SPEECH-EVOKED AUDITORY LATE LATENCY RESPONSE (ALLR) IN HEARING AID SELECTION

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APRIL 2007.

Dedicated to

My beloved Papa and Mummy

All my Teachers

&

The Almighty

CERTIFICATE

This is to certify that this dissertation entitled **"SPEECH-EVOKED AUDITORY LATE LATENCY RESPONSE (ALLR) IN HEARING AID SELECTION** " is a bonafide work in part fulfillment of degree of Master of Science (Audiology) of the student registration no: 05AUD016. This has been carried under the guidance of a faculty of this institute and has not been submitted earlier to any other university for award of any diploma or degree.

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CERTIFICATE

This is to certify that this dissertation entitled **"Speech-evoked auditory late latency response (ALLR) in hearing aid selection"** 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 dissertation entitled **"Speech-evoked auditory late latency response (ALLR) in hearing aid selection"** is the result of my own study and has not been submitted earlier to any other university for that award of any degree or diploma.

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INTRODUCTION

The cortical auditory evoked potentials (CAEPs) are scalp recorded evoked potentials that occur in response to a variety of stimuli (Naatanen & Picton, 1987). Cortical auditory evoked potentials (CAEPs) can be classified into 'obligatory' and 'discriminative' potentials. Discriminative potentials are evoked by a change from frequent 'standard' stimulus to an infrequent 'deviant' stimulus. The discriminative potentials consist of mismatch negativity (MMN), P300. The 'obligatory' CAEP are classified in terms of their latencies or the time of occurrence after presentation of a stimulus (Hall, 1992). The obligatory CAEP is also called auditory late latency responses (ALLR).

The auditory long latency auditory evoked potentials are characterized by components comprising time domain of 50 to 500ms (Mc Pherson & Starr, 1993) and are labeled according to their latency and polarity at the vertex (Picton, Woods & Proulx 1978). 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 (μv) and a width of about 15ms. The second peak occurs between 90- 100ms (N100/ N1) and is a negative peak with an amplitude of 10μv and a width of 40- 50ms. The third peak is positive occurring at about 100- 160ms (P160/P1) and has an amplitude of about 6μv and width of 40- 50ms. The fourth peak occurring at 180- 200ms (N200/ N2), is a negative peak and has an amplitude of 6uv and a width of 70ms (Mc Pherson & Stan-, 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).

There has been little consensus on the precise generators of ALLR/ CAEPs because of the multiplicity and complexity of the central auditory pathway. Knight, Scabini, Woods, and Clayworth (1988) reported that late thalamic projections into the auditory cortex and /or early auditory cortex and the specific sensory system are the generators for the P1 potential. These investigators also stated that supra temporal auditory cortex and non-specific polysensory system are the generator sites for the N1 potential. Baumann, Rogers, Papanicollaou and Syadjari (1990) reported that lateral-frontal supra temporal auditory cortex and the non-specific polysensory system being the generators of the P2 potential. The last LLR potential i-e, N2, has its generation from the supra temporal auditory cortex and the non-specific polysensory system (Makela & Hari, 1990).

The major applicability of CAEPs comes from the fact that it can be recorded from premature and full term newborns, and from the older children (Barnet & Lodge, 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). Contrary to maturation effect seen in the early childhood, there is an increase in latency and decrease in amplitude with the advancing age (Cranford & Martin, 1991).

The clinical application of LLR has been limited. It can be used for threshold estimation in difficult to test population (Korzack, 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 dyssnchronous firing of auditory nerve (Kraus & Cheour, 2000). Recent studies indicate that ALLR may be useful in evaluation of auditory neuropathy/ auditory -dyssynchrony (Kraus et al. 2000). An investigation by Singh, Garg, Madappa, and Barman (2006) suggest that ALLR may help in differentiating between infants with auditory neuropathy/ auditory -dyssynchrony and those with maturation delay. Some of the reports indicate that ALLR may be used to assess the capacity of the auditory cortex to detect changes within the speech stimuli (Martin & Boothroyd, 1999).

CAEPs have been used very limitedly in auditory rehabilitation. These potentials have been used to provide functional measure of the benefit provided by personal hearing aids (Korzack, Krutzberg & Staplles, 2005). An investigation by Hinduja, Kusari and Vanaja (2005) revealed that ALLR of individuals with a hearing aid showed larger amplitude and shorter latency when the aided thresholds were within speech spectrum than compared to the hearing aid in which the aided thresholds were outside the speech spectrum. These pre- attentive cortical potentials have also been used to reflect on the auditory training induced changes. Several studies have shown that CAEPs change in morphology, amplitude, and latency with auditory experience in deaf children and adults receiving cochlear implants and in normal hearing receiving auditory training (Kraus, Mc Gee, Carell, King, Tremblay & Nicol, 1995; Purdy, Kelly & Throne, 2001; Tremblay & Kraus. 2002).

Need for the study

Objective measures such as auditory evoked potentials offer the possibility of evaluating the effectiveness of hearing instruments in infants and older children who have limited behavioural repertoire due to developmental delay or other disabilities. Preliminary research has shown that CAEPs correlate very well with pure tone audiometric thresholds (Tomlin, Rance, Graydon & Tsialios, 2006; Maanen & Stapells, 2005). The presence of speech-evoked CAEPs indicates that speech stimuli have been detected (Hyde, 1997). Various studies have examined the relationship between the CAEPs and auditory perception. These studies also indicate that CAEP waveform is affected by changes in speech stimulus parameters such as voice onset time (VOT) and place of articulation (Tremblay, Friesen, Martin & Wright, 2003). Recently, Agung, Purdy, McMahon and Newall (2006) reported that different speech stimuli (ling sounds) evoked differences in the CAEP waveform in adults with normal hearing, suggesting that the underlying neural representation of the stimuli differs. However, additional studies are required to validate these results. There is a need to investigate if CAEPs for different speech stimuli evoke different responses in children also.

