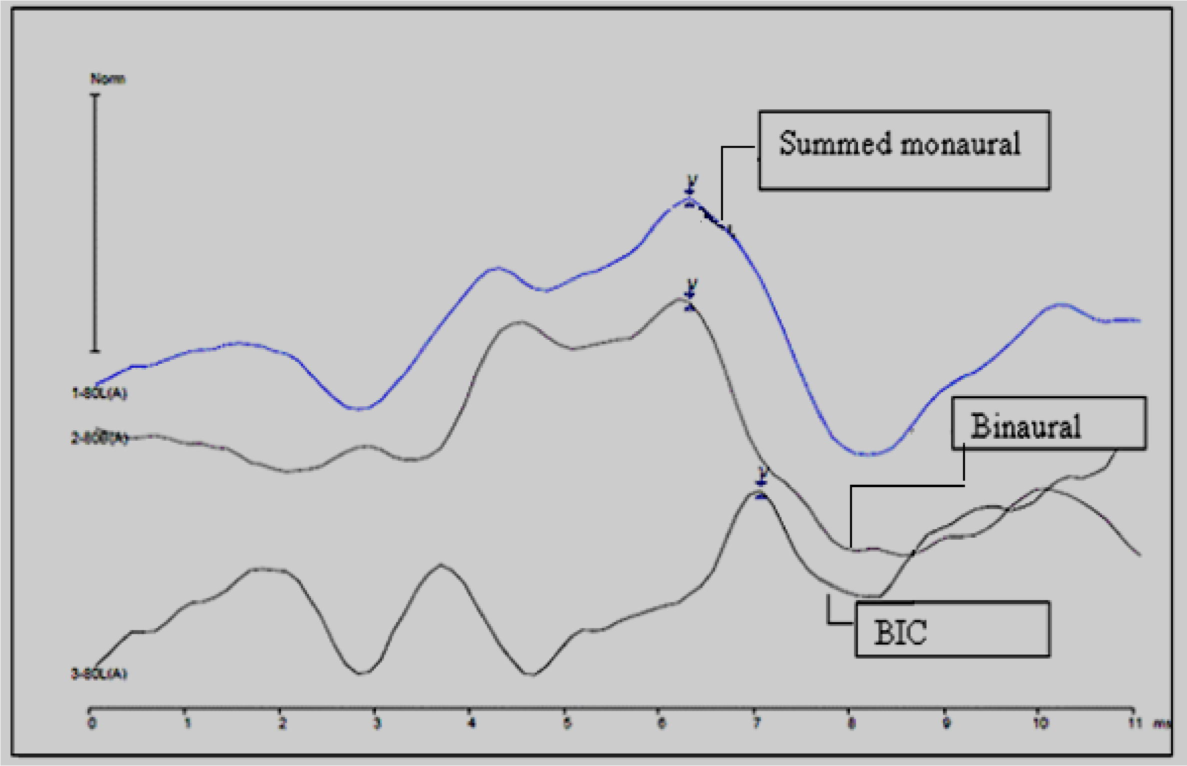

Figure 4.3. Sample waveforms of summed monaural Binaural and Binaural interaction component using speech stimuli.

Descriptive statistics was done to find out the mean latency of the binaural interaction component, and mean latency for the wave V of summed monoaural and binaural responses. The details of the mean and standard deviation (S.D) of latency of BIC and wave V latency of summed monoaural and binaural ABR are given in table 4.2.

Table 4.2.

Mean and standard deviation of latency for speech stimuli across the group

	Groups →	**I**	**II**	**III**	**IV**	**V**	**VI**
Summed Monaural Wave V latency	Mean(ms)	5.92	5.92	5.94	6.02	6.05	6.19
	S.D (ms)	0.27	0.19	0.28	0.19	0.30	0.27
Binaural Wave V latency	Mean(ms)	6.01	5.98	6.03	5.96	6.18	6.22
	S.D (ms)	0.29	0.19	0.36	0.32	0.27	0.31
BIC	Mean(ms)	7.06	6.95	6.42	6.25	6.43	6.48
	S.D (ms)	0.41	0.42	0.23	0.33	0.28	0.30

From table 4.2 it is clear that the latency of wave V of summed monoaural response is almost similar for I, II and III group, whereas latency is slightly longer for the IV, V and VI group. It can also be seen from table 4.2 that the latency of wave V of the binaural response elicited using speech waveforms is variable across the age groups. It is also clear that the latency of BIC obtained for I and II group were longer compared to the other four groups. The same can be seen in the figure 4.4.

