CORTICAL AUDITORY EVOKED POTENTIALS

IN CHILDREN USING

SPEECH AND NON-SPEECH STIMULI

Rohith. H.
Register No: 08AUD024

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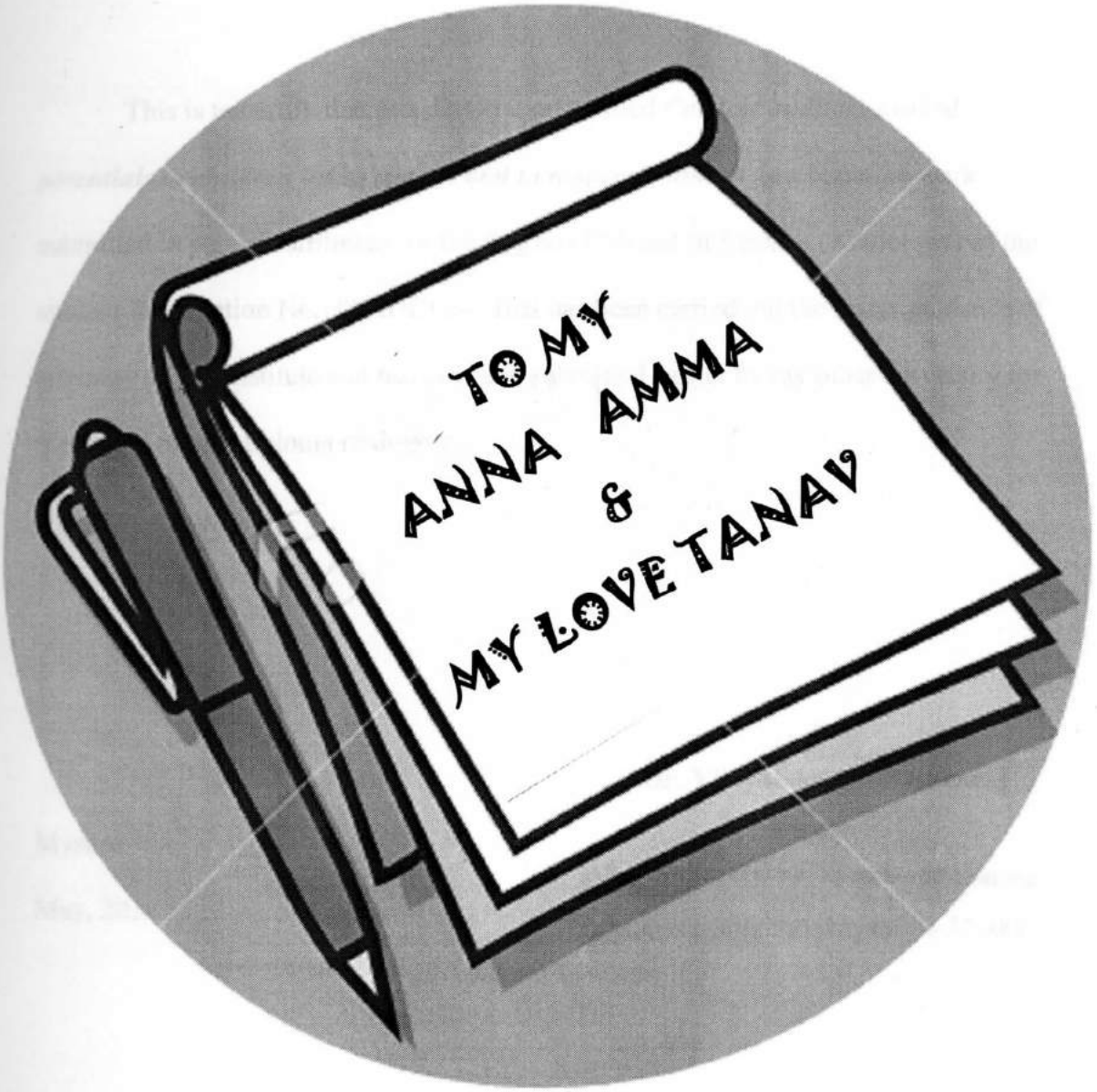
TO MY
ANNA AMMA
&
MY LOVE TANAV

CERTIFICATE

This is to certify that this dissertation entitled ***Cortical auditory evoked potentials in children using speech and non-speech stimuli*** is a bonafide work submitted in part of fulfilment for the degree of Master of Science (Audiology) of the student Registration No.: 08AUD024. This has been carried out the under guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

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CERTIFICATE

This is to certify that this dissertation entitled ***Cortical auditory evoked potentials in children using speech and non-speech stimuli*** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

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DECLARATION

This is to certify that this master's dissertation entitled ***Cortical auditory evoked potentials in children using speech and non-speech stimuli*** is the result of my own study under the guidance of Dr. Animesh Barman, Reader in Audiology, Department of Audiology, All India Institue of Speech and Hearing, Mysore, and has not been submitted earlier to any other university for the award of any diploma or degree.

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Chapter 1

Introduction

Auditory evoked potentials (ERPs) are bioelectrical time locked responses elicited by a sound. The slow "obligatory" cortical P1-N1-P2 evoked potentials occur within about 300ms after stimulus onset in adults. The slow cortical potential is referred to as obligatory because it is primarily determined by the physical properties of the stimulus and it invariably occurs when sound is detected by the subject (Hyde, 1997; Stapells, 2002). P1 and N1 components primarily reflect sensory encoding of auditory stimulus and precede more endogenous components such as N2 and P3 which are concerned with attention and cognition. Cortical potentials are affected by both arousal level and attention and are typically recorded when the subjects is awake and alert or in a light sleep stage (Cody, Klass & Bickford, 1967). It has been reported that cortical potentials are similar when infants are awake and in "active" sleep (Novak, Kurtzberg, Kreuzer & Vaughan, 1989; Kusherenoko,et al.,2002). As noted by cone-Wesson and Wunderlich (2003), CAEPs can be used to obtain threshold in infants if subject state is closely monitored and if any appropriated normative data is available.

There are studies which have showed considerable changes in AEP morphology and latency across childhood and adolescence (Barnet et al., 1975; Courchesne, 1978; Bruneau et al., 1997; Sharma et al., 1997).This existing evidence suggests that maturation of the AEPs and, thus, their underlying generators, may have distinct maturational time courses (Kraus et al., 1993).

An important factor in the development of language and speech function is the normal maturation of auditory processing. Although many behavioral studies have examined how language and speech develop, it is more difficult to investigate auditory processing using behavioral measures (Pang & Taylor 2000). So by recording age-related changes in the neurophysiological responses evoked by auditory stimulation, one can assess the maturation of the thalamic-cortical portions of the central auditory system (NaÈaÈtaÈnen & Picton, 1987; Vaughan & Arezzo,1988). It has been proposed that this maturational processes occurring earlier in primary auditory cortex in the superior temporal plane, which is believed to generate the response recorded at the midline, and later in the secondary auditory cortex, on the lateral surface of the superior temporal gyrus (Kurtzberg et al. 1984).

The behavioral and perceptual correlates of infant and child ERPs are yet to be established. In children, especially young, behavioral data on ERP correlates are scarce since they are either difficult to collect or unreliable. One way to infer the functional significance of children's ERPs is to determine their correlates in adult ERPs, which have been extensively endorsed by behavioral data. The cross-sectional (between different ages) comparisons are rendered problematic due to substantial differences in the ERP composition between young children and adults (Ceponiene et al, 2005).

Cortical auditory evoked potentials (CAEPs) have been recorded using a wide range of stimuli including tones, clicks and speech stimuli. Several studies have shown differences in CAEPs latencies for different stimulus frequencies recording using conventional evoked potentials and magnetoencephalography techniques (Crottaz-Herbette & Ragot., 2000, Jacobson., et al 1992; Roberts & Poepple,1996; Salajegheh,

et al., 2004; Verkindt, Bertand, Perrin et al.,1995; Woods, Alain, Covarrubias & Zaidel, 1993). There is some evidence that CAEPs in infants evoked by different speech phonemes differ in latency and morphology (kurtzberg, 1989). CAEPs differences between speech stimuli are an indication of different underlying neural representations of speech sounds and suggest that the information needed to differentiate the stimuli is available to the listener. There has been increasing interest in the use of cortical potentials to investigate the neural encoding of speech (Tremblay, Billings, Friesen & Souza, (2006).

Speech evoked ERPs provides information about the biological processes underlying speech processing. The recording of cortical auditory evoked potentials (AEPs) to human speech sounds in infants have value as an index not only of the maturational state, but of the functional integrity of those regions of the cortex which process acoustically complex stimuli that are critical for the development of normal speech and language. For this reason, ERPs are of great value to hearing scientists and audiologists. The assumption is that speech perception is dependent on the neural processing of the frequency, amplitude and timing cues contained within the speech signal (Kraus et al., 1996).

Pasman et al (1999) studied the maturation of auditory cortical evoked response from birth to 14 years and found that auditory cortical responses shows age related changes in morphology of waveform and also recognized two transitional periods. First between 36 months and 41 weeks conceptional age and second between 4 to 6 years of age. The adult waveform complex is achieved between 14 to 16 years of age.

The P1/N1 complex is a robust and ubiquitous component of the adult response. In contrast, its characteristics (and even presence) are ambiguous in children. Children's long-latency obligatory auditory ERPs are dominated by the P1 and N1 peaks, whereas those of adults are dominated by the P1–N1–P2 complex. These developmental changes in the wave shape and topography of sensory evoked potentials observed in the normal human infant reflect the regional maturation of the cerebral cortex (Vaughan 1975; Vaughan & Kurtzberg 1989).

P1 amplitude is larger and earlier for speech than compare to click and tone. Wunderlich, et al., (2006) reported CAEP component latencies were relatively stable from birth to 6 years, but adults demonstrated significantly shorter latencies compared to infants and children. Amplitude of P1 component decreased, while N1 and P2 amplitude increased from birth to adulthood. Words evoked significantly larger CAEPs in newborns compared to responses evoked by tones, but in other age groups the effects of stimulus type on component amplitudes and latencies were less consistent (Purdy et al, 2005).

Amplitude of the N1 to P2 complex is larger for speech sounds than for single frequency tonal stimuli, but latency values for the N1 and P2 are usually earlier for tonal versus speech stimuli (Ceponiene et al 2001; Tiitinen et al 1999). The latency of the ALR N1 component varies with the frequency of tonal signals (Crottaz-Herbette & Ragot, 2000; Roberts, Ferrari, Stufflebeam & Poepple, 2000), where as for natural speech sounds the N1 latency is consistently about 120ms (Makela et al., 2001).

Natural vowel sound generated ALR components (N1 and later waves) that are detected with consistently larger amplitude from the left hemisphere, whereas tonal stimuli produced symmetrical brain activity (Szymanski et al., 1999). There is

long standing evidence that tonal stimuli and synthetic speech sounds produced repeatable ALRs (Pekkonen, Rinne & Naatanen, 1995; Tremblay et al 2001).

Need for the study

A thorough characterization of the AEP changes that continue into adolescence is a first step in establishing whether a relationship exists between physiological maturation and the prolonged development of some psychophysical abilities (Palva & Jokinen, 1975; Marshall et al., 1979; Elliott, 1979; Schneider & Trehub, 1992; Trehub et al., 1995; Litovsky, 1997). So in the present study, age related changes for two different stimuli (syllable /da/ and 500Hz tone burst) were seen.

There is dearth of information regarding the ALLR recording using non-speech and speech stimuli in younger population. Most of the studies either taken non-speech or speech stimuli to record ALLR. However, a comparison would give idea about the type of stimulus which can be used to record ALLR from children and percentage of population showing such responses.

Literature says that brief stimuli click do not produce consist well defined waveform for the long latency auditory potentials. Tone, tone pips or tone burst or speech is advised (Mc Pherson 1996).

Studies shows that N1and P2 complex amplitude is larger for speech sounds than for single frequency tonal stimuli, but latency value for N1 and P2 are usually earlier for tonal versus speech stimuli (Cepohiene et al 2001, Tiitinen et al 1999). So in order to find out which is the suitable stimuli to elicite response both tonal and speech signal is taken for study.

A comprehensive description of age-related AEP changes in neurologically intact and normal-hearing children will provide a useful reference for assessing suspected neuromaturational deficits or central auditory processing disorders in children. These reference data may also be useful in evaluating children with hearing disorders (e.g. unilateral deafness) or profoundly deaf children fitted with cochlear implants (Ponton & Don, 1995, Ponton et al., 1996a,1996b). So the present study was carried out to get the reference in diagnosing normal from disordered population.

Aim of the study

Aim of the study was to:

- Investigate the effect of age on latency, absolute amplitude and peak to peak amplitude of ALLR waves elicited by syllable /da/ and 500Hz tone burst stimuli.
- Investigate any difference in ALLR waves elicited by non-speech and speech stimulus.
- Investigate the most effective stimuli among syllable /da/ and 500 Hz tone burst to elicit ALR response in children.