The potential advantages offered by the CAEPs/ALLR are that these potentials allow the investigator to assess the integrity of the entire auditory system including the cochlea, brainstem, auditory cortex and associated cortical areas. Secondly, since these potentials can be recorded for speech stimuli, such as consonant- vowel syllables, words, full sentences, therefore provide insight into the early and later cognitive processes that underlie the detection and discrimination of speech. The earlier auditory evoked potentials, in contrast, are best recorded for the transient stimuli, such as clicks or tone bursts, and thus provide only limited information regarding the speech processing. A review of literature indicates that C AEPs can be reliably recorded from individuals wearing a hearing aid (Korzack et al. 2005). However, there is a dearth of literature on usefulness of CAEPs/ LLR in evaluating hearing aid benefit using natural speech tokens. Also it is not known whether CAEPs can be useful in comparing performance among different hearing aids. If it can, then this measure will be a useful tool in selection, fitting and validation of hearing aids in difficult to test population. It might also be instrumental in monitoring the performance during and after the auditory training.

Aims

The present study was designed to investigate the following aims:

-To compare the CAEP waveform obtained for naturally produced speech tokens, /i/, /m/ and /ʃ/ in children with normal hearing.

-To evaluate the usefulness of CAEPs for naturally produced speech tokens, /i/, /m/ and /ʃ/ in validation of appropriate hearing aid.

REVIEW OF LITERATURE

In the habilitation of infants and children with hearing impairment a crucial factor is the selection of appropriate amplification (Ross & Tomasetti, 1980). With the widespread implementation of universal new born hearing screening programs there is a need for fitting and evaluating hearing instruments in young infants and children. After the hearing loss is diagnosed, fitting of the hearing instruments can occur when infants are as young as five weeks old (Yoshinaga-Itano, 2004). However, hearing aid selection in preverbal children is difficult and there is not a generally accepted method for selecting a hearing aid that will provide optimum benefit (Lewis, 1985).

Traditional hearing aid selection procedures (e.g. comparative methods and prescriptive methods) are oriented towards the adult population. The comparative approach given by Carhart (1946) and its modifications require the participant to give a voluntary response for the stimuli that are delivered through the hearing aid. Prescriptive methods (Byrne & Dillon, 1986) require that the behavioral thresholds, most comfortable loudness levels (MCLs) and loudness discomfort levels (LDLs) be obtained before a hearing aid can be chosen. Neither type of procedure is suitable for infants and young children.

Most widely used comparative approach for the selection of hearing aid gain in infants and children is the comparison of aided and unaided threshold measures (Jerger, Jerger, & Fahad, 1985; Ross & Tomasetti, 1980). Testing can be conducted with a variety of acoustic stimuli such as warble tones and narrow band noises. The hearing aid that best approximates normal thresholds is considered to be the most appropriate. While this procedure is workable with non-verbal youngsters and can differentiate between the gain and frequency response of different hearing aids, it does have several disadvantages. One of the major disadvantages being that these hearing aid selection procedures only reflect hearing aid performance at threshold levels. Jerger et al. (1985) have expressed concern about the validity of using threshold results as a prediction of the child's ability to understand everyday sounds, including speech. Another problem encountered in such evaluation is that children tend to rapidly habituate to the test stimuli and accurate thresholds cannot be obtained during the relatively lengthy test sessions necessary for the comparison of several hearing aids (Jerger et al. 1985).

Probe microphone measurements of insertion gain alleviate some of these concerns by allowing rapid comparison of gain provided by various hearing aids without repeated threshold testing. However, accurate measures of insertion gain (especially high frequency gain) must be obtained with the probe tube in precisely the same location of the ear canal and with the clients head in the same position for each measurement (Skinner, 1988). Thus, while these measurements may be useful with adults and older children, they are not feasible for very young children who may not tolerate insertion of the probe microphone nor sit quietly during the test session. Other alternative for testing infants and young children is the use of physiological measures of hearing. The physiological measures that have been used for hearing aid selection include acoustic reflex threshold and evoked potentials. Investigations carried out to study the usefulness of these physiological measures in hearing aid selection are discussed in this chapter.

Acoustic Reflex Thresholds

Acoustic reflex measures can be used to estimate the threshold of discomfort (Niemeyer, 1971), to determine appropriate gain settings for maximum discrimination (Rapport & Tait, 1976) and to compare real ear responses of different hearing aids (Rines, Stelmachoic & Gorga, 1984; Tonnisson, 1975).

Tonnison (1975) reported that Acoustic Reflex Threshold (ART) can be used for hearing aid gain prescription as an alternative method to real ear measurements. Twenty normal hearing individuals (14 males and 6 females), in the age range of 18 to 38 years served as participants. Intra-aural reflexes were measured in right ear using a loud speaker at six l/3rd octave bands (0.5kHz, 1 kHz, 1.6 kHz, 2.0 kHz, 3.5 kHz, 4 kHz). The difference in aided and unaided ARTs were considered as gain and these gains at different frequencies were compared with gain prescribed using a 2 cc coupler. Results indicated that a lot of individual variability and also variabilities across frequencies were present. Average gain prescribed using ART was lesser than the gain measured in a 2 cc coupler. The limitation of this study was that only normal hearing individuals were used as participants and the results obtained from normal hearing subjects cannot be generalized to subjects with sensori-neural hearing loss.

Very limited information is available on relationship between ART and speech discrimination. One of the studies was that of Rappaport and Tait (1976) who investigated whether speech discrimination scores for inexperienced hearing aid users vary as a function of intensity level proximity to the reflex threshold. The later part of the study compared the intelligibility scores at the gain settings that elicited the threshold and intelligibility scores obtained at the traditionally determined gain setting. Aided speech discrimination scores were obtained for 18 participants with sensori-neural hearing loss. Monosyllabic word lists with a competing message of connected discourse at a signal-to-noise ratio of+10 dB were used as the test stimuli. The measurements were made at four hearing aid gain settings for each individual. One of the gain settings was determined by measuring the ART for filtered noise in the ear contra lateral to the aided ear. Two other settings were at + 10 dB relative to the reflex threshold gain setting; the fourth setting was determined with a traditional approach. Results indicated that the mean speech discrimination scores were highest at the reflex threshold gain setting by 7.34% than the three other settings where the scores were similar. The 7.34% difference between the mean scores obtained at the reflex gain setting and traditionally established setting is not clinically significant and suggests that there is no need to change the traditional protocol.