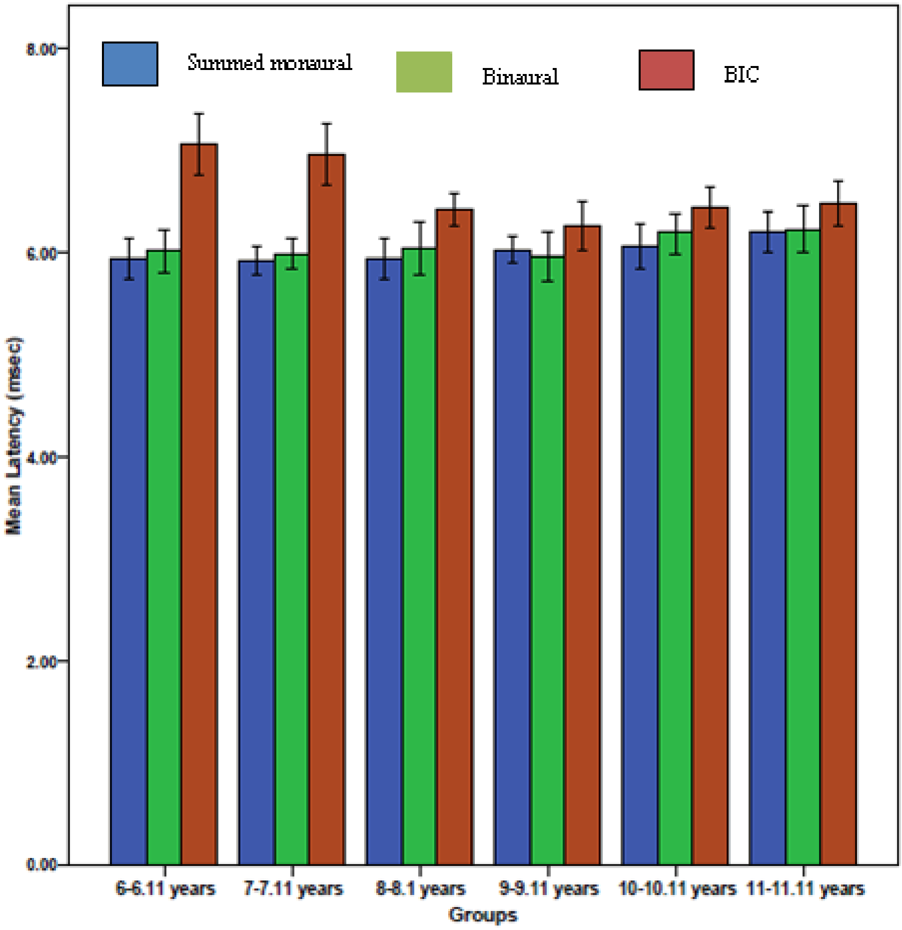

Figure 4.4 Bar graph of the latency of BIC, and wave V of summed monaural and binaural ABR for speech stimulus for different age groups.

Multiple analysis of variance (MANOVA) test was carried out to check the significant difference in mean latency of summed monaural, binaural and binaural interaction component for speech stimuli across each groups. MANOVA results indicated no significant difference for wave V latency of summed monaural recording for speech stimuli across age groups [F (5, 54) = 1.63, P> 0.05]. MANOVA also revealed no significant difference for wave V latency of binaural recording for speech stimuli across age groups [F (5, 54) = 1.32, P> 0.05]. However, MANOVA revealed a significant difference for the binaural interaction component for the speech stimulus [F (5, 54) = 9.35, P<0.05]. To further understand the group differences the Duncan's post Hoc analysis test was done. The results of Duncan's post hoc analysis are given in the table 4.3.

Table 4.3.

Result of Duncan's post hoc analysis.