Chapter 2

Review of Literature

Between the early preterm period and term date the auditory cortical evoked response (ACR) shows a complex maturation. In contrast to the maturation of the auditory brainstem evoked response (ABR) and the middle latency evoked response (MLR) the maturation of the ACR is not only reflected by changes in amplitudes and/or latencies but also by changes in waveform morphology. Until the late 1980s it was assumed that the ACR waveform morphology was almost completed by the end of the first year of life. We observed that the ACR waveform morphology at 5 years of age clearly differed from the adult ACR waveform morphology. Recently, several authors reported that the maturation of the ACR and auditory event related response (AERR) continues until the adolescent period (Pasman et al 1999).

Auditory evoked potentials (AEPs) provide a complex but rich source of information about the central nervous system pathways and structures activated by auditory stimulation. By thoroughly characterizing AEP maturation, it may be possible to determine whether a relationship exists between age-related physiological changes reflected in the AEPs and the development of both normal and abnormal auditory behavioral skills. Gaining better insights into the auditory event related brain potentials (ERPs) that predominate during childhood (Ceponiene, Cheour, & Naatanen, 1998; Ceponiene et al., 2001; Gomot ,Giard, Roux, Barthelemy, & Bruneau , 2000; Korpilahti & Lang, 1994; Neville, Coffey, Holcomb, & Tallal, 1993) is important for understanding auditor y information processing and its maturation. One w ay to address this is to define the variation of auditory ERPs as a f unction o f speech sound in children and adults. This addresses the question o f how speech

sounds are processed at the sensory level, an issue relevant for understanding developmental language disorders. Therefore, this study examined auditory ERPs elicited by speech sounds (syllables) and their acoustically matched non-phonetic correlates in children and adults (Ceponiene et al 2005).

Speech-evoked auditory event-related potentials (ERPs) provide information about the biological processes underlying speech processing. For this reason, ERPs are of great value to hearing scientists and audiologists. ERPs frequently used to examine the processing of acoustic and phonemic aspects of speech sounds. These ERPs include the P1–N1–P2 complex, acoustic change complex (ACC), mismatch negativity (MMN), and P300 (Martin et al., 2008).

Cortical auditory evoked potentials components and its latency

The ALR was actually the first auditory electrical response to be recorded from the central nervous system (CNS). It is recorded in a time period from about 50 to 400ms ms after acoustic stimulation at a relatively slow rate (one stimulus every 1 or 2 seconds, or even slower rates). In comparison to earlier responses, amplitude for the ALR is larger, usually within the 3 to 10microvolt range and occasionally larger. The main components and their characteristic latency values are P1 (50 to 80ms), N1 (100 to 150ms), P2 (150 to 200ms) and N2 (180 to 250 ms). The labels for these peaks refer to the expected voltage polarity of the response as recorded from the vertex ("P" for positive and "N" for negative). Nomenclature for describing ALR waveforms according to vertex positive and negative peaks was proposed by Williams, Tepas, and Morlock in 1962. The major components in the ALLR are characterized by an initial positive peak between 60-80ms (P60/P1), having an amplitude of about 7 microvolt (microV) and a width of about 15ms. The second peak

occurs between 90-100ms (N100/N1) and is a negative peak with an amplitude of 10microV and a width of 40-50ms. The third peak is positive occurring at about 100ms-160ms (P160/P1) and has an amplitude of about 6microV and width of 40-50ms. The fourth peak occurring at 180ms-200ms (N200/N2), is a negative peak and has an amplitude of 6microV and a width of 70ms (Mc Pherson & Starr, 1993). While P1, N1, P2 are predominantly exogenous potentials, N2 is not truly an exogenous potential, as it is affected by intrinsic factors such as attention and sleep (Ritter, Simson & Vaughan, 1983).

Factors influencing auditory late latency responses.

There are several factors which affect ALLR. They can be broadly categorized as subject related factors, stimulus related factors, acquisition factors etc. among them some of the factors which affects ALLR are as follows.

State of Arousal and sleep

In sleep, the intensity at which the ALR was first obtained in normal hearers was elevated by approximately 20 to 30 dB and with a increased in ALR latency (Cody, Klass & Bickford, 1967; Mendal, Hosick, Williams et al, 1975). Amplitude generally becomes more variable in sleep (Rapin, Schimmel & Cohen 1972; Mendal, Hosick, Williams et al, 1975; Tepas & Cohen, 1962). Williams et al in 1962 reported that amplitude of N2 component is markedly increased during sleep.

Attention

For the N1 wave, an increase in attention to the eliciting signals is associated with a prominent increase in amplitude on the order of up to 50percent Particularly for the N2 or processing negativity component (Davis, 1964; Hillayrd, Hink, Schwent & Picton 1973; keating & Ruhm, 1971). The P2 wave, however, appears to diminish

with increased attention by the subject on the signals (Michie, Solowij, Crawford & Glue 1993). Characteristically, the Nd (100 ms, negative wave that persists beyond the signal) wave is enhanced (greater negativity) when the subject's level of attentions to a signal, or even some aspect of the signal, increased (Alho et al 1986), whereas the superimposition of this negativity in the latency region of 175 to 250ms has just the opposite effect on the positive voltage P2 component, i.e., smaller amplitude.

Sedatives

ALLR variability increased with sedatives (Hosick & Mendel 1975; Skinner & Antinoro, 1969; Skinner & Shimota, 1975). Measurement of ALR response under sedation is ill advised, as validity of finding may be compromised. Mendal et al (1975) reported that secobarbital-induced sleep was associated with increased variability in ALRs and in turn, less accurate auditory threshold estimations. ALR N1, P2 and N2 component amplitude is reduced, but latency was not affected (Lader, 1977).

Type of Stimulus

Cortical auditory evoked potentials (CAEPs) have been recorded using a wide range of stimuli including tones, clicks and speech stimuli. Several studies have shown differences in CAEPs latencies for different stimulus frequencies recording using conventional evoked potentials and magnetoencephalography techniques (Crottaz-Herbette & Ragot,2000; Jacobson, Lombardi, Gibbens, et al 1992; Roberts and Poepple,1996; Salajegheh, Elster, Burghoff, et al., 2004; Verkindt, Bertand, Perrin et al.,1995; Woods, Alain, Covarrubias and Zaidel, 1993). Most commonly used stimuli for the clinical assessment are the long duration stimuli. The use of long

duration stimuli minimizes the spread of cochlear excitation and maintains the frequency specificity (Hyde. 1997).

Tone stimulus

Since early investigations in the 1960's by Davis and Colleagues, tonal stimuli have typically been used to elicit the ALR (Davis, Bowers & Hrish, 1968). As a rule, amplitude for the N1 and P2 components of the ALR are larger and latencies were longer, for low frequency tonal signals in comparison to higher frequency signals (Alain, Woods & Covarrubias, 1997; Antinoro et al 1969; Jacobson et al 1992).

Complex tones stimulus

Some components of the ALR (P100 and N250) show larger amplitude and shorter latency for complex tones than for single-frequency (sinusoidal) tonal stimuli. Two major ALR components N1 and P2 can also be elicited by the modulation of amplitude or frequency of a tonal signal, reflecting neural detection of the acoustic changes (Kaukoranta, Hari & Lounasamaa, 1987; Naatanen & Picton, 1987).

Speech stimulus

There has been increasing interest in the use of cortical potentials to investigated the neural encoding of speech (Tremblay, Billings, Friesen, & Souza, 2006). There is some evidence that CAEPs in infants evoked by different speech phonemes differ in latency and morphology (kurtzberg, 1989). CAEPs differences between speech stimuli are an indication of different underlying neural representations of speech sounds and suggest that the information needed to differentiate the stimuli is available to the listener.

ALLR findings have been reported for different types of speech signals, including natural and synthetic vowels, syllables, and words (Ceponiene et al 2001; Kurtzberg, 1989).Although it allows the researchers to manipulate certain aspects of stimulus, but still they are only a low dimensional approximation of natural speech. for this reason, natural speech tokens, rather than non-speech stimuli, may be more effective in identifying neural processing problems in people with hearing impaired speech understanding (Tremblay, Friesen, martin & Wright, 2003).however, because natural stimuli contain highly complex time varying signals evoking multiple overlapping neural response patterns, some investigators belived that CAEP's evoked by naturally produced speech might be less reliable compared with those elicited by clicks, tones or synthesized speech sounds.

In general, amplitude of the N1 to P2 complex is larger for speech sounds than for single frequency tonal stimuli, but latency values for the N1 and P2 are usually earlier for tonal versus speech stimuli (Ceponiene et al 2001; Tiitinen et al 1999). The latency of the ALR N1 component varies with the frequency of tonal signals (Crottaz-Herbette & Ragot, 2000; Roberts, Ferrari, Stufflebeam & Poepple, 2000), where as for natural speech sounds the N1 latency is consistently about 120ms (Makela et al., 2001).

Natural vowel sound generated ALR components (N1 and later waves) that are detected with consistently larger amplitude from the left hemisphere, whereas tonal stimuli produced symmetrical brain activity (Szymanski et al., 1999).

There is long standing evidence that tonal stimuli and synthetic speech sounds produced repeatable ALRs (Pekkonen, Rinne & Naatanen, 1995; Tremblay et al 2001). Tremblay et al (2003) demonstrated that natural speech sounds also elicit

reliable ALR components (P1,N1 and P2). Inter-subject reliability was high, and the ALR was stable within subjects from one test session to the next.

Among some of the earlier studies of eliciting CAEP's using speech stimuli, Ostroff, Martin & Boothroyd (1998) obtained P1-N1-P2 responses in 8 adults with normal hearing. The morphology and latency of the response suggests that it is an N1-P2 potential to the acoustic changes occurring at the CV transition. This change occurring during an acoustic stimuli changes occurring during an acoustic stimulus is called Acoustic change complex (ACC).

Subsequently Sharma, Marsh & Dorman (2000) examined the relationship between morphology of N1 and the perception of voicing contrast in syllable initial position in 5 males and 5 females in the age range of 20-30 years. Two sets of continua of CV speech sounds varying in VOT were generated. For /ga to ka/ VOT varied from 0-70 ms and for /ba - pa/ VOT varied from 0-60 ms. behavioral identification and N1 response was obtained. Results revealed that behavioral identification scores from 10 subjects showed a mean category boundary at a VOT of 46ms for the /ga-ba/ continua and a VOT of 27.5ms for the /ba-pa/ continua. The reliability of CAEPs using naturally produced speech sounds was evaluated by Tremblay, Friesen, martin & Wright (2003). P1-N1-P2 responses were obtained from 7 normal hearing young adults in response to four naturally produced speech tokens /bi, pi, si, ʃi/. Results revealed that P1-N1-P2 responses were reliably recorded using naturally produced speech token, representing different acoustic cues, evoking distinct neural response patterns. it was concluded that this has potential application to the study of neural processing of speech in individuals with communication disorders as well as changes over time after various types of auditory rehabilitation.

Rate and inter-stimulus interval (ISI)

The ALLRs are highly dependent on ISI (Budd et al., 1998; Davis et al., 1966). The duration of monoaural signals used in eliciting the ALR is often about 50 or 60 ms (20 ms rise and fall times, plus a 20 ms duration), or even longer. Consequently, the total accumulated duration constitutes a considerable portion of the analysis time. Importantly for the ALR, recovery times (neural refractory periods) are also longer. Some of the early studies confirmed that longer ISIs and, concomitantly, slower stimulus rates produced substantially larger amplitudes for N1 and P2 components, but had little effect on the latency of these ALR components (Davis et al., 1966; Hari et al 1982). The effect of ISI on the ALR amplitude was interpreted as linear relation with the refractory period of neurons in the auditory cortex. Presentation of a signal during the neuronal recovery process results in smaller than optimal amplitude. Conversely, with increases in the ISI there are predictable increases also in ALR amplitude (Davis et al., 1966; Davis & Zerlin, 1966).

P2 is enhanced by higher intensity sounds and longer interstimulus intervals (Ceponiene, Rinne,et al., 2002; Picton, Hillyard, Krausz, & Galambos, 1974; Picton, Woods, & Proulx, 1978a), and diminished during sleep (Paavilainen et al., 1987; Picton e t al., 1974), but w as also enhanced when sounds were actively ignored (Alho, Tottola, Reinikainen, Sams, & Naatanen, 1987; Rif, Hari, Hamalainen, & Sams, 1991; Woods, Hillyard, & Hansen, 1984). Therefore, it is possible that the P 2 generators modulate conscious perception thresholds.

Clinical application

P1-N1-P2 responses are typically used by audiologists to estimate threshold sensitivity, especially in adults; to index changes in neural processing with hearing

loss and aural rehabilitation; and to identify underlying biological processing disorders in people with impaired speech understanding.

The major application of CAEPs comes from the fact that it can be recorded from premature and full term newborns, and from the older children (Barnet et al., 1996). Various researchers have reported that CAEP latency decreases and amplitude increases as a function of age during the childhood until ten years of age, although the most pronounced changes occur within first year of life, and to lesser extent within two to five year age range (Rapin & Grazaini, 1967). Cranford & Martin (1991) study showed that amplitude decreases with advancing age.