Kiessling (1980) used input-output function of hearing aid for gain prescription. The assumption was that, the pathological input-output function should be approximated to normal input-output characteristics by a suitable hearing aid. This was successfully used in 40 non-cooperative participants. The pathological input-out functions were approximated to normal range with suitable hearing aids at all frequencies (0.5, 1, 2 and 4 kHz). The drawback of this study was that the prescribed gain settings were not validated through other procedures.

Rines, Stelmachowicz and Gorga (1984) described ART as an alternative method for determining functional gain of hearing aids. 5 normal hearing and 5 individuals with mild to moderate hearing loss participated in the study. Initially, sound field behavioral unaided and aided thresholds were obtained using warble tones. Subsequently the sound field ART's were obtained using test frequencies 500, 1000, 1500, 2000, 3000, 4000 Hz. Results indicated that for normal hearing subjects, the behavioral measures always underestimate the gain by 20-30 dB. For the individuals with hearing impairment, the functional gain predicted by behavioral measures and ARTs were in close agreement. It was concluded that, for individuals with frequency region of normal hearing, the ART might provide good measure of real ear gain. However, very few hearing impaired individuals with normal hearing regions require hearing aids. The other limitation of this study was that it compared only threshold measurements and no comparison was made on speech perception tasks.

Aided acoustic reflex measures have the advantage of being an objective supra threshold procedure requiring no voluntary responses and no demand on concentration or judgment by participants. However, several disadvantages are associated with this technique. The acoustic reflexes are absent in many children. As the severity of the hearing loss exceeds 60 dB HL, the likelihood of obtaining a reflex diminishes rapidly

(Jerger, Harford, Clemis & Alford, 1974), and even minimal conductive pathologies (5 to 15 dB), which are common in infants can obliterate the response (Jerger et al. 1974). Since the acoustic reflexes require high intensities for measurements the true functional gain may be underestimated with compression hearing aids. And finally, the relationship between ARTs, speech discrimination abilities and loudness discomfort level is not clearly established (Hall & Ruth, 1985; Kiessling, 1987, Mahoney, 1985). For these reasons ARTs did not gain wide acceptance as a tool for evaluating benefit from a hearing aid and attempts have been made to use the various electrophysiological tests in evaluating the benefit of hearing aids.

Auditory Brainstem Response (ABR)

ABR threshold and latencies provide objective and physiological correlates of hearing loss and hence, initially a number of investigators had advocated the use of ABR techniques in the selection of hearing aids. The procedures focused on three aspects of the ABR - threshold, latency and amplitude for the use in hearing aid selection process.

There were basically two groups of studies who used ABR for hearing aid selection procedure. The studies done by Cox and Metz (1980), Kileny (1982), Beauchaine, Gorga, Reiland, Larson (1986) and Mokotoff and Krebs (1976) used aided ABR threshold as the parameter for hearing aid selection, wherein the hearing aid that produced the lowest (most normal) ABR threshold was the hearing aid that was selected. Second group of studies by, Beauchaine et al. (1986); Cox and Metz (1980); Hecox, Breninger and Krebs (1975); McPherson and Clark (1982) focused on aided ABR latency measures or the aided slope of the latency-intensity function as the parameter for hearing aid selection.

Hecox et al. (1975) pioneered the use of ABR in selection of amplification. They tested three normally hearing adults who were fitted with moderate gain hearing aids. It was noted that increases in the gain of the hearing aid corresponded to shorter latencies and larger amplitude responses to tones, noise burst and clicks. The use of ABR in hearing aid prescription was investigated by Cox and Metz (1980). For this study eight adult hearing aid users with moderate to severe sensori-neural hearing loss were considered. ABRs were obtained for both click and tone pip stimuli. The tone pips used were 1000, 2000, 3000 Hz. Speech recognition data were collected and compared to the ABR wave V latencies. Results demonstrated that the hearing aid ranking based on participant's speech recognition scores generally agreed with the ABR latency rankings, with the shortest wave V latencies correlating with the highest speech recognition scores. The other finding of this study was that there was poor agreement between the aided ABR threshold and speech recognition scores. Hence, they concluded that hearing aid gain adjusted to result in maximum reduction of wave V latency setting would be representative of the best gain setting for that individual. The investigators also estimated that hearing aid selection using ABR techniques could be 75% as accurate as traditional methods. Accuracy was related to the configuration of the hearing loss and was higher for flat and precipitous hearing losses. It was also suggested that use of tone pip stimuli increased the accuracy of hearing aid selection.

Kileny (1982) presented four case studies in which brainstem responses were used in determining the effectiveness of amplification. The aided and unaided responses of infants and children were obtained using clicks and tone pips. Though this study demonstrates the usefulness of ABR in early selection of amplification, but several problems were encountered during the measurement of aided responses. The recorded ABR waveform was contaminated by the prolonged "ringing" of hearing aids in response to transients (clicks and tone pips) used to evoke the ABR. It was also noted that clicks produce relatively little ringing when compared to tone pips, wherein the ringing lasted up to 20 ms when presented to a high gain hearing aids, thus precluding the frequency specific estimates of hearing aid gain.

Parallel to these studies, Kiessling (1982, 1983a, 1983b, 1984, 1987) described a different approach for prescription of hearing aid using ABR. Normal hearing as well as individuals with hearing impairment, ranging in age from 1 to 5 years and young adults were tested and normative latency amplitude functions were obtained and from this a mathematical calculation was derived for optimal hearing aid output characteristics. ABR amplitude was used based on the assumption that ABR amplitudes reflect an individual's perception of loudness and hearing aid fitted on this basis should exhibit near normal values. Utilizing intensity- amplitude data of unaided ABR, a mathematical formula and hearing aid characteristics such as average gain in dB, dynamic range, compression and type of compression, hearing aids were prescribed. But the drawback of this study was that the method was based on the assumption that ABR amplitude is directly related to the loudness of the signal, which may not be true in all the participants, and the method is complex.