	II group	III group	IV group	V group	VI group
I group	P> 0.05	P<0.05	P<0.05	P<0.05	P<0.05
II group		P<0.05	P<0.05	P<0.05	P<0.05
III group			P>0.05	P>0.05	P>0.05
IV group				P>0.05	P>0.05
V group					P>0.05

It can be seen from table 4.3 that the latency of Binaural Interaction component for the I and the II group did not differ significantly whereas, the latency of BIC for the I and II groups were significantly different from each other.

Amplitude of BIC

Amplitude of BIC for Click stimulus

Click evoked ABR could be recorded for all the subjects. Binaural interaction component of wave V was present for all the subjects. Amplitude of binaural interaction component and wave V of the summed monaural and binaural, ABR was measured.

Descriptive statistics was done to find out the mean and standard deviation of amplitude for the binaural interaction component, summed monaural and binaural component for the click stimuli. The details of the mean and standard deviation are given below in table 4.4.

Table 4.4.

Mean and standard deviation of amplitude for click stimuli across the group

	Groups	**I**	**II**	**III**	**IV**	**V**	**VI**
Amplitude (µV) of summed monoaural	Mean	0.90	0.90	0.66	0.70	0.61	0.73
	S.D	0.29	0.24	0.30	0.13	0.36	0.33
Binaural Wave V amplitude (µV)	Mean	0.67	0.59	0.51	0.66	0.56	0.53
	S.D	0.31	0.19	0.23	0.31	0.18	0.18
BIC amplitude (µV)	Mean	0.26	0.21	0.27	0.35	0.33	0.25
	S.D	0.09	0.12	0.13	0.20	0.22	0.19

As it can be seen from the table 4.4 that the mean amplitude of wave V for the summed monoaural response is slightly higher for I and II groups compared to the other four groups, the amplitude of the wave V for other four groups were almost similar. The amplitude of wave V for the binaural responses and BIC is slightly varying across all the age groups. It can also be noted that the standard deviation for the amplitude of summed monaural, binaural and BIC is very high for all the age groups. This can be seen from the figure 4.5.

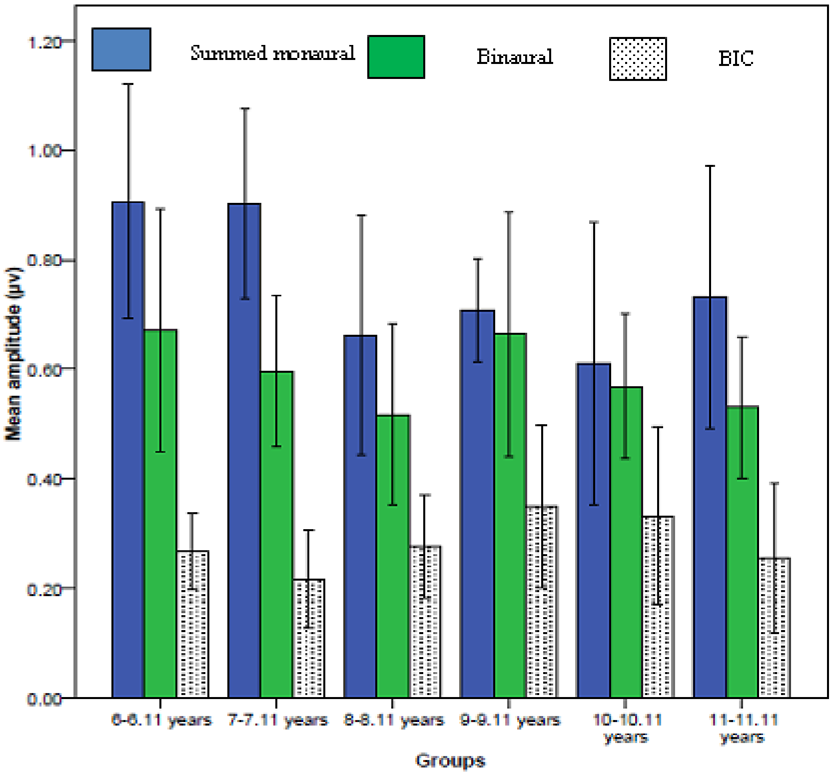

Figure 4.5 Bar graph of amplitude of BIC and amplitude of wave V of summed monaural and binaural waveform for different age groups

MANOVA test was carried out to check the significant difference in mean values of the amplitude obtained for BIC, summed monaural and binaural waveform across each groups. MANOVA results revealed no significant difference for wave V amplitude of summed monaural recording for click stimuli across all the age groups [F (5, 54) = 1.83, P> 0.05]. There was also no significant difference for wave V amplitude of binaural recording for click stimuli across all the age groups [F (5, 54) = 0.73, P> 0.05]. MANOVA also failed to show any difference for the amplitude of binaural interaction component of the click stimuli across different age groups [F (5, 54) = 0.86, P> 0.05].