Estimation of hearing sensitivity

The clinical application of LLR has been limited. It can be used for threshold estimation in difficult to test population (Korczak, Krutzberg & Staplles, 2005). However since factors such as sleep and alertness affect the responses (Picton & Hillyard, 1974), it is not widely used for threshold estimation. It may play a role in assessing hearing sensitivity when auditory brainstem responses (ABR) are absent due to dyssynchronous firing of auditory nerve (Kraus & Cheour, 2000).

Suzuki and Origuchi (1969) compared thresholds of averaged evoked response to auditory stimulation for sleeping young children with thresholds obtained from conditioned orientation reflex (COR) audiometry. They recorded the evoked response using tone bursts of 500, 1000, 2000 and 4000 Hz. Results showed that for normal children the mean difference between both thresholds was 10.38 dB and COR threshold was more sensitive, and 96.2 per cent of measurements fell within the range between 0 and 20 dB. For slightly or moderately impaired children the mean difference decreased to 6.38 dB and COR thresholds were more sensitive. For

severely impaired subjects the mean difference was only 0.43 dB and evoked response was more sensitive.

Tsu, Wong & Wong (2002) verified the magnitude of discrepancy between thresholds estimated by CAEPs and by pure-tone audiometry (PTA). They found that the mean discrepancy values between PTA and thresholds obtained using CAEPs were less than 5 dB at high frequencies. More than 83.2% of adults had a cortical evoked response audiometry thresholds and PTA threshold discrepancy within 10 dB.

Bindu (2008) studied the relationship between ALLR threshold and the behavioral threshold in normal and hearing impaired individuals using click stimulus. It was found significant correlation between behavioral threshold and ALLR threshold in sensorineural hearing loss individuals but, there was no significant correlation in normal hearing individuals.

Hearing aid fitting

CAEPs may be a good electrophysiological tool for assessing hearing aids because they are reliably present in infants (Kurtzberg et al, 1984; Pasman et al, 1991) and they can be recorded using relatively long duration stimuli (Hyde, 1997). A few case studies reported in the literature have shown that cortical evoked potentials can be used to demonstrate the benefits of amplification in children and infants with hearing impairment (Gravel et al, 1989; Rapin & Graziani, 1967).

Rapin and Grazianni (1967) found that the majority (5 of 8) of 5 to 24-month-old subjects with severe to profound sensorineural hearing loss showed an

improvement in ERP thresholds of at least 20 dB in the aided, compared with the unaided, condition.

Kurtzberg et al. (2005) compared cortical ERPs with speech stimuli in the aided versus unaided conditions in four children with moderate to profound sensorineural hearing loss. Result showed that one child with a progressive hearing loss initially demonstrated a large obligatory response in the aided condition that later disappeared when she could no longer behaviorally respond to the sound.

Shruthi (2007) recorded ALRs using /i/, /m/ and /s/ in 10 hearing impaired SN hearing loss children in the age range of 5 to 7 years. The ALR were recorded in the unaided and aided conditions. The responses were compared with that of 10 age matched controls. The ALR were reliably elicited in all the participants of normal hearing group and in aided condition in the hearing impaired cases for all the stimuli. The response obtained for the three stimuli resulted in distinct responses indicating that the stimuli are coded differently in the auditory system.

Cochlear implant

The P1 component of the P1–N1–P2 complex has been used to monitor development of the central auditory system in normal hearing children and children with cochlear implants (Cunningham, et al., 2000; Eggermont, et al., 1997; Ponton, et al., 1996a, 2000b; Sharma, et al., 1997, 2002).

Ponton et al. (1996a, b,) have extensively studied auditory system plasticity in young children with cochlear implants. They found that children who used cochlear implants have response patterns that are immature and show prolonged latency relative to their normal-hearing peers. Interestingly, the degree of immaturity was

proportional to the number of years of auditory deprivation, suggesting that the central auditory system does not fully mature without stimulation. Because the reintroduction of sound through electrical stimulation restored the normal maturational process, they concluded that the auditory system retains its capacity for change (plasticity) during the period of deafness. This link between auditory ERPs and the duration of auditory deprivation has been supported by the findings of other researchers (Firszt, et al., 2002; Kelly, et al., 2005; Singh, et al., 2004; Sharma, et al., 2002), and, indeed, ERPs may provide evidence for a "critical period" for auditory development in this population (Sharma, et al., 2005).

Sharma, et al., (2002) reported that children implanted before 3.5 yrs of age tend to show normal P1 latencies within 6 months of implantation; children implanted at 7 yrs of age generally show persistent prolongations in P1 latencies; and children implanted between 3.5 and 7 yrs of age show mixed results.

Auditory dys-synchrony

Recent studies indicate that ALLR may be useful in evaluation of auditory neuropathy/ auditory dyssynchrony (Kraus et 2000). Earlier investigations have reported a good correlation of morphology of ALR with acoustic features of speech. Rance et al (2002). Found that the development of reasonable speech perception performance in children with auditory neuropthy was correlated with ALRs of normal latency, amplitude and moprophology whereas, the absence of ALR was correlated with poor speech recognition scores. Thus, ALRs are thought to reflect the functional integrity o f the auditory pathway involved in processing of comlex speech stimuli (Trembley et al., 2003).

An investigation by Singh, Garg, Madappa & Barman (2006) suggest that ALLR may help in differentiating between infants with auditory neuropathy/auditory dys-synchrony and those with maturation delay.

Aural rehabilitation

One of the recent applications of CAEPs is monitoring experience related changes in neural activity. Because the central auditory system is plastic, that is, capable of reorganization as a function of deprivation and stimulation, CAEPs have been used to monitor changes in the neural processing of speech in patients with hearing loss and various forms of auditory rehabilitation such as use of hearing aids, cochlear implant and auditory training (Jacobson, 1993).

The goal of the auditory training would be improve the perception of acoustic contrasts. In other words, patients are thought to make new perceptual distinctions. ALRs have been used to examine the brain and behavior changes associated with auditory training. Trembley and Kraus (2002) reported that when individuals were trained to perceived different sounds, changes in the N1-P2 complex were observed. As perception improves, N1-P2 peak to peak amplitude increase. Because ALR changes have been shown to occur prior to improvement in behaviour perception of speech sounds, physiological recording may be helpful to predict the prognosis (Trembley, 1998).

When individuals are trained to perceive and identify two different sounds, changes in the N1–P2 complex are observed (Tremblay, et al., 2001; Tremblay & Kraus, 2002). More specifically, as perception improves, N1 and P2 amplitudes increase. Changes in the N1–P2 were interpreted to reflect changes in neural encoding patterns.

Tremblay, et al. (1998) showed that changes in ERPs occur before improvements in the behavioural perception of speech sounds, thus electrophysiologic recordings might help the clinician in aural rehabilitation.

Generation and developmental changes of CAEP components.

The use of tonal and speech sounds as stimuli for the cortical AEP affords a capability for examining maturational differences in the frequency-specific cortical responses to complex sounds during this critical early period (Gerald et al 1989).

Studies of age-related changes in auditory evoked potentials (AEPs) have demonstrated at least 3 features of human central auditory system maturation (Ponton et al., 2002)

- ✓ First, maturation rates are not the same throughout the auditory system (Ponton et al., 1996a,b).
- ✓ Second, comparisons of maturation rates for latencies of the different AEP peaks indicate that this activity must arise from parallel subsystems in the thalamo-cortical pathway, since the early maturing peak P2 has a longer latency than the more slowly maturing shorter latency N1b (e.g. Ponton et al., 1996a, 2000a).
- ✓ Third, generators or pathways contributing to a single evoked response peak may be distinguished by very different maturation rates.

P1component

P1 is the first vertex positive peak of the CAEP (P1–N1–P2 complex). It typically occur approximately 50 msec after stimulus onset in adults with normal hearing. It is a positive peak occurs between 60 to 80ms and having amplitude of

about 7microvolts with a width of about 15ms. It is thought to represent late thalamic projections in to the early auditory cortex and is part of the specific sensory system (Velasco et al, 1989). The P1 response appears to be strongly related to stimulus parameters.

LieÈgeois-Chauvel et al., (1994) recorded intracerebral auditory cortical areas in humans which indicate that a major source of activity contributing to the P1 peak (adult latency of 40-60 ms) originates from the lateral portion of Heschl's gyrus, i.e. secondary auditory cortex. Some studies showed that neural generators of P1 include primary auditory cortex (Heschl's gyrus), hippocampus, planum temporale, and lateral temporal regions and possibly subcortical regions (Goff, 1978; Grunwald, et al., 2003; Howard, et al., 2000; Huotilainen, et al., 1988; Kisley, et al., 2003; Liegeois- Chauvel, et al., 1994, 1999; Reite, et al., 1988; Wood & Wolpaw, 1982).

The early positive peak, P1, is initially very broad with a latency of about 80 ms; it is identifiable at electrodes C3, C4, Cz and Fz. As age increases, the latency of this peak decreases to less than 50 ms. Commensurate decreases in the amplitude of P1 also occur. Morphological changes in the P1 peak, as well as latency and amplitude changes, are easily traceable across the age range, a fact that has been used previously to quantify its maturation (Ponton et al., 1996a, 1996b). Both latency and amplitude of P1 decrease as a function of age. The peak latency decreases from approximately 80-110 ms in 5-6 year olds to 30-50 ms in 18-20 year olds (Ponton et al 2000).

The P1 predominated at and around the vertex. However, its amplitude and latency changed significantly with age. During early childhood (1–4 years), the P1 is the most predominant peak (Kushnerenko et al., 2002; Pang and Taylor, 2000). In

children 8 years of age and younger, the AEPs are dominated by positive peaks when elicited at relatively fast stimulus presentation rates of 1 Hz or more. Thus, when these short inter-stimulus intervals are employed, the P1 component is robustly present even in 5 year olds (Ponton et al., 1996a, 1996b).

The latency of P1 did not change during the first six years of life. But in children 5 years and over, there is generally a decrease in P1 latency with age (Cunningham et al., 2000; Molfese et al., 1975; Oades et al., 1997; Ponton et al., 2000; Ponton et al., 1996; Rojas et al., 1998; Sharma et al., 1997; Tonnquist-Uhle´n et al., 1995). There is little change in P1 latency from 5–10 years but a marked decrease after 12 years (Cunningham et al., 2000).

From 4 to 9 years, there was a trend for the P1 amplitude to increase, which was consistent with the findings of Ponton et al. (2000) who reported a spurt of P1 amplitude growth at around 9–10 years. In children 6–7 years the response is equally large over the frontal and central scalp and larger than over the posterior scalp (Satterfield et al., 1988), whereas in older children (8–14 years) it is maximal frontally (Kurtzberg et al., 1995; Nelson et al., 1997) or at the vertex (Ceponiene et al., 2002).

In the 4-year-old children, the P1 (114 ms) was significant at all electrode sites measured, except for the first frontal line. Their P1 was significantly larger at the locations surrounding the vertex than at the front or the back of the head (anterio-posterior effect. In the 9-year-old children, the P1 (104 ms) also predominated around the vertex, its anterio-posterior amplitude effect being highly significant: As in the 4-year-olds, this effect originated from the P1 amplitudes being larger over the central than over the frontal or parietal areas. For the P1 amplitudes, the age effect was

significant for tone burst. The stimuli were harmonic tones composed of the 3 lowest partials of a 500 Hz sinusoidal. The second (1000 Hz) and the third (1500 Hz).

The P1 in children was larger in amplitude than that in adults for both syllable (/ba/, /da/ and /ga/) and non phonetic stimuli, respectively. The P1 for syllable was anterior than compare to non phonetic, but no such difference w as found in adults. The P1 latency was longer in children than in adults (Ceponiene et al, 2005).

N1component

It is a second, negative peak occurs between 90-100ms with amplitude of about 10microvolts and a width of 40 to 50ms. N1 consists of multiple components observed at the vertex and over temporal sites (NaÈaÈtaÈnen and Picton, 1987). The vertex N1 (or N1b), evoked at about 100 ms to tones, is a fronto-central negativity generated by bilateral vertically oriented dipoles on the supratemporal planes of the auditory cortices (Vaughan & Ritter, 1970). The T-complex N1 (Wolpaw & Penry, 1975) is largest at temporal electrodes and consists of a negative component, the N1a, at approximately 75 ms, and a second negative component, the N1c, at approximately 130 ms (McCallum & Curry, 1980; Giard et al., 1994). This complex originates in the auditory association cortices in the superior temporal gyri and can be modeled by bilateral radially-oriented dipoles (Scherg & von Cramon, 1986).

Studies on N1 generators in children are still scarce. Bruneau and coworkers (1997) showed that in children younger than 6 years, the N1b peak corresponding to the supratemporal N1 component; was anterior to that in adults. After age 6, its predominance shifted centrally (Woods, 1995).