Hecox (1983) reported that the most significant contribution of ABR for use in amplification selection, was the quantification of supra threshold auditory function, primarily that of the dynamic range of hearing. It was also reported that latency-intensity (L-I) function of ABR could be used for hearing aid fitting, using a large population of adults (18-56 years) and infants. It was demonstrated that appropriate hearing aid could be judged by 'normalization' of slope of L-I function and shift in absolute latency of wave V. The observations made from this study were that: 1) the larger the displacement of the L-I function, greater are the gain requirements. 2) Given a 60 dB HL input signal (conversation level), amplification should not result in exceeding 6ms latency. 3) Amplification is very unlikely to improve communication behavior in individuals with pure central auditory dysfunction. 4) Steeper L-I function indicate the requirement of a compression circuit in the aid. But it has been reported that the slope, at least in part, is related to the configuration of hearing loss and not to the percept of the loudness (Gorga, Reiland & Beauchaine, 1985).

In order to determine and assess the ABR parameters that contributed most to the selection of hearing aid, McPherson and Clark (1983), tested ten normal hearing individuals of the age range 18 to 26 years. The subjects were tested for most comfortable listening level (MCL) and loudness discomfort level (LDL) under four conditions: (1) unaided under earphones, (2) unaided in sound field, (3) unaided in sound field with a simulated conductive hearing loss of approximately 15 dB (by occluding the external ear canal), and (4) aided sound field with simulated conductive hearing loss condition. Results revealed that the effects of the simulated conductive hearing loss on the ABRs were greatest at threshold and not as severe at supra threshold levels. They concluded that the ABR wave V latency was useful in adjusting the dynamic range of the hearing aid and that compression amplification should limit wave V latency to greater than 5.3 ms, the wave V latency at which subjects reported loudness discomfort (as the stimulus intensity increases, latency decreases, therefore stimulus intensity has limited intensities that elicit wave V responses that exceed 5.3 ms in latency). The limitations of this study were that, hearing loss was simulated and individuals with actual hearing impairment were not tested. The hearing loss simulated was that of conductive hearing loss and generally individuals with conductive hearing loss are not prescribed hearing aids.

Beauchaine et al. (1986) used click evoked ABR for hearing aid selection process. Four normal hearing adults, and four adults with hearing impairment, were tested with hearing aid set at three different frequency response settings. Estimates of gain were calculated using shifts in wave V thresholds, shifts in wave V latency-level functions, acoustic reflex measurements and coupler gain measurements and measurements of functional gain. Results suggested that the click evoked ABR did not distinguish between differing amounts of low-frequency gain, although reasonable estimates of high frequency gain was possible. The information regarding differing amounts of low frequency gain is important as excess amount of low frequency gains can result in upward spread of masking. It was concluded that click evoked ABR should be used cautiously in the hearing aid selection process.

Contrary to these reports, an investigation by Gorga, Beauchaine and Reiland (1987) suggested that ABR measurements may not provide accurate estimates of comprehensive characteristics of hearing aids. They measured input-output functions of hearing aids in response to a 2000 Hz tone burst, having 0.5 ms rise/fall time and 10 ms duration. Input-output functions, measured with a hearing aid analyzer, served as reference conditions. Hearing aid outputs at onset and during steady state portion of the waveform differed; these differences often depended on the stimulus rate. The relation between onset and steady state estimates of output were not always predictable from hearing aid attack and release times. These findings indicate that the steady-state output limitation characteristics of hearing aids cannot be estimated from their onset responses

Kiessling's (1982) ABR amplitude projection method based on the assumption that ABR amplitude is directly related to the loudness of a signal was tested by Davidson, Wall and Goodman (1990). Ten normal hearing and three individuals with hearing impairment of age range 22 to 24 years were tested. The results showed that ABR amplitude measure obtained in a single trial did not correlate well with the loudness, but ABR amplitudes averaged over nine trials did correlate well with the loudness. In the second phase of the study, a comparison was made between hearing aids chosen by ABR amplitude projection procedure and hearing aids chosen by the conventional methods. The results indicated that the projection procedure prescribed appropriate gain and compression characteristics for two out of three individuals with hearing impairment. The limitations of this procedure are that there is lack of frequency specificity which might be an important factor in rising and sloping configurations. The second limitation is that in order to obtain reliable ABR amplitude measures time required is more or it can spread over more than one session especially in infants and young children.

ABR provides useful measurement of the auditory information through brainstem. The advantages of ABR are that active participation of the subjects is not required and it is not affected by sedation or natural sleep unlike the mid and late potentials. ABR being sensitive to mid to high frequency region i.e. 2000-4000 Hz (Jerger & Mauldin, 1978) is important for successful selection and fitting of hearing aid. This region is important for the discrimination and identification of many consonants of English and also contains F2 and F3 formant transitions for vowel and diphthong identification. But the potential disadvantages of aided ABR overshadow the advantages of ABR in hearing aid selection process. When ABR threshold is used as parameter for hearing aid selection then information provided is only on the performance of hearing aid at threshold levels without providing any information regarding supra threshold function which can lead to selection of hearing aids which are uncomfortably loud. When wave V and Wave V latency- intensity functions are used as parameters, lengthy test tones are necessary to generate repeated latency-intensity functions (Kiessling, 1982). The other disadvantages being that, the stimuli used for ABR recording (clicks, tone bursts, tone pips), may be too brief to activate a hearing aids compression circuitry (Brown, Klein & Snydee, 1999) and it may be perceived as noise by hearing instruments with speech detection algorithm

(Alcantra, Moore, Kuhnel & Launer, 2003). Aided ABR functions cannot distinguish between hearing aids with differing amounts of low-frequency amplification (Beauchiane et al. 1986), this might be critical in determining the upward spread of masking. ABR procedure cannot be used in subjects with severe to profound hearing loss where ABR cannot be generated (Kiessling, 1982 & 1983). There are technical difficulties in obtaining aided ABR recordings. Kiessling (1982) reported that shape of the acoustic stimuli is distorted considerably by many hearing aids. Kileny (1982) noted contamination of the ABR waveform by prolonged "ringing" (more so for tone pip stimuli) of hearing aids, due to electromagnetic pick up of the loudspeaker and hearing aid transduced signal by recording electrodes. Changes in frequency spectrum and temporal characteristics introduced by the hearing aids can preclude the use of ABR in the selection process (Kilney, 1982 & Beauchaine et al. 1986), e.g. temporal delays introduced by hearing aids can preclude the use of wave V latencies in aided and unaided conditions to determine the appropriate hearing aid. Purdy, Katsch, Dillon, Storey, Sharma and Agung (2006), reported that compared to speech, clicks have a much higher peak level compared to their RMS (root mean square) but consequently hearing instruments will amplify clicks differently than they would speech stimuli.