Amplitude of BIC for Speech stimulus

Speech evoked ABR could be recorded for all the subjects. Binaural interaction component of wave V was present for all the subjects. Amplitude of wave V of the summed monaural waveform, binaural and binaural interaction component was measured.

Descriptive statistics was done to find out the mean and standard deviation of amplitude for summed monaural, binaural and binaural interaction component for the speech stimuli. The details of the mean and standard deviation are given below in table 4.5.

Table 4.5.

Mean and standard deviation of amplitude for speech stimuli across the group

	Groups	**I**	**II**	**III**	**IV**	**V**	**VI**
Summed Monaural amplitude (µV)	Mean	0.87	0.72	0.62	0.78	0.79	0.69
	S.D	0.29	0.39	0.50	0.41	0.35	0.32
Binaural ABR amplitude (µV)	Mean	0.68	0.75	0.43	0.60	0.58	0.54
	S.D	0.33	0.24	0.22	0.31	0.26	0.18
BIC amplitude (µV)	Mean	0.60	0.39	0.33	0.36	0.32	0.31
	S.D	0.35	0.20	0.27	0.11	0.11	0.18

From the table 4.5 It can be seen that the mean amplitude of wave V recorded for summed monaural waveform is more for I and II group (i,e age range of 6- 6.11 years and 7-7.11 years). The amplitude of the wave V of binaural waveforms however varies across the different age groups. The amplitude for the binaural interaction component is also higher for the I group compared to the other groups. It can also be noted that the standard deviation for the amplitude of summed monaural, binaural and BIC is very high for all the age groups. This can be seen in the figure 4.6.

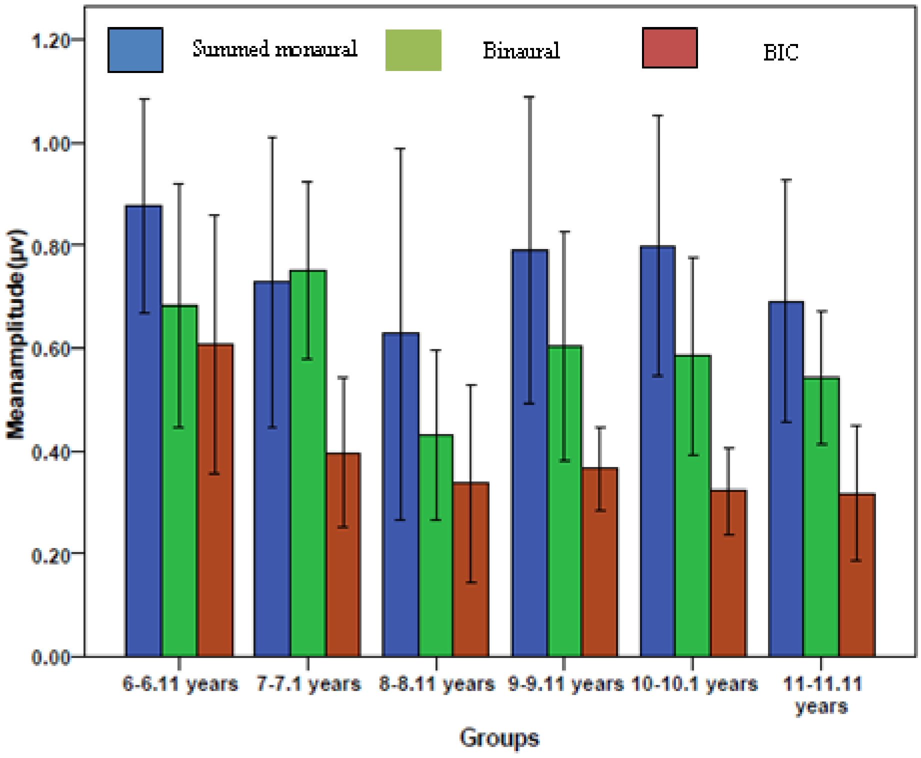

Figure 4.6 Bar graph of amplitude of summed monaural, binaural and BIC evoked using speech stimuli for different age groups.