Similarly, Tonnquist-Uhlen (1995) in 8- to 16-year-old children found that the topography of the N1b was similar to that in adults. The aforementioned evidence pointed to the differences in the generator morphology of young children's and adult N1. However, in these studies, in children, the N1 was obtained with long interstimulus intervals(ISIs) only. Whereas in adults, the component structure of the N1 differs with short vs. long ISIs, it remains uncertain whether it is the same in case of children.

The N1b peak is not consistently present until age 9 and older. A small but consistent N1b may be recorded from 5-7 year olds, but only for slower stimulus presentation rates (e.g. Paetau et al., 1995; Bruneau et al., 1997; CeponieneÂ et al., 1998). In contrast, the AEPs putatively generated by the lemniscal pathway, such as N1b, mature more slowly and do not reach adult latency values until adolescence (Courchesne, 1978, 1990; Tonnquist-UhleÂn, 1996; Sharma et al., 1997).

Karhu et al. (1997) said that in 9-year-old children, the N1 was largest in response to the first tone in a sequence (though smaller than that in adults) and decreased in amplitude with tone repetition by approximately 50%. This diminution of children's N1, coupled with its longer latency, caused it to nearly fuse with the N2 peak.

Although in adults, the N1 has been well characterized, studies on N1 generators in children are still scarce. Bruneau and coworkers (Bruneau and Gomot, 1998; Bruneau et al., 1997) showed that in children younger than 6 years, the N1b peak (corresponding to the supratemporal N1 component; Woods, (1995) was anterior to that in adults. After age 6, its predominance shifted centrally.

Similarly, Tonnquist-Uhlen (1995) in 8- to 16 year old children found that the topography of the N1b was similar to that in adults. The aforementioned evidence pointed to the differences in the generator morphology of young children's and adult N1. However, in these studies in children, the N1 was obtained with long ISIs only. Whereas in adults, the component structure of the N1 differs with short vs. long ISIs, it remains uncertain whether it is the same case in children.

In adults, the N1 also decreased in amplitude with tone repetition but remained as the largest negativity across all trials. Further, the scalp distributions of N2 were found to change with the maturation, which might indicate different component structure (and thus the function) of children's and adults' N1. The neural bases underlying these maturational N1 are unclear. In particular, does the enhancement of the N1 mainly reflect the functional refinement of the underlying networks, or could these changes be linked to the substantial structural reorganization of their generators (Bruneau et al., 1997).

Oades et al. (1997) reported that the scalp distribution of N1 was more widely distributed in their younger participants (10–14 years) andt it became more localised, and less widespread in older adolescents and young adults (15–22 years).

The latency of N1 did not change during the first six years of life. But in children 5 years and over, there is generally a decrease in N1 latency with age (Cunningham et al., 2000; Molfese et al., 1975; Oades et al., 1997; Ponton et al., 2000; Ponton et al., 1996; Rojas et al., 1998; Sharma et al., 1997; Tonnquist-Uhle´n et al., 1995). N1 latency decreases at midline sites for 6–8year olds compared to 4–6year olds but not at temporal ones (Bruneau et al., 1997).

P2 component

It is a third positive peak occurring at about 100-160ms with amplitude of about 6 microvolts and a width of about 40 to 50ms.In children, the P2 was strictly posterior to the vertex, whereas in adults it was distributed widely over the scalp.The P2 peak, which has an adult latency of 140-170 ms, follows the N1b peak in the AEPs. Convergent results from several studies indicate that unlike the N1b peak, P2 is not generated in temporal cortex. This peak at least partly reflects auditory driven output of the mesencephalic reticular activating system (RAS), which responds to input from all sensory modalities (Skinner and Yingling, 1977; Knight et al., 1980, 1988; NaÈaÈtaÈnen and Picton, 1987; Rif et al.,1991; Woods et al., 1993; Yingling and Skinner, 1997).

The AEP data reported by Barnet et al. (1975) indicate that the latency of the P2 peak reaches adult values at age 2-3 years, closely following the maturational time course of the auditory brainstem response wave I-V interpeak latency (Eggermont, 1985; Ponton et al., 1992). Ponton et al., 2000 found that at 5–6 years the response was (almost) only present at Pz, and at very low amplitude or absent over temporal, central and frontal scalp. Around 9 years the response became evident at central and frontal sites as well as parietally and after 10 years there was a transition to a more fronto–central distribution. Oades et al. (1997) also found that in 10 year olds the maximal response was posterior to the vertex and clearly larger than at frontal sites.

The latency to P2 in the 19-20 year olds is apparent at electrode Pz in the 5-6 year olds. The P2 peak is apparent at electrodes Fz and Cz by age 9 and is larger at the midline electrode locations than elsewhere on the scalp in older subjects. The P2 peak did not differ in overall amplitude between the 9-year-old children and the adults. In

the children, the P2 sharply increased in amplitude posteriorly and was inverted in polarity frontally. In the adults, the P2 was distributed more evenly and widely over the scalp, which was slightly anterior to that of the children. The significant differences between the children's and adults' P2 amplitudes were obtained frontally where adults showed the P2 and children showed none, and over the most posterior areas, where the children's P2 was larger in amplitude than that in adults (Ceponiene et 2002).

It is evident from the above review of literature that there is a shift in latency and decreased amplitude with the increase in age. It is also reported that different components of CAEP appears at different age and tend to reach adult value at different age. Most of the earlier studies have been carried out in this regard using only the non-speech stimulus like click or tone burst. Hence the current study was taken with the aim to see changes in ALLR responses with changes in age in pediatric population for both speech and non-speech stimulus and also to know whether the speech evoked ALLR follows the similar pattern that is observed for non-speech evoked ALLR.

Chapter 3

Method

The present study was taken up with the aim to investigate the cortical auditory evoked responses in children using syllable (/da/) and non-speech stimuli (500Hz tone burst). The current study also aimed to observe any difference in ALLR response exists between non-speech and speech stimulus and the stimulus which would elicit a better ALLR response in children.

Subjects

To arrive at the aim of the current study, a total of 30 Children were taken. The age of the participants ranged from 2 to 15 years and they were divided into 3 groups.

Group 1: had 10 children from 2 to 4 years 11 months of age.

Group 2: had 10 children from 5 to 9 years 11 months of age.

Group 3: had 10 children from 10 to 15 years of age.

This groups were made based on the developmental changes observed by Anu Sharma et al. 1997, Courchesne, 1990, Cunningham et al., 2000; Molfese et al., 1975; Oades et al., 1997; Ponton et al., 2000; Ponton et al., 1996; Rojas et al., 1998; Sharma et al., 1997; Tonnquist-Uhle´n et al., 1995. They observed that frequency of occurrence of the cortical potentials appears to increase with age. The latency of P1 and N1 did not change during the first six years of life. But in children 5 years and over, there is generally a decrease in both P1 and N1 latency.

Subjects selection criteria

The subjects were selected based on the following criteria.

- Hearing sensitivity was within normal limits. This was assessed either using Visual reinforcement audiometry (VRA) or Auditory brain stem response (ABR) in young children and Pure tone audiometry in children who could give voluntary response to the pure tone stimulus.
- They had 100 percent speech identification scores (picture identification task for younger children and repetition task was used for the older children).
- All of them had 'A' type tympanogram with presence of acoustic reflexs.
- TEOAE were present in all the subjects.
- No relevant Otological or neurological history or symptoms were present or expressed.

Instrumentation

In the current study the following instruments were used

- A calibrated two channel diagnostic audiometer (OB-922) was used for visual reinforcement audiometry, pure tone and speech audiometry.
- A calibrated Grason Stadler (GSI) Tympstar was used to carry out the tympanometry and reflexometry in order to rule out the presence of middle ear pathology, to know that the causing absence of the TEOAE or prolongation of LLR waveforms was not because of middle ear pathology.
- ILO- Version 6 was used to record TEAOEs in order to examine the status of the outer hair cells.

- An evoked potential system (Biologic navigator pro version 7.0) was used to record ABR to check the integrity of neural pathway at the levels of brainstem and ALLR to check the maturation of neural pathway at the cortical level respectively.
- All the instruments were calibrated prior to use.

Test stimuli

500Hz tone burst of 60 ms (20 ms rise time/fall time and 20 ms plateau) and the syllable /da/ was used to record ALLR. The syllable /da/ was spoken by a male speaker and digitally recorded using adobe audition version 3.0 with the sampling frequency of 44,000Hz and 16 bit resolution. The naturally recorded /da/ syllable was then edited. The voice onset time, burst portion and a little portion of the vowel was retained to make the syllable duration approximately 150ms. The /da/ syllable used in this study as this syllable pose great perceptual challenges to clinical populations such as the hearing and learning impaired (Tallal & Stark 1981; Turner et al 1992; Kraus et al 1996).

Test environment

All the audiological evaluation and AEP recording was carried out in a well illuminated and sound treated room. The noise level inside the room was within the permissible levels as recommended by ANSI (1991; S3.1).

Procedure

Pure tone audiometry

The behavioral threshold in octaves frequencies from 250 Hz to 8 kHz for air conduction and 250Hz to 4 kHz for bone conduction was obtained. The thresholds were traced using modified Hughson and Westlake method (Carhart & Jerger, 1959).

Visual reinforcement Audiometry

One of the difficulties is to make the child respond to a sound which is audible to them. This procedure was carried out to younger children who were not cooperative for pure tone audiometry. The child was made to sit in front of the equipment. On either side of child speaker was kept which was connected to audiometer. The computer and monitor kept in the clients room was used to present the pictures. The child was trained to look immediately towards the pictures when ever they heard the tone. A head turn in the direction of the picture was recorded as a response. The testing was started with presentation of 500 Hz warble tone at 70 dBHL, (Day et al.,2000) gradually reducing the intensity and the minimum intensity at which response was observed was taken as threshold. Same procedure was carried out for 1 KHz, 2 KHz and 4 KHz.

Speech audiometry

For elderly children speech identification scores (SIS) were obtained at 40 dB above the Speech recognition threshold (SRT) using speech stimuli developed by Vandana (1998) and in case of younger group SIS was obtained using picture identification list in kannada developed by Vandana (1998).

Typmanometry and reflexometry

It was carried out using 226Hz probe tone. Reflex eliciting tone of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were presented ipsilaterally and contralaterally to find out the presence or absence of acoustic reflexes. A significant change of admittance value of at least 0.03ml was considered as presence of reflex. This was done to rule out middle ear pathology.

TEOAE

It was measured using the default setting in the instrument (ILO-V6) using non-linear click trains of 260sweeps. Foam tip was properly positioned in the external auditory canal to get a flat frequency spectrum across the frequency. The overall TEOAEs amplitude of 6 dB SPL above the noise floor with the reproducibility >80% was considered as presence of TEOAEs Dijk & Wit (1987).

Recording of auditory brainstem response (ABR)

It was recorded for those children where pure tone threshold could not be obtained. Electrode sites were cleaned using NU prep cleaning gel to remove the dead cells and dirt. Conductive paste was used to increase the conductivity between skin and the electrode. A surgical tape was used to hold the electrode in place firmly. 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.

Subjects 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. The protocol used to record ABR is given in table1.

Table 1: *Protocol used to acquire ABR*

Stimulus parameter		**Acquisition parameters**	
stimulus	Clicks	Mode of stimulation	Monoaural
Polarity	Rarefraction	Electrode montage:- Inverting electrode(-) was placed on test ear mastoid, where as non-inverting electrode(+) were placed on higher fore head (fz) and Ground electrode on non-test ear mastoid	
Number of sweeps	2000	Filter setting	30Hz to 3KHz
Stimulus rate	30.1	Transducer	ER-3A Insert ear phone
Intensity	40 dB nHL	Analysis window	15ms
		Notch filter	On
		Replicability	Twice
		Amplification	1,00,000

Subject with presence of wave V at 40 dB HL was considered as having normal hearing. Children who fulfilled subject selection criteria have undergone ALLR recording for both speech and non-speech stimulus.

Recording of Auditory long latency response (ALLR)

Older children were instructed to sit comfortably on a reclining chair and relax during the testing. They were also instructed to stay awake during the testing. They were asked to ignore the stimulus and restrict the movement of head, neck and eye during testing. For younger children ALLR was recorded when they are quite and /or sleeping. Preparation of the subjects and electrode montage used to record ALLR was the same as used for ABR recording.

ALLR were recorded twice for the reproducibility for both speech and non-speech stimuli.The protocol used to record ALLR is given in table 2

Table 2: *Protocol used to record ALLR*

Stimulus parameter		**Acquisition parameters**	
Stimulus	500 Hz tone burst speech stimuli /da/	Mode of stimulation	Monoaural
Polarity	Alternate		
Number of sweeps	300	Filter setting	1 to 30Hz
Stimulus rate	1.1	Transducer	ER-3AInsert ear phone
Intensity	80 dB nHL	Analysis window	500 ms
		Notch filter	off
		Amplification	50,000

Waveform analysis

Waveforms recorded from each subject were given to three audiologists for identification of peaks. Once there was agreement in identification of ALLR wave components (P1, N1and P2), the latency of P1, N1and P2 and the peak to peak amplitude of N1-P2 complex were noted is calculated for both speech and non-speech stimuli.