In the recent years, studies have been carried out on speech evoked ABR and FFR (frequency following response) (King, Warrier, Hayes & Kraus, 2002; Kraus & Nicol, 2003, 2005, Russo, Nicol, Zecker, Hayes & Kraus (2005); Johnson, Nicol & Kraus, 2005, Song, Banai, Russo & Kraus, 2006). All these investigators have studied the transient and sustained responses of the brainstem in normal hearing individuals or individuals with learning problems. A brainstem response to speech in individuals with hearing impairment and in hearing aid selection and validation is yet to be investigated. Further research is needed to assess if brainstem response to speech can overcome the disadvantages of click, tone burst, tone pip evoked ABR.

Auditory Steady State Resposne (ASSR)

The auditory steady state response (ASSR) is a continuous scalp recorded potential that can be elicited by a range of stimuli including continuous amplitude modulated (AM) and frequency modulated (FM) tones (Cohen, Richards & Clark, 1991). Clinical testing typically employs a combined AM/FM stimulus which provides the frequency specificity required for audiogram estimation while optimizing response amplitude (Cohen et al. 1991).

ASSR for tones modulated at fast rate primarily reflects activity in the auditory brainstem and is not affected by sleep (Herdman, Lins, Van Roon, Stapells, & Scherg 2002). Picton, (1998) used ASSRs generated by amplitude modulated sinusoids to measure unaided versus aided hearing thresholds in children with hearing impairment. It was reported that aided thresholds for ASSR were approximately 13 to 17 dB higher than behavioral thresholds. Vanaja and Manjula (2004) studied the benefit of ASSR as an objective method for hearing aid fitting by comparing aided ASSR responses with the behavioral functional gain. Results revealed that there was a positive correlation between these two measures suggesting that ASSR can be used for fitting hearing aids. Venkat (2005) further investigated the correlation between the gain obtained in real ear measurements and gain obtained through ASSR. The study was carried out on 20 adult participants with mild to moderately severe sensori-neural hearing loss. The results revealed that there was a significant correlation between the gains obtained through real ear insertion gain and gain measured through ASSR at all test frequencies i.e. 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

ASSR offers many advantages which makes it a potential tool for hearing aid selection. Firstly, the use of AM/FM continuous tones makes it easier for the hearing aid to process the stimuli. Secondly, ASSR gives the frequency specific information and does not require subjective analysis of the waveform. Third, it is useful in pediatric population and non-cooperative subjects, as it is not affected by sleep or sedation.

Hearing aid selection by ASSR also has certain potential limitations. Gorga, Beauchaine and Manning (2004), reported that ASSR gets contaminated with artifacts when the stimulus intensity is greater than 100dBHL. Hence, care must be taken while evaluating individuals with high gain hearing aids. The other limitations being that, with ASSR it is difficult to distinguish between mild hearing loss and normal hearing (Rance & Rickards, 2002), which is critically important for determination of amplification needs. Lastly, ASSR are recorded using tonal stimuli and not speech stimuli. Therefore, ASSR does not provide information about the perception of the amplified speech, i.e. if the aided thresholds are below the speech spectrum; it implies that the aid will not be beneficial in improving the speech perception.

In order to overcome the last disadvantage Dimitrijevic, John and Picton (2004) investigated the correlation between the number and amplitude of ASSR components evoked by independent amplitude and frequency modulation (IAFM) of tones and the word recognition scores in adults. The IAFM parameters were selected such that the stimulus had acoustic properties similar to that of everyday speech. Dimrtrijevic et al. (2004) finally concluded that the ASSR evoked by the IAFM stimulus may provide an objective tool for examining the brain's ability to process the auditory information needed to perceive speech. But research is still going on and depending on the progress of this research; this approach may be useful for infant hearing instruments evaluation at some stage in the future.

Auditory Middle Latency Response (MLR)

Auditory middle latency responses are the potentials that occurring after ABR and before the auditory late latency responses. MLR can be reliably recorded in infants at supra threshold levels if recording and stimulus parameters are optimized (Tucker & Ruth, 1996). There are very few studies that indicate the usefulness of AMLR in assessing perception of amplified speech.

Groenen, Snik and Broek (1997) recorded electrical MLR (EMLR) from 12 post lingually deaf and four congenitally deaf cochlear implant users. Comparison of EMLR with behavioral measures of speech perception indicated that poor performers had more diversity in amplitude of EMLR component peaks and more diffuse AMLR peak latency organization across the electrode than better performer. In a further investigation, Makhdoum, Groenen, Snik and Brock (1997) studied the intra and inter individual correlations between auditory evoked potentials (EABR, EMLR, EALR) and speech perception. Results demonstrated significant correlations between peak V amplitude of the EABR and the Na-Pa and Nb-Pb amplitudes of EMLR. No significant correlation was found between the latency or amplitude of EALR peaks to any of the earlier peaks. In addition, no significant correlations were found between any of the EABR or EMLR peak amplitudes and speech perception test results. A moderate but significant relation was found between the EALR peak amplitudes and speech perception test results. Unlike latencies of earlier peaks, the latency of EALR peak P2 was significantly related to speech perception scores. The authors concluded that, EMLR measurements are more promising than EABR for the assessment of neural responsiveness. However, as EALR measures were significantly related to speech perception, the EALR seems to be the first choice for pre operative and post operative evaluations of the benefit of cochlear implantation. But in this study the set up used for EALR measurements was different from the set up for EABR and EMLR. For the EALR measurements, stimuli were presented in a free field condition, whereas for the EMLR and EABR measurements, all stimuli were presented by direct electrical stimulation. This difference in set up was not accounted in the study. On the similar lines, it has been reported that normal amplitude and lower thresholds of EMLR were associated with good speech perception both in noise and quiet condition (Firzt, Chamber & Kraus, Reed, Ruth 2002).