MANOVA test was carried out to check the significant difference in mean values of the amplitude of BIC, summed monaural and binaural for different age groups. No significant difference was observed for wave V amplitude of summed monaural recording for speech stimuli across age groups [F (5, 54) = 0.51, P> 0.05]. There was also no significant difference for wave V amplitude of binaural recording for speech stimuli across age groups [F (5, 54) = 1.74, P> 0.05]. But significant difference was observed for amplitude of binaural interaction component for speech stimuli across different age groups [F (5, 54) = 2.42, P< 0.05]. Duncan's Post hoc analysis was done to check which group was significantly different from each other. The results of the Duncan's Post Hoc analysis are given in table-4.6

Table 4.6.

Results of Duncan's Post Hoc analysis

	II group	III group	IV group	V group	VI group
I group	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$
II group		$P>0.05$	$P>0.05$	$P>0.05$	$P>0.05$
III group			$P>0.05$	$P>0.05$	$P>0.05$
IV group				$P>0.05$	$P>0.05$
V group					$P>0.05$

Thus, it is clear from table 4.6 that the amplitude of BIC for the first group was significantly higher compared to the other groups. Bar graph was computed for the amplitude of binaural interaction component for speech stimuli for all the age groups.

To summarise the results, with maturation there is no significant difference in the latency and amplitude obtained for summed monaural, binaural and binaural interaction component for non speech stimulus i.e, click stimulus. However, there was a significant difference obtained for the latency of the BIC of the speech stimuli. Latency of BIC for the I and II group was longer compared to the other groups and this was statistically significant compared to the other groups. However, the amplitude of BIC recorded for both stimuli i.e. the click and the speech stimulus had a large standard deviation for all the age groups.

Chapter-5

Discussion

The aim of the study was to determine the maturational changes in the binaural interaction component using click and speech stimuli for the children in the age range of 6 years to 12 years.

Latency of BIC for click and speech stimuli

The result of the present study showed that there was systematic age related change in the latency of the speech evoked binaural interaction component (BIC). Latency of BIC of speech obtained for children in the age range between 6-6.11 years and 7- 7.11 years were significantly prolonged compared to the children in the age range between 8 to 12 years, whereas there was no difference for the BIC evoked by the click stimulus.

In the present study the mean latency of the binaural interaction component for the click stimulus was found to be in the range of 6.80 - 6.99 msec for the different age group of children. The latency obtained for BIC for the click stimulus in the present study is longer compared to the studies (Chiappa et al., 1979; Dunn Mendelson & Salamy, 1981; Gopal & Pierel 1999) reported in the literature. Chiappa et al., (1979) reported a mean latency of 5.75± 0.25 msec, Dunn et al., obtained BIC latency as 5.67±0.21 msec, Gopal and Pierel reported latency as 5.63±0.26ms. The prolonged latency of BIC for the click stimulus in the present study can be attributed to the intensity of the stimulus used in the present study. Earlier studies have used an intensity of 80 dB nHL to record the auditory brainstem responses whereas, in the present study an intensity of 80 dB SPL was used. Thus, the lower presentation of the stimulus level would have caused a delay in the latency of the BIC obtained for the click stimulus.

For the speech stimulus the latency of BIC recorded was in the range of 6.25-7.06 msec. In the literature there are only a few studies which have reported the BIC using speech stimulus. Deepti (2008) reported a latency of 6.99± 0.29 msec for the BIC using speech stimulus in a group of children. The present study is in agreement with the latency reported by Deepti (2008).

However, latency of BIC for speech stimulus obtained for children in the age range between 6-6.11 years and 7- 7.11 years were significantly prolonged compared to the children in the age range between 8 to 12 years. Prolonged latency of the BIC for speech stimulus in the age group of 6-6.11 and 7-7.11 years indicates that the BIC continues to develop till 8 years of age. Maturation of the binaural interaction component using the auditory brainstem responses is thus analogues to the other tasks of binaural interaction component such as masking level difference (MLD), which continues to develop till 6 years of age.