The mean, standard deviation and range for latency P1,N1,P2 and peak to peak amplitude of P1-N1 and N1-P2 complex were calculated for both speech and non-speech stimuli.

The latencies of P1, N1and P2 and amplitude of P1-N1 and N1-P2 complex were compared across the groups and between the stimuli to see if there was any significant difference between the groups and across stimuli to assess the maturation and the stimuli which could elicit better ALLR response in children.

The N2 component was not studied as it may or may not be present in normal subjects (Hall, 2007) and considered as not truly an exogenous potential, as it is affected by intrinsic factors such as attention and sleep (Ritter, Simson & Vaughan, 1983; Shibasaki & Miyazaki 1992). Most of the subjects in group 1 were asleep during recording. It also shows more intersubject variability and it amplitude depends on subject expectation of the occurrence of the stimulus (Duncan-Johnson & Donchin, 1977; Roth, Ford, Lewis, & Kopell, 1976). It is particularly affected by the attention to the stimulus and varies with the perceptual acoustic features of the audition (Mc person, 1996).

Chapter 4

Result and discussion

The aim of the study was to investigate the effect of age on latency, absolute amplitude and peak to peak amplitude of syllable /da/ and 500Hz tone burst evoked cortical auditory evoked potentials. Also aimed to know whether there is any difference in ALLR parameter elicited by non-speech and speech stimuli and the most effective stimulus which would elicit better ALLR response in children. To arrive at the goal, the peak latency of P1, N1, P2, absolute amplitude of P1, N1, P2 waves and peak to peak amplitude of P1-N1, and N1-P2 component elicited by syllable /da/ and 500Hz tone burst were noted and compared.

Statistical analysis

To analyze the data, the following statistical analysis were carried out within and across the group of subjects for each ALLR parameter elicited by syllable /da/ and 500Hz tone burst:

- ***Descriptive statistics***: was administered to obtain the mean and standard deviation for all the parameters elicited by both the stimuli, across all age groups.
- ***One way ANOVA***: was administered to see the significant difference across groups for each parameter elicited by syllable /da/ and 500Hz tone burst. Though there were two stimuli and three groups as independent variables repeated measure ANOVA and MANOVA could not be administered due to uneven and reduced sample size as ALLR were absent in few individual in certain group for certain stimulus.

- ***Duncan's Post Hoc test***: was administered to see significant difference between any two groups for each CAEP component, when one way ANOVA showed significant difference.
- ***Kruskal-Wallis test***: was administrated to see the significant difference for N1-P2 complex amplitude elicited by syllable /da/ and 500Hz tone burst across groups as the sample size was small to compare.
- ***Wilcoxon's signed ranks test***: was administrated to see the significant difference for syllable /da/ and 500Hz tone burst evoked ALLR parameters (P1, N1 and P2 components) within the group due to uneven and reduced sample size.

Waveform morphology

The overall results showed that younger children had longer latency and higher amplitude than the older group of children. As the age increased, the latency reduced and amplitude decreased.

ALLR record from group 1

Out of ten subjects participated, CAEPs could be recorded in 9 subjects. ALR was absent in one subject and hence it was not considered for statistical analysis. All nine subjects showed the presence of P1 and N1 components, where as four subjects had P2 component for both syllable /da/ and 500 Hz tone burst. They showed longer latency and larger amplitude compare to other two groups. ALLR recorded for syllable /da/ and 500 Hz tone burst from a subjects in group 1 is show in figure 1.

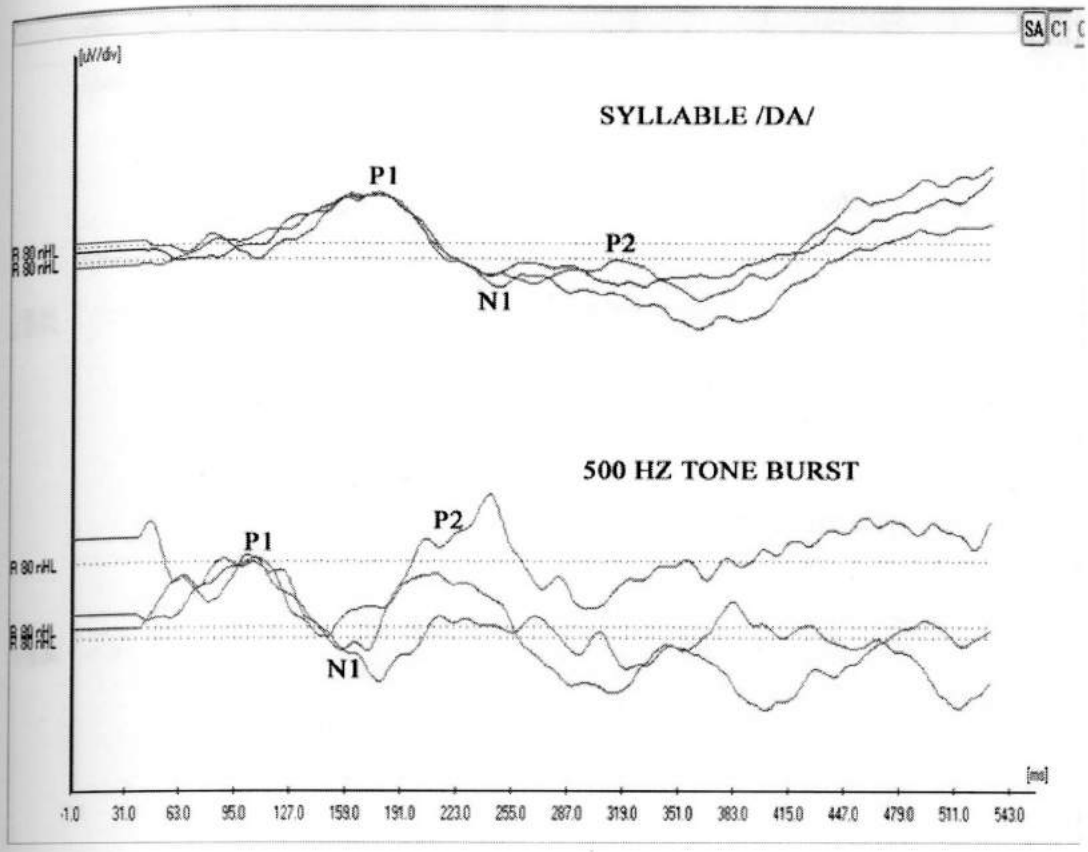

Figure 1. ALLR waves recorded using syllable /da/ and 500 Hz tone burst in a subject from group 1.

ALLR record from group 2

A total of ten subjects participated in this group. CAEPs could be recorded in 8 subjects for both syllable /da/ and 500 Hz tone burst and two subjects had more artifacts as they were not relaxed during ALLR recording. Hence, ALLR was not obtained. All the eight subjects showed the presence of P1, N1, where as four subjects showed the presence of P2 component. The latency was shorter and amplitude was less compare to group 1 but latency was longer and amplitude was more compare to group 3. ALLR recorded for syllable /da/ and 500 Hz in a subjects from group 2 is show in figure 2.

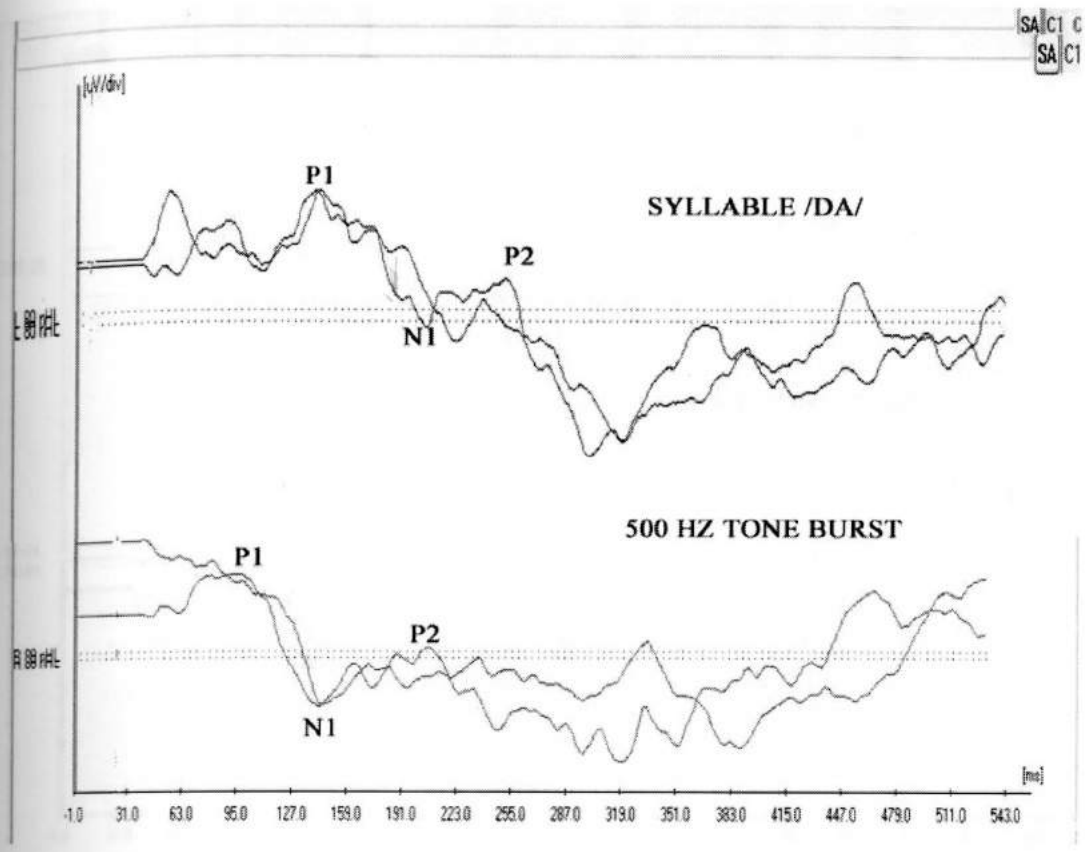

Figure 2. ALLR waves recorded using syllable /da/ and 500 Hz tone burst in a subject from group 2.

ALLR record from group 3

A total of ten subjects participated in this group. All the subjects showed the presence of P1 and N1 and P2 components for both syllable /da/ and 500 Hz tone burst. They all showed the shorter latency and reduced amplitude compare to the younger groups. ALLR recorded for syllable /da/ and 500 Hz tone burst in a subjects from group 3 is show in figure 3.

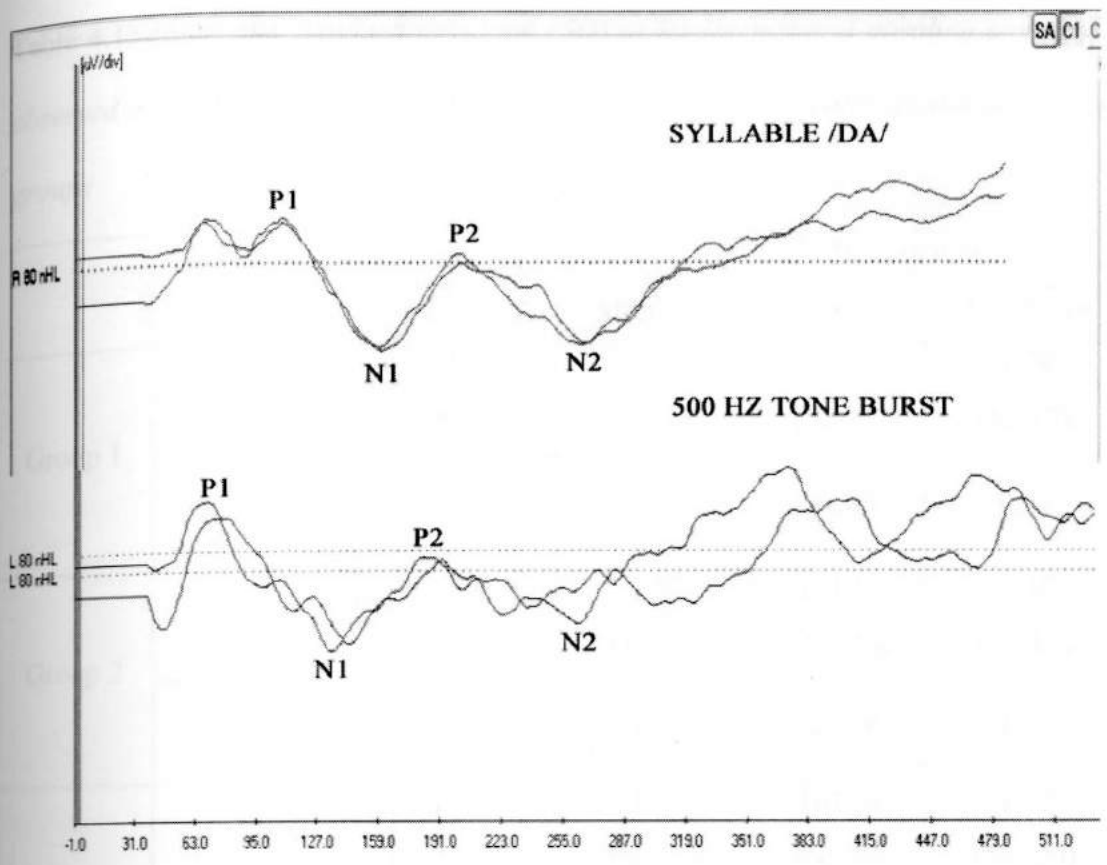

Figure 3. ALLR waves recorded using syllable /da/ and 500 Hz tone burst in a subject from group 3.