There is, however, dearth of studies investigating the usefulness of AMLR in hearing aid users. This might be because AMLR is more affected by subject state

(McGee & Kraus, 1996) and is more variable across and within subjects than ABR (Dalebont & Roby, 1997). Hence, AMLR may not be an ideal tool for objective hearing instrument evaluation.

Cortical auditory evoked potentials (CAEPs):

The cortical potentials include P1, N1, P2, N2, MMN and P300. MMN is an electrical brain response, a negative component of event related potential (ERP), elicited by any discriminable change (deviant) in some repetitive aspects of auditory stimulation (standard), usually peaking at 100- 200ms (Naatanen, Pakarinen, Rinne & Takegata, 2004). P300 is a positive potential elicited by stimuli that require some response or judgment and whose occurrence is uncertain and occurring between 220- 380ms (Hyde, 1997). These two potentials are categorized as 'discriminative' CAEPs. P1-N1-P2-N2 waves that occur within about 300 ms after the stimulus onset area are also referred to as auditory long latency responses (ALLR) or 'obligatory' response because it is primarily determined by the physical properties of the stimuli (Hyde, 1997).

Various studies have shown that the amplitude of MMN increases as the discriminability of standard and deviant stimuli increases (Aaltonen, Tumainen, Laine & Niemi 1993). Hence, MMN can be used for evaluation of improvement in audibility and discriminability of auditory stimuli, provided by the hearing aids in difficult to test population. It has been reported that MMN can differentiate between individuals with good speech perception and those with poor speech perception (Kraus & McGee, 1994; Groenenetal. 1996).

Oates, Kurtzberg and Stapells (2002) studied MMN and P300 potentials in response to /ba-da/ speech stimuli in adults with mild to severe-profound hearing loss who wore hearing instruments. The results showed that sensori-neural hearing loss caused amplitude and latency response changes for earlier (Nl, MMN) cortical responses. The impact of sensori- neural hearing loss was greater for the later evoked potentials (N2/P300) that reflect higher-level stimulus processing. They also reported improvement in cortical response detectability, amplitudes, and latencies in aided condition. Hence, it was concluded that cortical evoked potentials may provide a useful objective diagnostic index for measuring amplification benefits. The investigators cautioned that the speech need to be presented at least 12 dB above the average 1000 to 2000 Hz pure tone thresholds to reliably record cortical ERPs in individuals with varying degrees of sensori- neural impairment. Finally, it was concluded that feasibility of MMN as a diagnostic tool for the hearing impaired population is limited due to its high variability and lower detection rates in comparison with other cortical responses (Nl, N2 & P300).

In a comparative study Korczak, Kurtzberg andStapells (2005) recorded MMN, N1 and P300 for /ba-da/ pair in 14 adults with and without their personal hearing aids and from 20 normal hearing participants. The hearing loss in the hearing impaired groups ranged from moderate to profound hearing loss. Recording was done at two levels 65 dBHL and 80 dBHL. Behavioral discrimination was also obtained and d' reaction time was calculated. Results revealed that the use of personal hearing aids substantially improved the detectability of all the cortical ERPs and behavioral d' scores of both stimulus intensities. Even though the majority of subjects with hearing loss showed increased amplitudes, decreased latencies and better waveform morphology in aided condition, the amount of response change (improvements) seen in these measures showed considerable variability across participants . When compared with the response obtained from normal hearing participants, both the groups of hearing impairment had significantly prolonged aided reaction time latencies at both stimulus intensities.

In order to asses the application of MMN in rehabilitation, Hari Prakash (2005) evaluated usefulness of MMN as a measure of amplification benefit in hearing aid users in normal and individuals with hearing impairment both adults and children. Aided speech identification scores were obtained at 45 and 65 dB HL. MMN was recorded in sound field for /ka-ga/ stimuli pair. Results revealed good correlation between MMN amplitude and speech identification. Hence, it was concluded that MMN cannot only be used for evaluating hearing aid benefit but also prognosis of auditory training program can be measured.

From the above studies, MMN does not appear as an ideal tool for clinical evaluation of aided performance in individual children. Even in children with normal hearing sensitivity and normal auditory processing MMN is not always present (Kraus, Koch, McGee & Nicol & Cunningham, 1999), though Naatanen, Pakarinen, Rinne and Takegata (2004) suggests that with improvements in optimizing stimulus and recording parameters the situation may change in future.

In the earliest study evaluating the benefit of CAEPs/ALLR, Rapin and Grazianni (1967) found that a majority of their 5 to 24 months old infants with severe to profound sensori-neural hearing loss had cortical ERPs threshold 20 dB lower/better in comparison to the unaided thresholds for click and tonal stimuli. Most of the research later on concentrated on evaluation hearing aid benefit using speech stimuli.

Tremblay, Billings, Friesen and Souza (2006) obtained CAEPs using amplified speech sounds /si and /ʃ from 7 normal hearing young adults. Participants were tested and then retested within an 8 day period in both aided and unaided conditions. Results revealed that speech evoked CAEPs can be recorded reliably in individuals in both aided and unaided conditions. Hearing aids that provide a mild high frequency gain only subtly enhance peak amplitudes relative to unaided conditions. If the consonant-vowel (CV) boundary is preserved by the hearing aid, it can also be detected neurally resulting in different neural response patterns for /si/ & /ʃi/. It was concluded that speech evoked cortical potentials can be recorded reliably in individuals during hearing aid use.

In a similar study Tremblay, Kalstein, Billings and Souza (2006) recorded CAEPs in adult hearing aid users using acoustic change complex (ACC). 7 adults (50-76 years) with mild to severe sensori-neural hearing loss participated in the study. When presented with two identifiable CV syllables (/si and ʃi/, the neural detection of CV transitions as indicated by the presence of a P1-N1-P2 response was different for each speech sound.

More specifically, the latency of the evoked neural response coincided in time with the onset of the vowels.