Hall and Grose (1990) found that the MLD for a pure-tone presented in a wide band (300 Hz) masker progressively increased up to approximately 5 to 6 years of age. In addition, MLD presented in a narrow band (40Hz) masker continued to be smaller in the 6 years old children compared to the adults. The authors concluded that these developmental changes observed in the MLD of children up to 6 years of age are most likely related to the central auditory processing development than to sensitivity to interaural timing cues.

However, the auditory brainstem responses to click stimulus reaches adult values by the age of 18-24 months in children, indicating the maturation of brainstem pathway by this age, whereas, the brainstem responses to speech continue to develop till 5 years of age (Johnson, Nicol & Kraus, 2008). This dichotomy suggests that brainstem neurons react differently to encode click versus speech sounds. There may be a possibility that the higher level processing responsible for integration and process of binaural cues for speech stimulus may continue to mature beyond this age i.e. 5 years of age. Thus, the prolonged latency obtained for BIC of the speech stimulus for the lower age groups in the present study reflects a neuromaturation development of binaural interaction component.

The prolongation in latency of BIC was not seen for the click stimulus. Latency of click evoked BIC for all the age groups was similar. Auditory brainstem responses using speech stimulus has been found to be superior to click stimulus in evaluating the children with learning problems. According to Wible, Nicol and Kraus (2004) onset of the speech sound /da/, i.e. wave V of the auditory brainstem response (ABR) had a significantly shallower slope in learning impaired children. The authors suggested that poor representation of crucial component i.e. the onset responses of speech sounds could contribute to difficulties with higher-level language processes. Also Goncalves et al., (2011) reported a longer latency for wave V of speech ABR in children with phonological disorders compare to normal children with age range of 7- 11 years.

The difference in the latency of the BIC obtained for speech and click stimuli can be attributed to stimulus differences. Whereas, clicks contain a broad range of frequencies, speech is more spectrally shaped. In addition, the onset of the /da/ stimulus occurs more gradually relative to the instantaneous rise time of the click. The onset of the /da/ syllable may also be more susceptible to the effects of backward masking by the larger-amplitude formant transition (Johnson et al., 2007). Finally, brainstem activity can be experience dependent (Tzounopoulos & Kraus, 2009), i.e. the latency effects of the two stimuli may be due to the greater exposure to and use of speech sounds.

Although the acoustic differences discussed above may be partially responsible for the findings in this study, it is important to know that human beings are exposed to speech stimulus in the environment and not the click stimulus. Particularly relevant is that brainstem encoding of sound has been shown to be shaped by lifelong linguistic and musical experience (Krishnan et al., 2004, 2005; Musacchia et al., 2007; Wong et al., 2007). That is, brainstem activity evoked by Mandarin tones and music is enhanced in musicians and speakers of tonal languages relative to non-musicians and non-native speakers. Additionally, short-term training has been shown to lead to changes in speech-evoked brainstem responses (Russo et al., 2005; Song et al., 2008). Also the reversed speech is processed differently at the brainstem level compared to the forward speech (Sinha & Basavaraj, 2010), indicating a differential processing of a forward and reversed speech at the brainstem. Moreover, recent animal work has also shown that experience can lead to large-scale reorganization of the inferior colliculus tonotopic organisation (Yu et al., 2007) and that experience dependent pruning of synaptic inputs is important for the maturation of the functional inhibition in brainstem nuclei (Magnusson et al., 2005).

If it is assumed that humans have little exposure to clicks and that clicks have little relevance, regardless of age, the auditory system would not be expected to change its response to such a stimulus. Conversely, with speech, which is relevant in the real world, experience dependent pruning is necessary. Because younger children have less linguistic and phonemic exposure, it is perhaps the case that synaptic pruning has not been fully refined such that young children have delayed/less precise neural response timing when encoding acoustic elements that are relevant to speech (Johnson et. al., 2008). Thus, it is reasonable to speculate that the developmental differences found in the present study for the BIC of speech stimulus may not be just from acoustic differences of the stimuli but also perhaps from their extensive use and relevance.

Amplitude of BIC for click and speech stimulus

In the present study there was no variation in the amplitude of BIC obtained for click and speech stimulus across the different age groups.