Age related changes of CAEP elicited by syllable /da/ and 500Hz tone burst

P1 component

The mean and standard deviation of P1 latency and absolute amplitude were calculated for all the groups recorded at 80dB nHL. This is shown in table 4.1.

Table 4.1: *Mean and standard deviation (SD) of P1 latency and absolute amplitude observed at 80dB nHL for both syllable /da/ and 500Hz tone burst stimuli across the groups*

		Syllable /da/		500 Hz tone burst	
		Latency	Amplitude	Latency	Amplitude
Group 1	Mean	135.29 (N= 18)	2.11 (N=18)	128.78 (N=17)	1.79 (N=17)
	SD	22.69	0.85	31.89	0.87
Group 2	Mean	121.76 (N=16)	1.77 (N=16)	111.06 (N= 16)	1.36 (N=16)
	SD	15.43	1.26	22.89	1.07
Group 3	Mean	115.14 (N=20)	1.05 (N= 20)	101.34 (N=20)	1.07 (N= 20)
	SD	12.88	0.99	14.93	0.47

N= number of ears in whom P1 could be recorded.

The table 4.1, shows that as the age increased, the P1 latency decreased and its absolute amplitude reduced for both the stimuli. Group 1 had longer latency and larger amplitude compare to group 2 and group 3 for both the stimuli. It can also be seen that P1 latency for 500 Hz tone burst was shorter and amplitude was reduced compare to syllable /da/.

One way ANOVA was administered to see the effect of age on P1 latency and amplitude for each stimulus. ANOVA results indicated a significant group interaction for P1 latency [$F(2, 51) = 6.496$, $P<0.05$] for syllable /da/. A significant interaction was also observed across the group for P1 latency elicited by 500Hz tone burst [$F(2, 50) = 6.175$, $P<0.05$]. Similar results was also obtained for P1 amplitude for both

syllable /da/ [F (2, 51) = 5.129, P<0.05] and 500 Hz tone burst [F (2, 50) = 3.541, p<0.05].

Duncan's post Hoc test was administered to see whether there were any significant difference between any two groups for P1 latency and amplitude elicited by syllable /da/ and 500Hz tone burst. It showed that both P1 latency and amplitude was significantly different across groups at 0.05 significance level for both the stimulus. The details of the test results are shown in table 4.2.

Table 4.2: *Duncan's post Hoc test results of P1 latency for both the stimuli.*

Groups	Syllable /da/		500Hz tone burst	
	1	2	1	2
10 to 15 years	115.14		101.34	
5 to 9.11 years	121.76		111.06	
2 to 4.11 years		135.29		128.78

It can be seen in the above table that the p1 latency obtained in group 1 was significantly different from group 2 and 3. P1 amplitude also showed the similar results which can be seen in table 4.3. The P1 amplitude obtained in group 3 was significantly less than that was obtained in group 1 for both the stimuli.

Table 4.3: *Duncan's post Hoc test results of P1 amplitude for both the stimuli.*

Groups	Syllable /da/		500Hz tone burst	
	1	2	1	2
10 to 15 years	1.0585		1.0755	
5 to 9.11 years		1.7769	1.3631	1.3631
2 to 4.11 years		2.1133		1.7971

Table4.5: *Mean and standard deviation (SD) of N1 latency and absolute amplitude observed at 80dB nHL for both syllable /da/ and 500Hz tone burst stimuli across the group*

		Syllable /da/		500 Hz tone burst	
		Latency	Amplitude	Latency	Amplitude
Group 1	Mean	229.12 (N=18)	-2.35 (N=18)	198.78 (N=17)	-1.49 (N=17)
	SD	43.95	1.55	34.70	0.77
Group 2	Mean	191.10 (N=16)	-1.83 (N=16)	183.00 (N=16)	-2.00 (N=16)
	SD	52.80	1.67	53.43	1.48
Group 3	Mean	166.89 (N=20)	-1.45 (N=20)	149.54 (N=20)	-1.70 (N=20)
	SD	25.76	0.84	24.07	0.47

N= number of ears in whom N1 could be recorded.

From the table 4.5, it can be seen that as the age increased, the N1 latency decreased and its absolute amplitude reduced for syllable /da/ where as for tone burst no such specific pattern could be noticed. Group 1 had longer latency compare to group 2 and group 3 for both the stimuli where as amplitude of N1 elicited by /da/ was maximum for group 1. Latency for 500 Hz tone burst was shorter compare to syllable /da/. Where as, for tone burst, group 2 and group 3 showed larger amplitude than group 1.

One way ANOVA was administered to see the effect of age on N1 latency and amplitude for each stimulus. ANOVA results indicated a significant group interaction for N1 latency [$F(2, 51) = 10.810$, $P<0.05$] for syllable /da/. A significant interaction was also observed across the group for N1 latency elicited by 500Hz tone burst

[F(2,50) = 8.068, P<0.05]. Where as no significant difference for N1 amplitude elicited by syllable /da/ [F (2, 51) = 2.072, P>0.05] and 500 Hz tone burst [F (2, 50) = 1.156, P>0.05] was noticed.

Duncan's post Hoc test was administered to see is there any significant difference between any two group's N1 latency elicited by syllable /da/ and 500Hz tone burst. It showed that N1 latency was significantly different across groups at 0.05 significance level for both the stimulus. The details of the test result is shown in the table 4.5.

Table 4.6: *Duncan's post Hoc test result of N1 latency for both the stimuli.*

Groups	Syllable /da/		500Hz tone burst	
	1	2	1	2
10 to 15 years	166.8980		149.5405	
5 to 9.11 years	191.1031			183.0038
2 to 4.11 years		229.1278		198.7819

It can be seen in the above table that N1 latency elicited by syllable /da/ in group 1 was significantly different from group 2 and 3. However group 3 N1 latency elicited by tone burst was significantly different from other two groups.

Effect of stimulus on N1 latency and amplitude

It can be seen from the table 4.5 that the mean latency for speech evoked N1 latency was longer than the 500 Hz tone burst evoked N1 latency with in the same group. Where as, N1 amplitude was high for tone burst than syllable for group 2 and 3. Wilcoxon Signed Ranks Test was administrated to see the effect of syllable /da/

and 500Hz tone burst on N1 latency and amplitude within the age group. The result is shown in the table 4.7.

Table 4.7: *z-value and the significant level for N1 latency and amplitude between the stimulus /da/ and 500 Hz tone burst within the group*

	/da/N1 -TBN1 Latency		/da/N1 -TBN1 amplitude	
Groups	Z-value	Significant level	Z-value	Significant level
Group 1	-3.48	0.00	-2.77	0.00
Group 2	-1.08	0.27	-0.62	0.53
Group 3	-3.36	0.00	-1.64	0.10

From the table 4.7, it can be seen that there was a significant difference between syllable /da/ and 500 Hz tone burst evoked N1latency for group 1 and group3. Where as there was no significant difference noticed for both latency and amplitude in group 2 for both the stimulus. It can also be noticed that there was significant difference between the amplitude for N1 elicited by syllable /da/ and 500 Hz tone burst was seen only in group 1 and not in group 2 and 3.

P2 component

The mean and standard deviation of P2 latency and absolute amplitude were calculated for all the groups recorded at 80dB nHL. The result is shown in tables 4.8.

Table 4.8: *Mean and standard deviation (SD) of P2 latency and absolute amplitude observed at 80dB nHL for both syllable /da/ and 500Hz tone burst stimuli across the group*

		Syllable /da/		500 Hz tone burst	
		Latency	Amplitude	Latency	Amplitude
Group 1	Mean	281.00 (N=8)	0.31 (N=8)	266.36 (N=10)	0.78 (N=11)
	SD	33.39	1.08	37.20	0.59
Group 2	Mean	257.54 (N=9)	0.61 (N=9)	267.25 (N=9)	0.42 (N=9)
	SD	63.64	1.16	72.79	1.11
Group 3	Mean	244.92 (N=17)	0.75 (N=17)	212.28 (N=13)	0.63 (N=13)
	SD	31.13	0.50	44.33	0.37

N= number of ears in whom P2 could be recorded.

From the table 4.8, it can be seen that as the age increased, the P2 latency decreased for both syllable /da/ and 500 Hz tone burst. Group 1 showed shorter amplitude for syllable /da/ compare to other two groups where as for tone burst, group 1 had larger amplitude compare to other two groups. Latency for 500 Hz tone burst was shorter and amplitude reduced compare to syllable /da/ except for group 2.

One way ANOVA was administered to see the effect of age on P2 latency and amplitude for each stimulus. ANOVA results indicated there was no significant group interaction for P2 latency [$F(2, 31) = 1.971$, $P>0.05$] for syllable /da/ but a significant interaction was observed across the group for P2 latency elicited by 500Hz tone burst [$F(2, 29) = 4.239$, $P<0.05$]. Where as for P2 amplitude, there was no significant group interaction observed for both the stimuli.

Duncan's post Hoc test was administered to see whether there is any significant difference between any two groups for P2 latency elicited by 500Hz tone burst. It showed that P2 latency obtained in group3 was significantly different from other groups and there was no significant difference between group1 and group2 P2 latency. The details of the test result are shown in table 4.9.

Table 4.9: *Duncan's post Hoc test results of P2 latency for 500Hz tone burst stimulus*

Groups	500Hz tone burst	
	1	2
10 to 15 years	212.2885	
5 to 9.11 years		266.3670
2 to 4.11 years		267.2567

Effect of stimulus on P2 latency and amplitude

It can be seen from the table 4.8 that the mean latency for speech evoked P2 latency was longer than the 500 Hz tone burst evoked P2 latency with in the same group, where as P2 amplitude showed variability. Wilcoxon Signed Ranks Test was administrated to see the effect of syllable /da/ and 500Hz tone burst as P2 latency and amplitude within the group. The result is shown in the table 4.10.

Table 4.10: *z-value and the significant level for P2 latency and amplitude between the stimulus /da/ and 500 Hz tone burst within the group*

	/da/P2 –TBP2 Latency		/da/P2 –TBP2 amplitude	
Group	Z-value	Significant level	Z-value	Significant level
Group 1	-2.20	0.02	-0.84	0.40
Group 2	-0.56	0.57	-0.21	0.83
Group 3	-3.11	0.00	0.00	1.00

From the table 4.10, it can be seen that there was a significant difference between syllable /da/ and 500 Hz tone burst evoked P2 latency for group 1 and group 3, where as there was no significant difference between stimuli for group 2. There was no significant difference for P2 amplitude for all the groups.

P1-N1 complex amplitude

The mean and standard deviation of P1-N1complex amplitude were calculated for all the groups recorded at 80dB nHL. The results are shown in table 4.11.

Table 4.11: *Mean and standard deviation (SD) of P1-N1complex amplitude observed at 80dB nHL for both syllable /da/ and 500Hz tone burst stimuli across the group*

		Syllable /da/	500 Hz tone burst
		Amplitude	Amplitude
Group 1	Mean	4.44 (N= 18)	3.28 (N=17)
	SD	2.09	1.30
Group 2	Mean	3.54 (N= 16)	3.42 (N= 16)
	SD	2.16	2.02
Group 3	Mean	2.47 (N= 20)	2.82 (N= 20)
	SD	0.67	0.79

N= number of ears in whom P1-N1complex amplitude could be recorded.

From the 4.11, it can be seen that as the age increased the P1-N1 complex amplitude reduced. Group 1 has larger P1-N1 complex amplitude than compare to group 2 and 3. It also observed that P1-N1 amplitude elicited by syllable /da/ has larger amplitude than compare to 500 Hz tone burst.

One way ANOVA was administered to see the effect of age on P1-N1complex amplitude for each stimulus. ANOVA results indicated that there was a significant group interaction for P1-N1 complex amplitude [$F(2, 51) = 6.128$, $P<0.05$] for syllable /da/ but there was no significant interaction was observed across the group for P1-N1complex amplitude elicited by 500Hz tone burst [$F(2, 50) = 0.907$, $P>0.05$].

Duncan's post Hoc test was administered to see is there any significant difference between any two groups for P1-N1 complex amplitude elicited by syllable /da/. The details of the test results are shown in table 4.12.