Earlier, Hinduja, Kusari and Vanaja (2005) investigated changes in ALLR as a function of hearing aid gain in 6 hearing impaired children having moderately severe to profound hearing loss. The aided behavioral thresholds and aided ALLR responses were obtained with two hearing aids in all the participants. The low gain hearing aid yielding behavioral threshold outside speech spectrum or at the higher end, called poor and the other hearing aid yielding thresholds within the spectrum called good was, taken in the study. Results showed that with the good hearing aid ALLR amplitude was larger and latency was shorter when compared to the poor hearing aid.

CAEPs have also been obtained in individuals implanted with cochlear implant. Four sound contrasts were presented (500 - 1000 Hz, /ba-da/, /ba-pa/, and /i-a/). Nl, P2 responses were present in all participants for all conditions. Prolonged Nl, P2 and P300 latencies were found in cochlear implantee group compared to a control group of participants with normal hearing. Cochlear implant users showed smaller amplitudes of P2 for the consonants compared to the controls (Groenen, Beynon, Snik & Broek, 2001). The results also show that P300 are also useful and have additional value to speech recognition evaluation in cochlear implant users. But there are very few studies investigating the usefulness of P300 in hearing aid selection.

CAEPs/ ALLR allow the investigators to assess the integrity of the entire auditory system including the cochlea, brainstem, auditory cortex, and associated cortical areas. These potentials can be recorded to a variety of auditory stimuli ranging from simple tonal stimuli to complex speech stimuli, such as consonant-vowels syllables, words and even full sentences (Naatanen & Picton, 1987). The earlier AEPs in contrast are best recorded to transient stimuli, such as clicks, and / or tones burst and thus provide little information regarding speech processing. Also, these responses can be reliably recorded in well babies as well as low birth weight babies (Krutzberg et al. 1984), hence overcoming the disadvantages of MMN and P300.

Therefore, the purpose of using aided C AEP to validate the hearing instrument fitting is to show that speech stimuli across the spectrum evoke a neural response at the level of auditory cortex and therefore are likely to be perceived. If the neural responses evoked by different speech stimuli differ, as evidenced by differences in the CAEP waveforms, this suggests that the stimuli should also be discriminated from each other. The presence of speech evoked CAEPs indicates that the speech stimuli have been detected (Hyde, 1997). Differences in the aided cortical responses to different speech stimuli indicate the underlying neural representation of the stimuli differs. If the neural representation of the stimuli differs at the level of the auditory cortex the infant should be able to behaviorally discriminate the stimuli, if other abilities are intact. Among the other advantages it has also been found that CAEPs are closer to behavioral threshold typically 10 dB of behavioral hearing threshold in both normal and impaired participants for stimuli at frequencies across the audiometric range (MC Candless & Best, 1966). CAEPs are closer to threshold and more robust and less variant than 40 Hz ASSR (Tomlin, Rance, Graydon & Tsialios, 2006; Maanen & Stapells, 2005).

The above literature has opened avenues for clinical utility of CAEP/ALLR. These potentials can be used for objective validation of hearing aid fitting in young infants to ensure that the speech sounds are both detected and discriminated. The assumption underlying this approach is that a hearing aid fitting that causes CAEPs for different sounds to be present and differentiated is likely to be more useful to the child than a fitting where the responses are either absent or undifferentiated.

Though ALLR/CAEP has been found to be very useful in assessing the capacity of the auditory cortex to detect the acoustic changes within the speech stimuli (Martin & Boothroyd, 1999) and by the speech sounds that encompass entire frequency range (Agung, et al, 2006), but some of the factors can affect these responses. A number of factors related to subject and procedure affect the responses obtained with a hearing aid the clinician using CAEP in hearing aid selection should be aware of these factors.

Factors Affecting ALLR / CAEPs

Some of the major factors that can affect CAEP responses are discussed in terms of stimuli, developmental changes, attention and most importantly the hearing loss.

Stimuli used in ALLR Recording

ALLR can be elicited by a range of transient stimuli i.e. clicks, tone bursts, noise bursts, and speech sounds (Naatanen & Picton, 1987). 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). The long duration stimuli are also processed better by the hearing aid circuitry (Brown et al. 1999).

The tonal stimuli give very limited information about the perception of speech, which is the ultimate aim of the most appropriate hearing aid. Hence, tonal stimuli are not preferred to evaluate benefit of a hearing aid. Speech stimuli have better validity for evaluating hearing aid benefit

Cortical responses have been used extensively in studying the neural representation of speech cues. Among the various studies, very few studies have used real word speech tokens. Naturally produced speech stimuli represent highly complex time-varying signals that are poorly approximated by non-speech stimuli such as clicks, tones and noise bands. Even in case of synthetic speech, 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 impaired speech understanding (Tremblay, Friesen, Martin & Wright, 2003). However, because natural speech stimuli contain highly complex time varying signals evoking multiple overlapping neural responses patterns, some investigators believe that CAEPs evoked by naturally produced speech might be less reliable compared with those elicited by clicks, tones or synthesized speech sounds.

Among some of the earlier studies of eliciting CAEPs using speech stimuli, Ostroff, Martin and Boothroyd (1998) obtained P1-N1-P2 responses in 8 adults with normal hearing using naturally produced stimuli which was later synthesized. Three speech stimuli were used, syllable /sei/, sibilant /s/ extracted from the syllable and the vowel /ei/ extracted from the syllable. Results revealed that isolated sibilant and vowel preserved the same time relationships to the sampling window as they did in the complete syllables. Response amplitudes to the /ei/ stimulus showed largest amplitude followed by /sei/ and then /*s*/. The response to /*s*/ and /ei/ both follow the classic N1 -P2 pattern for stimulus onset. The response to/ei/also contains a clear P1 component. The investigators also noted that, N1 in response to /ei/ is offset from N1 in the response to / *s*/ by approximately 130 ms which roughly corresponds to the onset delay to the stimulus /ei/ relative to that of /*s*/. P2 in the response to /ei/ is similarly offset from P2 in response to /*s*/ by approximately 120 ms. The investigators finally made the following conclusions: 1) the complete response to the entire CV syllable /sei/ is combination of the response to the two constituent phonemes /*s*/ and /ei/ but it is not the sum of the responses of the two. 2) The morphology and latency of the response suggests that it is an N1-P2 potential to the acoustic change occurring at the CV transition. This change occurring during an acoustic stimulus is called acoustic change complex (ACC).