Amplitude obtained for click stimulus was within the range of 0.21-0.35 µV, whereas, amplitude obtained for speech stimuli was within the range of 0.31-0.60 µV. Group I showed significant difference from the other groups for BIC of speech stimulus. For the speech as well as the click stimulus the amplitude variation was large for all the age groups i.e. the standard deviation was very high. Large standard deviation in amplitude of BIC might be a result of the large standard deviation obtained for the summed monoaural and binaural recording. Large standard deviation might be a reason that the first group attended a significant difference in terms of amplitude for speech stimulus.

Previous studies (Hurley, 2004; Deepti, 2008) have also reported a very large variation in amplitude of the binaural interaction component recorded with click or speech stimulus. It is known that the electrophysiologic recordings often don’t replicate well and the peak-to-peak measures of the components vary widely. This has led to many researchers to believe that amplitude measure of the ABR components is highly variable (Burkard, Don & Eggermont, 2007). While it is true that the measurements often vary widely from run to run, it is not necessarily true that the variation is solely due to electrophysiologic changes. The measured average waveform (i.e. the ABR amplitude) is composed both of synchronous neural component-the true electrical potential and the residual noise. Therefore, it is possible that the variation in the measurement is due to the variation in the residual noise and that there is little or virtually no variation in the EP component. Also there are episodic noise bursts or changes in the level of background noise from one run to the other. As a result, the residual noise can vary greatly from one run to the next when a fixed number of sweeps are used, thus, a fixed number of sweeps will not guarantee the same SNR for repeated runs (Hall, 1992; Hood, 1998; Burkard et al., 2007). The measured amplitude thus is influenced by many factors such as recording bandwidth, stimulus type, individual's gender, anatomy and physiology, the technique used by the software for averaging, impedance at the surface electrode (Hall, 1992; Hood, 1998; Burkard et al., 2007).

Therefore relying on the amplitude measure of BIC will be misleading the audiologist while identifying children with (c) auditory processing disorder and/or learning disability. Thus it is preferable to use a more reliable measure to decreases the errors in the evaluation. Therefore the latency parameter of the BIC can be used to evaluate the binaural interaction component in identifying the binaural interaction deficits in children with auditory processing disorders.

Chapter-6

Summary and Conclusion

Binaural processing is evaluated clinically by behavioural assessment of skills such as, auditory localization and the masking level difference. There have been attempt made by the researchers to use the measurement of binaural processing through binaural interaction component of the auditory brainstem responses.

The auditory brainstem responses have been used for studying binaural interaction component elctrophysiologically. The Binaural interaction component (BIC) is derived by subtracting the ABR obtained with binaural stimulation from the waveform obtained by adding the responses from the left and right monaural stimulation. This concept is expressed as: Binaural difference waveform = (L + R) – BI; where, L + R is the sum of the left and right evoked potentials obtained with monaural stimulation, and BI is the response acquired from binaural stimulation.

Present study was undertaken with an objective of studying maturational changes of binaural interaction component using click and speech stimuli for different age groups. 60 children with normal hearing in the age range of 6- 12 years participated for the study. They were categorized in to 6 subgroups. Each subgroup consisted of 10 children. Groups were as follows. Group I: 6 to 6.11 years.

Group II: 7 to 7.11 years.

Group III: 8 to 8.11 years.

Group IV: 9 to 9.11 years.

Group V: 10 to 10.11 years.

Group VI: 11 to 11.11 years.

To achieve the objectives first the children were screened for a normal hearing, normal middle ear functioning and normal auditory process. To screen the hearing sensitivity, normal middle ear functioning and no auditory processing problems following tests were carried out.

1) Puretone audiometry

2) Tympanometry

3) Screening checklist for auditory processing

Once the subjects passed the selection criteria, they were subjected to electrophysiologic testing. Click and Speech evoked ABR was recorded monaurally for both ears and binaurally. Monaural responses were added together to obtain summed monaural wave form. To determine the binaural interaction component binaural responses were subtracted from the summed monaural responses for both click as well as speech stimulus.

BIC = [(left monaural + right monaural)-Binaural].

Following parameters were calculated-

a. Latency and amplitude of wave V of click evoked ABR summed monaurally.

b. Latency and amplitude of wave V of click evoked ABR recorded binaurally.

c. Latency and amplitude of wave V of speech evoked ABR summed monaurally.

d. Latency and amplitude of wave V of speech evoked ABR recorded binaurally.

e. Latency of binaural interaction component for click and speech stimuli.