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Table 4.12: *Duncan's post Hoc test results of P1-N1complex amplitude for syllable /da/*

Groups	500Hz tone burst	
	1	2
10 to 15 years	212.2885	
5 to 9.11 years		266.3670
2 to 4.11 years		267.2567

It can be seen in the above table that the P1-N1 complex amplitude elicited by syllable /da/ showed significantly different that is group 3 was significantly different from group 1 and 2. Where as there was no significant difference between group 1 and 2.

Effect of stimulus on P1-N1 latency and amplitude

It can be seen from the table 4.11 that the mean P1-N1 complex amplitude evoked by syllable /da/ was greater than the 500 Hz tone burst for group 1 and 2. Where as group 3 showed better amplitude for 500 Hz tone burst than syllable /da/. Wilcoxon Signed Ranks Test was administrated to see the effect of syllable /da/ and 500Hz tone burst on P1-N1 complex amplitude within the age group. The results are shown in the table 4.13.

Table 4.13: *z-value and the significant level for P1-N1 amplitude between the stimulus /da/ and 500 Hz tone burst within the group*

	/da/P1-N1complex amplitude	
Groups	Z-value	Significant level
Group 1	-2.15	0.03
Group 2	-0.20	0.83
Group 3	-1.49	0.13

From the table 4.13, it can be seen that there was a significant difference between syllable /da/ and 500 Hz tone burst evoked P1-N1 complex amplitude for group 1, Where as there was no significant difference between stimuli for group 2 and 3.

N1-P2 complex amplitude

The mean and standard deviation of N1-P2 complex amplitude were calculated for all the groups at 80dB nHL presentation level. The results are is shown in table 4.14.

Table 4.14: *Mean and standard deviation (SD) of N1-P2 complex amplitude observed at 80dB nHL for both syllable /da/ and 500Hz tone burst stimuli across the group*

		Syllable /da/	500 Hz tone burst
		Amplitude	Amplitude
Group 1	Mean	1.53 (N= 8)	1.70 (N= 11)
	SD	1.08	0.33
Group 2	Mean	2.26 (N= 9)	-
	SD	0.19	-
Group 3	Mean	2.16 (N= 17)	2.44 (N= 13)
	SD	0.36	0.25

N= number of ears in whom N1-P2 complex amplitude could be recorded.

It can be seen in the table N1-P2 complex amplitude showed a lot of variability for both syllable /da/ and 500 Hz tone burst. Only less number of individuals in each group could be recorded for N1-P2 complex amplitude. For group 2, P2 was not obtained for 500 Hz tone burst recording but was present for stimuli /da/. Due to this variability in the data non-parametric test (Kruskal-Wallis test) was administered.

Kruskal-Wallis test was administrated to see the significant difference for N1-P2 complex amplitude elicited by syllable /da/ and 500Hz tone burst across groups as the sample size was small to compare. The result reveals that there was no significant difference across the groups (chi-square=5.691, degrees of freedom=2, P>0.05) for both the stimuli.

Effect of stimulus on N1-P2 latency and amplitude

It can be seen from the table 4.14 that the mean N1-P2 complex amplitude evoked by 500 Hz tone burst was greater than syllable /da/ for all the recorded groups. It was not recorded consistently in group 2 for tone burst as subjects were not relaxed. Wilcoxon Signed Ranks Test was administrated to see the effect of syllable /da/ and 500Hz tone burst on N1-P2 complex amplitude within the age group. The results are shown in the table 4.15.

Table 4.15: *z-value and the significant level for N1-P2 amplitude between the stimulus /da/ and 500 Hz tone burst within the group*

	/P1-N1complex amplitude	
Groups	Z-value	Significant level
Group 1	-0.53	0.59
Group 2	-	-
Group 3	-2.21	0.02*

From the table 4.15, it can be seen that there was a significant difference between syllable /da/ and 500 Hz tone burst evoked N1-P2 complex amplitude for group 3. Whereas, no significant difference between stimuli for group 1 was noticed. In group 2, P2 was not obtained for 500 Hz tone burst. So P2 recording for stimulus /da/ could not be compare P2 recording for 500 Hz tone burst.

Thus, from the above results we can conclude that:

- There were systematic age-related changes in magnitude and timing for P1, N1 and P2 components of the CAEP evoked by syllable /da/ and 500 Hz tone burst and extends well into the late teenage years. As the age increased, the

latency and amplitude of P1, N1 and P2 component and P1-N1 complex amplitude decreased.

- It also showed that there was difference in waveform morphology elicited by syllable /da/ and 500 Hz tone burst.
- Younger group shows longer latency and larger amplitude compare to older group.
- Syllable /da/ has longer latency and larger amplitude compare to 500 Hz tone burst.
- The latency of P1, N1 and P2 decreased as age increased, where as amplitude of P1 decreased as age increased for both speech and non-speech stimuli. The amplitude of N1 decreased as age increased for the syllable /da/ whereas, 500 Hz tone burst showed variability of N1 amplitude across groups.
- There was increased in amplitude as age increased. P1-N1 amplitude reduced as age increased, whereas, N1-P2 complex amplitude showed variability between stimulus and groups.

Discussion

The goal of the present study was to investigate the effect of age on latency, absolute amplitude and peak to peak amplitude for syllable /da/ and 500 Hz tone burst evoked cortical auditory evoked potentials. Aim was also to know whether there was any difference in ALLR parameters elicited by non-speech and speech stimuli.

The results of the present study showed that there were systematic age-related changes in magnitude and timing for P1, N1 and P2 components of CAEP, evoked by syllable /da/ and 500 Hz tone burst. It also showed that there was difference in waveform morphology elicited by syllable /da/ and 500 Hz tone burst.

These developmental changes in the wave shape observed in the normal children reflect the regional maturation of the cerebral cortex. It reflects maturational refinements of neural processes necessary for adult like auditory processing skills (Kurtzberg , 1989).

Waveform morphology

The younger children had longer latency and higher amplitude than the older group of children. This is consistent with the results reported by various investigators (Barnet et al., 1975; Kurtzberg et al., 1984; Little et al., 1999; Rotteveel et al., 1986; Sharma & Dorman, 2006; Shucard et al., 1987; Weitzman & Graziani, 1968). They observed as the age increased, the latency and amplitude decreased. This is typically accounted for by the larger numbers of synapses, thinner skulls and feasibly, immaturity of functional specialization in children than adults (Huttenlocher, 1990).

In the current study, the Peak latency of P1, N1 and P2 component declined with age. This is consistent with the results reported by Bruneau et al (1997), Cunningham et al (2000) Kraus et al (1993), McArthur and Bishop (2002), Molfese et al(1975), Oades et al (1997), Ponton et al (2000), Sharma et al (1997) and Shucard et al (1987).

Ponton et al. (2000) reported that general waveform morphology reaches maturity around 12 years of age although the latencies and amplitudes of the various components continue to change beyond this age that is components declining substantially in the late teens.

Peak amplitudes evoked by speech had greater amplitude than tone and also peak amplitude in younger children were greater than older group which was significant in this study. Wunderlich et al., (2006) also observed greater amplitude for younger children than older children and also amplitude obtained for speech stimulus was more than non-speech stimulus.

Age related changes of CAEP component

P1 component

The present study showed that as the age increased the latency and amplitude of P1component evoked by syllable /da/ and 500 Hz tone burst decreased. Younger group had longer latency and higher amplitude than older children. Speech evoked responses had greater amplitude and longer latency than the tone burst.

Latency

The result of the present study showed that as age increased the latency of P1 component decreased which is consistent with the results obtained in previous studies

(Cunningham et al., 2000; McArthur & Bishop., 2002; Oades et al., 1997; Ponton et al., 2000, 1996; & Wunderlich et al., 2006). They observed younger group had longer latency than older group. A similar finding were also observed by Cunningham et al., 2000; Molfese et al., 1975; Oades et al., 1997; Ponton et al., 2000; Ponton et al., 1996; Rojas et al., 1998; Sharma et al., 1997 and Tonnquist-Uhle´n et al., 1995. They observed decrease in P1 latency with age for children age over 5 years. Sharma et al., (1997) evoked CAEP using syllable /ba/ in 6 to 15 years and found that latency of P1 component reduced as age increased till 20 years of age.

The present study also showed P1 component which was predominant in younger group (2 to 4.11 years). A similar findings were also observed in previous studies (Kushnerenko et al., 2002; Pang & Taylor, 2000). They reported that P1 component is most predominant peak found during early childhood.

In the present study we can see that younger group showed presence of large positive response for syllable /da/ than 500 Hz tone burst which is consistent with the study done by Anu Sharma et al., (1997). A Similar results were also reported by Wunderlich et al., (2006). They used both speech (word) and non-speech tones (400 Hz and 3000 Hz) in infants and older children. They also reported higher prevalence of P1 when evoked by words compared with tones.

However, Eulitz, Diesch, Pantev, Hampson, and Elbert, (1995), Shtyrov, Kujala, Palva, Ilmoniemi , and Na ¨ a ¨ ta ¨ nen, (2000) and Szymanski, Rowley, and R ob erts , (1999) reported that there is no difference of P1 component latency for both speech and non-speech stimulus. Some studies reported that in children syllable /ba/, /ga/ and /da/ elicits shorter latency than non- phonetic sounds (Ceponiene , Alku,

Westerfield, Torki & Townsend., 2005) which was in contrary to the findings of the present study.

Moore (2002) reported that neurofilaments with axons radiating into the deeper cortical layers IV, V and VI first appear between 4 – 12 months of age. By 2 years of age, a light plexus of vertical and horizontal axons was apparent in the deeper cortical layers and this plexus becomes progressively denser by 3 to 5 years (axonal density in the layers III to VI increased until about 5 years). This explains the maturational changes observed in latency of P1 across the groups.

Amplitude

The result of the present study showed that as age increased the amplitude of P1 component decreased which is consistent with previous studies (Oades et al., 1997; Ponton et., 2000; Cunningham et al.,2000; Ceponiene et al., 2002; Ceponiene et al., 2003 and Wunderlich et al., 2006). They observe larger P1amplitude in younger children and decreased P1 amplitude in older children.

This decline in the P1 component as age increased is mainly reflects the decline of synaptic density which occurs in the auditory cortex during late childhood, reflects an ongoing process occurring throughout infancy and early childhood (Ponton et al., 2000).

Present study also showed that speech evoked CAEP results in larger amplitude than non-speech tone which was consistent with the results of the earlier studies (Anu Sharma et al.,1997 & Wunderlich et al., 2006). They reported that speech evoked greater amplitude than tone and also younger group have larger amplitude than older group. Similar results were also observed by Diesch, Eulitz,

Hampson, and Ross, (1996), Tiitinen, et al., (1999) and Woods and Elmasian, (1986) who reported that speech (vowel) evoked greater amplitude than non-speech (tones) stimulus.

Eulitz, et al., (1995), Shtyrov, et al., (2000) and Szymanski, Rowley, and Roberts , (1999) reported that there was no difference of P1 component amplitude for both speech and non-speech stimulus. Some studies reported that in children for syllable /ba/, /ga/ and /da/ elicited smaller amplitude than non- phonetic sounds (Ceponiene , Alku, Westerfield, Torki & Townsend., 2005) which was in contrary to the findings of the present study.

N1 component

The result of the present study showed that as the age increased, the latency of N1 decreased for both syllable /da/ and 500 Hz tone burst. The amplitude of N1 decreased as age increased for the syllable /da/, where as 500 Hz tone burst showed variability of N1 amplitude across groups. It was also seen that speech evoked N1 component had longer latency and larger amplitude than 500 Hz tone burst.

Latency

Present results is consistent with study done by Wunderlich et al., (2006) using both speech (word) and non-speech tones in infants and older children and reported that N1 latency decreased as age increased. Another study on CAEP by deCreÂvoisier et al., (1975) reported that N1 obtained in younger children had longer latency than older children. It was also supported by several studies (Molfese et al., 1975; Tonnquist-Uhle´n et al., 1995; Ponton et al., 1996; Oades et al., 1997; Sharma et al., 1997; Rojas et al., 1998; Cunningham et al., 2000 and Ponton et al., 2000). They reported that there was decrease in N1 latency with age. These decrease in

latency as age increased is supported by Rojas et al., (1998), who reported that there is a decrease in refractoriness of N1component as age increases from at least 6–18 years.

Present study also showed that speech evoked CAEP had longer in latency than non-speech tone which was consistent with the earlier studies (Diesch,et al., 1996); Tiitinen,et al., 1999 and Woods & Elmasian, 1986) they reported that speech (vowel) evoked longer N1latency than non-speech (tones) stimulus. It was also reported by Boyd, et al. (2003) that N1 latency was longer on syllable than on tone trials and they also reported that speech sounds caused better dipolar organization of neural activity than tones which results speech better than tones. Similar results were also reported by Szymanski et al., (1999) using natural vowel and tonal stimulus.

There are some studies which reported that N1 has several generators in the upper cortical layers including primary and secondary auditory cortex in or near the supratemporal plane (Ponton et al., 2002). The axons in the upper cortical layers are sparsely distributed in childhood and it becomes more numerous at ages 2 and 3 than at 1 year. After 5 years of age, mature axons begin to appear in cortical layers 2 and 3 and by 12 years of age their density is equivalent to that of young adults (Moore & Guan, 2001). These changes in the marginal layer of the auditory cortex might have attributed to maturational changes of N1 latency that was observed in this study.