For analyzing all the parameters following statistical analysis were done:

Descriptive statistics was carried out to find out the mean and standard deviation of

a) Latency of wave V of click and speech evoked ABR for summed monaural, binaural and binaural interaction component across different age group.

b) Amplitude of wave V of click and speech evoked ABR for summed monaural, binaural and binaural interaction component across different age group.

2) Multiple analyses of variance was done to compare the significant difference across the six age groups for

a) Latency and amplitude of wave V of click evoked ABR summed monaurally (i,e responses of the right and left ear added together).
b) Latency and amplitude of wave V of click evoked ABR recorded binaurally.
c) Latency and amplitude of wave V of speech evoked ABR summed monaurally (i,e responses of the right and left ear added together).
d) Latency and amplitude of wave V of speech evoked ABR recorded binaurally.
e) Latency of binaural interaction component for click and speech stimuli.
f) Amplitude of binaural interaction component for click and speech stimuli.

Results of the present study were as follows:

1. There was no significant difference in the latency and amplitude obtained for summed monaural, binaural and binaural interaction component across age groups for click stimulus.

2. A significant difference was obtained for the latency of the BIC of speech stimuli across age groups. Latency of BIC for I and II group was longer than compared to the other groups and that was significantly different from the other groups. But there were no significant difference obtained for the BIC latency between the I and II groups.
3. The amplitude of BIC recorded for click and speech stimuli had a large standard deviation for all the age groups.

Prolonged latency of the BIC for speech stimulus in the age group of 6-6.11 and 7-7.11 years indicated that the BIC for speech stimulus continues to develop till 8 years of age. Maturation of the binaural interaction component using the auditory brainstem responses is thus analogues to the other tasks of binaural interaction component such as masking level difference (MLD), which continues to develop till 6 years of age. For the speech as well as the click stimulus the amplitude variation was large for all the age groups i.e. the standard deviation was very high. This might be a reason that the first group attended a significant difference in terms of amplitude for speech stimulus.

Conclusion:

The Binaural interaction component of auditory brainstem responses can be used to evaluate the binaural interaction in children. This will be helpful in diagnosis of the children with (C) APD who have binaural interaction component. Additionally the test does not require any behavioural co-operation from the client, hence can be administered easily. However, latency of the BIC is a better parameter to evaluate the binaural interaction compared to the amplitude, as the amplitude of the BIC shows a very large variation.

Implications of the study:

1. It can be used to evaluate the neural encoding of speech sounds at the brainstem level.
2. It can serve as a diagnostic tool to evaluate the binaural interaction task in children.
3. BIC for speech can be a useful diagnostic tool in assessing the binaural interaction task in children with auditory processing problem.

Future Directions:

1. The Binaural interaction component to speech can be further evaluated in the lower age group children i.e. below 5 years of age.
2. The binaural interaction component can be correlated with the other task of binaural interaction such as masking level differences.
3. Across the different gender the development of binaural interaction task can be evaluated.

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APPENDIX-1

Screening checklist for central auditory processing (SCAP)

Yathiraj and Mascarenhas (2002)

All India Institute of Speech and hearing

Manasagangothari, Mysore-6.

Name: Age/Sex:

Class:

Class teacher:

School Name:

Medium of instruction:

Language(s) spoken at home:

Home address and telephone No:

Father’s occupation:

Mother’s occupation:

Please place a tick (√) mark against the choice of answer that is most appropriate.

Nos	Questions	Yes	No
1	Does not listen carefully and does not pay attention (requires repetition of instruction)		
2	Has a short attention span of listening (appr 5-15mins)		
3	Easily distracted by background sound		
4	Has trouble in recalling what has been heard in the correct order		
5	Forgets what is said in few minutes		
6	Has difficulty in differentiating one speech sound from other similar sound		
7	Has difficulty in understanding verbal instruction and tent to misunderstand what is said which other children of the same age would understand		
8	Show delayed response to verbal instruction or questions		
9	Has difficulty in relating what is heard with what is seen		
10	Poor performance in listening task, but performance improves with visual cues		
11	Has pronunciation problem (mispronunciation of words)		
12	Performance is below average in one or more subjects, such as social subjects, I/II language		