Amplitude

There is conflicting evidence to age related changes in amplitude of N1 component. Some studies have shown no age-related increase in N1 amplitude after 6 years (Ceponiene et al., 2002; Gomes et al., 2001; Johnstone et al., 1996; Kraus et al., 1993; Oades et al., 1997; Sharma et al., 1997 and Tonnquist-Uhle´n, 1996). Others have found that, increased in N1 amplitude as age increased (Bruneau et al., 1997;

Cunningham et al., 2000; McArthur & Bishop, 2002; and Ponton et al., 2000). One study found a positive amplitude gradient but only when the right ear was stimulated (Tonnquist-Uhle´n et al., 1995).

Result of the present study showed that amplitude for syllable /da/ is consistent with the earlier results (Ceponiene et al., 2001 and Tiitinen et al., 1999). They reported that speech evoked N1 component was larger in amplitude than non-speech stimulus. It is reported by Woods and Elmasian, (1986), that speech evoked (vowel) N1 amplitude is greater than the tones evoked N1 amplitude. Similar findings were also reported by Wunderlich et al., (2006).

However, Bruneau et al., (1997), Cunningham et al., (2000), Tonnquist-Uhle´n et al.,(1995) and Ponton et al., (2000) reported that low tones evoked a larger N1 amplitude than words and also reported that older children showed larger amplitude than younger children. There were a few studies which observed no difference in N1 amplitude elicited by speech and non-speech stimulus (Eulitz,et al., 1995; Shtyrov, et al., 2000 and Szymanski, et al., 1999). Similar findings were also reported by Ceponiene , et al., (2005).

P2 component

There was decreased in P2 latency and increased in amplitude as age increased. Latency for 500 Hz tone burst was shorter and amplitude was reduced compare to syllable /da/ but there was no such group interaction for both syllable /da/ and 500 Hz tone burst observed.

Latency

The result of P2 latency was consistent with studies done by Cunningham et al., (2000); McArthur and Bishop, (2002); Oades et al., (1997); Ponton et al.,(2000, 1996), Sharma et al., (1997) and Wunderlich et al., (2006). They reported as the age increases P2 component latency reduced. Younger children showed longer latency than older children. It was also reported by Oades et al. (1997) that the P2 latency decline with age. Courchesne, (1990) reported that the P2 elicited by speech stimulus showed larger latency in children than adults which is consistent with the results of the current study.

In literature there are conflicting findings regarding the development of P2 peak. Studies by, Johnstone et al., (1996) and Ponton et al., (2000) and Tonnquist-Uhlen, (1996) reported no age-related changes in P2 peak latency. Some researchers posit that auditory P2 emerges early in infancy (Barnet et al., 1975; Kurtzberget al., 1984; Novak et al., 1989), while others state that it does not appear until 5–6 years of age (Ponton et al., 2000).

Amplitude

Present results also showed that amplitude elicited by speech is greater than non-speech which is consistent with earlier study (Tiitinen, et al., 1999). They reported that P2 amplitude was larger for speech (vowel) than tones. It was also reported that the peak amplitude of P2 in older group was larger than in younger group which was consistent with the study done by Wunderlich et al., (2006), who reported that amplitude of P2 component increased as age increased.

Several studies have reported a positive P2 amplitude gradient (Johnstone et al., 1996; Kraus et al., 1993; and Oades et al., 1997) while one study found no change

in amplitude in children better 5–15 years (Tonnquist Uhle´n, 1996). Another reported a negative gradient of amplitude (Ponton et al., 2000). Woods and Elmasian, (1986) reported that vowels elicited smaller P2 amplitude than simple tones which is contrary to the results of the present study. Ceponiene et al., (2002) reported that younger children had larger P2 amplitude than older children which is also not in agreement with the results of the present study.

Peak to peak amplitude

P1-N1 and N1-P2 complex amplitude

The P1-N1 complex amplitude decreased as age increased. Younger group had greater amplitude than older group, where as N1-P2 complex amplitude showed variability between stimulus and groups.

This could be due to differential affect of age on P1 and N1 absolute amplitude. Wunderlich (2006a) reported a systematic decrease in the magnitude of P1 as age increased. Similar decrease in amplitude of P1 with age in order children was also reported by Ceponiene et al., (2002), Cunningham et al., (2000), Oades et al., (1997), paetau et al., (1995), ponton et al., (2000) and Sharma et al., (1997).

Bruneau et al. (1997) observed increased in N1 amplitude with age. A similar finding was also reported by Pang and Taylor (2000) and Wunderlich et al., (2006). They reported a systematic increase in N1 amplitude from newborn to adulthood. Hence, the differential affect of age on P1 and N1absolute amplitude might have resulted in inconsistency of amplitude of P1-N1 complex in the present study.

The present study also observed that N1-P2 peak amplitude increased as age increased which was consistent with the study by Wunderlich et al. (2006). They have

observed increased in N1 and P2 amplitude as age increased. Younger children have larger amplitude than older children. This increased in magnitude of N1 and P2 peak amplitude with age might have lead to the increase in N1-P2 complex amplitude with age which is observed in the current study.

Thus, it can be conclude from the result of the current study that the latency of the P1, N1 and P2 tend to decreased with age. Similar changes in latency can be expected for both speech and non-speech stimulus. P1 tend to show decrease in amplitude, whereas N1and P2 amplitude may not increase or decline with age for both the stimulus. However, speech evoked larger CAEP amplitude but latency of all the components was longer than the non-speech evoked CAEP components.

Chapter 5

Summary and Conclusion

An important factor in the development of language and speech function is the normal maturation of auditory processing. Although many behavioral studies have examined how language and speech develop, it is more difficult to investigate auditory processing using behavioral measures (Pang & Taylor 2000). So by recording age-related changes in the neurophysiological responses evoked by auditory stimulation, we can assess the maturation of the thalamic-cortical portions of the central auditory system (NaÈaÈtaÈnen & Picton, 1987; Vaughan & Arezzo, 1988).

Cortical auditory evoked potentials (CAEPs) have been recorded using a wide range of stimuli including tones, clicks and speech stimuli. Several studies have shown differences in CAEPs latencies for different stimulus recorded using conventional evoked potentials and magnetoencephalography techniques (Crottaz-Herbette & Ragot 2000, Jacobson, et al 1992; Roberts & Poepple,1996; Salajegheh, et al., 2004; Verkindt, et al.,1995; Woods, Alain, Covarrubias & Zaidel, 1993). ALLR recorded using brief stimuli click did not produce consist and well defined waveform for the long latency auditory potentials. So Tone, tone pips or tone burst or speech is advised (Mc Pherson 1996).

There is dearth of information regarding the ALLR recording using non-speech and speech stimuli in younger population. Most of the studies either taken non-speech or speech stimuli to record ALLR. There is some evidence that CAEPs in infants evoked by different speech phonemes differed in latency and morphology (kurtzberg, 1989). CAEPs differences between speech stimuli are an indication of

different underlying neural representations of speech sounds. Due to this, there has been increasing interest to use cortical potentials to investigate the neural encoding of speech (Tremblay, Billings, Friesen & Souza, (2006).

Hence, the present study was taken up with the objective to investigate the effect of age on latency, absolute amplitude and peak to peak amplitude of ALLR waves elicited by syllable /da/ and 500Hz tone burst stimuli. It was also aimed to investigate, is there any difference in ALLR components for speech and non-speech stimuli and also which stimulus would elicit a better ALLR.

To arrive at the aim of the current study, a total of 30 Children were taken between 2 to 15 years of age and divided them into three groups.

Group 1: had10 children from 2 to 4 years 11 months of age.

Group 2: had 10 children from 5 to 9 years 11 months of age.

Group 3: had 10 children from 10 to 15 years of age.

The subjects participated in the study had normal hearing sensitivity, presence of TEOAE, normal middle ear function and no relevant history of Otological symptoms. VRA was carried out for young children and ABR were recorded for those children for those pure tone thresholds could not be obtained.

ALLR were recorded twice for the reproducibility for both speech and non-speech stimuli. The latencies and amplitude of P1, N1and P2 peak and amplitude of P1-N1 and N1-P2 complex were compared across the groups and between the stimuli to see, whether there was any significant difference between the groups and also

across stimuli to assess the maturation and also to see effective stimulus to elicit ALLR response in children.

To analyze the data, the following statistical analysis were carried out within and across the group of subjects for each ALLR parameter elicited by syllable /da/ and 500Hz tone burst.

- ***Descriptive statistics***: was administered to obtain the mean and standard deviation for all the parameters across all age groups.
- ***One way ANOVA***: was administered to see the significant difference across groups for each parameter elicited by syllable /da/ and 500Hz tone burst. ***Duncan's Post Hoc test***: was administered to see significant difference between any two groups for each CAEP component, when one way ANOVA showed significant difference.
- ***Kruskal-Wallis test***: was administrated to see the significant difference for N1-P2 complex amplitude elicited by syllable /da/ and 500Hz tone burst across groups as the sample size was small to compare.
- ***Wilcoxon's signed ranks test***: was administrated to see the significant difference for syllable /da/ and 500Hz tone burst evoked ALLR parameters (P1, N1 and P2 components) within the group.

The mean latency and amplitude of each ALLR component was calculated for both the stimulus separately. The details are shown in the table.

Table: 5.1: Mean value of latency and amplitude of CAEP components.

			Group 1	*Group 2*	*Group 3*
Syllable /da/	*Latency*	P1	135.29	121.76	115.14
		N1	229.12	191.10	166.89
		P2	281.00	257.54	244.92
	Absolute amplitude	P1	2.11	1.77	1.05
		N1	-2.35	-1.83	-1.45
		P2	0.31	0.61	0.75
	Peak to peak amplitude	P1-N1	4.44	3.54	2.47
		N1-P2	1.53	2.26	2.16
500 Hz tone burst	*Latency*	P1	128.78	111.06	101.34
		N1	198.78	183.00	149.54
		P2	266.36	267.25	212.28
	Absolute amplitude	P1	1.79	1.36	1.07
		N1	-1.49	-2.00	-1.70
		P2	0.78	0.42	0.63
	Peak to peak amplitude	P1-N1	3.28	3.42	2.82
		N1-P2	1.70	-	2.44

Results obtained in the current study are as follows:

- There were systematic age-related changes in magnitude and timing for P1, N1 and P2 components of the CAEP evoked by syllable /da/ and 500 Hz tone burst.
- There was difference in waveform morphology elicited by syllable /da/ and 500 Hz tone burst.
- The younger children had the longer latency and higher amplitude than the older children.

- Younger group had longer P1 latency and higher amplitude than older children. Speech evoked greater amplitude and longer latency than tone burst.
- The latency of N1 decreased for both syllable /da/ and 500 Hz tone burst with the age. The amplitude of N1 decreased as age increased for the syllable /da/, where as 500 Hz tone burst showed variability of N1 amplitude across groups. It was also seen that speech evoked longer N1 latency and larger amplitude than 500 Hz tone burst.
- There was decreased in P2 latency and increased in amplitude as age increased. Latency for 500 Hz tone burst was shorter and amplitude was reduced compare to syllable /da/.
- The P1-N1 complex amplitude decreased and N1-P2 complex amplitude increased with age, where as N1-P2 complex amplitude shows variability between stimulus and groups.

The results of the present study are consistent with the studies reported in the literature. These developmental changes in the wave shape observed in the normal children reflect the regional maturation of the cerebral cortex. This decline in the latency reflects maturational refinements of neural processes necessary for adult like auditory processing skills. This morphological changes typically accounts for the larger numbers of synapses, thinner skulls, and, feasibly, immaturity of functional specialization in children than adults (Huttenlocher, 1990).

Conclusion

It can be concluded from the study that auditory cortical responses can be used to assess complex maturation of the thalamic-cortical portions of the central auditory system by measuring morphological changes in waveforms. Speech stimulus can be used to elicit CAEPs as it showed greater amplitude than tone burst for P1, N1 and P2 component. This would assist to observe morphological changes and also provides information about the biological processes underlying speech processing which is essential for speech and language development.

Implications

1. A comprehensive description of age-related AEP changes data obtained form current study will provide norms for normal-hearing children.
2. It can also provide useful reference for assessing suspected neurologically intact and neuro-maturational deficits or central auditory processing disorders in children.
3. It is also useful in evaluating children with hearing disorders or profoundly deaf children fitted with cochlear implants especially in children.
4. It is a good electrophysiological tool for assessing hearing aids especially in smaller age group who is not co-operative for behavioral testing.
5. It is also useful in aural rehabilitation to monitor changes in the neural processing after an intervention.
6. CAEPs differences between speech and non-speech are an indication of different underlying neural representations of speech sounds and non-speech stimuli and suggest that the information needed to differentiate the stimuli is available to the listener.
7. It also helps in assessing neural encoding of speech signals.

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