Subsequently Sharma, Marsh and Dorman (2000) examined the relationship between morphology of Nl 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 to pa/ VOT varied from 0-60 ms. Behavioral identification and Nl response was obtained. Results revealed that behavioral identification scores from 10 subjects showed a mean category boundary at a VOT of 46 ms for the /ga-ba/ continua and a VOT of 27.5 ms for the ba-pa continua. N1 component was seen for stimuli with VOTs of 0-30 ms/ and two components Nl and Nl were seen for stimuli with VOTs 40-70ms for both continua. The change in N1 morphology, from single to double peaks consistent with the change in perception from voiced to voiceless for stimuli from the /ba-pa/ continua, but not for /ga-ka/ continuum. It was concluded that N1 morphology does not reliably predict phonetic identification of stimuli varying in VOT.

Similar to the Sharma et al. (2000) study, Tremblay, Piskosz and Souza (2002) studied the VOT perception distinguishing voiced /b/ from voiceless /p/ and compared between younger adults (19-32 years) and older adults (61-79 years). Results revealed that N1-P2 responses were prolonged in older adults. Through these results investigators suggested that speech perception difficulties described by older adults may be related to age-related changes regulating excitatory and inhibitory processes. Similar results have been reported by Tremblay, Billings and Rohila (2004).

The reliability of CAEPs using naturally produced speech sounds was evaluated by Tremblay, Friesen, Martin and 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/. Using repeated measure design, subjects were tested and retested within an 8 day period. 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 study 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.

The development of spoken language in prelingually hearing impaired individuals depends on the perception and discrimination of a broad range of speech sounds (Ling, 2002). In 1976, Ling identified a number of speech sounds with concentration of energy that spanned the entire range of speech frequencies. Accordingly, it was suggested that the ability to identify and discriminate these sounds behaviorally was correlated with speech recognitions and production (Wei et al. 2000). In difficult to test population, however, behavioral responses to assess discrimination ability cannot always be obtained.

Based on the above background, Agung, Purdy, McMahon and Newall (2006) determined whether CAEPs produced by the ling sounds, which together cover a broad range of frequencies across the speech spectrum, could be differentiated from each other based on response latency and amplitude measures. CAEPs were recorded from 10 normal adults in the age range of 20 to 29 years. Naturally produced speech stimuli consisting of 4 vowels (I, a, u, ɔ) and 3 consonants (s, ʃ, m) were used. Two stimulus durations were used of 500ms and 100 ms presented at 65 dBSPL via loud speaker. Results revealed that all subjects showed cortical responses to all stimuli and no significant effect of duration on P1 was observed. P1 latencies were significantly earlier for shorter compared to longer stimulus durations. Shorter stimulus duration resulted in larger N1-P2 amplitudes and earlier N1-P2 response latencies. N1-P2 response amplitudes elicited by higher frequency speech stimuli (/s/, /ʃ/) produced significantly smaller amplitudes compared to stimuli that had dominant spectral energies in low frequencies (m, a, u, i). N1 latency decreased systematically when elicited by u, ɔ a, i. Similarly P1 and P2 elicited by longer duration vowels u, a, ɔ i decreased in latency in this order. Hence, it was concluded that CAEP latencies and amplitudes may provide an objective indication that spectrally different speech sounds are encoded differently at the cortical level. This information can be extrapolated in determining the benefit provided by the hearing aid when evaluated using speech stimuli.

Developmental Changes:

Some investigators report of decrease in latency and increase in amplitude as a function of age from childhood to about 10 years of age (Ponton, Don, Eggermont, Waring & Masuda, 1996; 1965). In contrast, some investigators described latency increase and amplitude decrease with advancing age (Callaway & Halliday, 1973).

The developmental time course of CAEPs in infants have been investigated extensively (Sharma, Kraus, McGee & Nicol, 1997). Because the cortical potentials are generated by multiple brain regions including primary auditory cortex, auditory association areas, frontal cortex and sub cortical regions (Stapells, 2002) that mature at different rates, there are complex changes in morphology, scalp distributions, amplitude and latency of P1-N1-P2-N2 waves with maturation (Cunningham, Nicol, Zecker & Kraus, 2000; Ponton, Eggermont, Kwong & Don, 2000).

P1 is a dominant waveform in school age children that can be reliably recorded using a variety of stimuli. Ponton et al. (1996) reported exponential decrease in P1 latency to brief click trains, as the age increased from 6 to 19 years. This finding was confirmed in the subsequent study using 143 normal children from 5 to 20 years (Ponton et al. 2000). Decrease in P1 latency (Kraus, McGee, Carrell, Sharma, Micco & Nicol, 1993; Sharma et al. 1991) and amplitude during school age years (Sharma et al. 1997) have also been shown in response to speech stimulus /ba/.

Various investigators have reported that unreliable N1 response in young children between ages 5 and 7 years (Goodin, Squires, Henderson and Starr, 197-8) that becomes progressively consistent as the age increases to 9 year (Ponton et al. 2000) or adolescence (Sharma et al. 1997). Stability of N1 response has been supported by Goodin et al. (1978). In contrast, Martin et al. (1988) described a small non-significant decrease in Nl latency from 6 to 23 years in response to binaural tone pips. Still others found significant decreases in Nl latency with stable amplitudes to both non-speech (Ponton et al. 1997) and speech stimuli (Kraus et al. 1993) across school-age years.

Developmental changes reported for the P2 responses elicited by simple stimuli have generally been minimal. In contrast, Ponton et al. (1997) reported that at birth and up to about 7 years of age wave P2 is absent and the response is dominated by a large late P1 response. Some researchers have shown that P2 latency increases with age (Goodin et al. 1978) whereas others have reported no maturational changes in P2 response (Barrett, Neshige & Shibasaki, 1987).

Ponton et al. (2000) suggested that the N1 response in children may actually correlate with the adult N2 response. To non-speech stimuli, N2 latency has been described as exhibiting a positive correlation with age from 6 to 15 years (Martin et al. 1988), 6 to 20 years and 20 to 89 years (Ponton et al. 2000). N2 amplitude increases in early childhood and then decreases from 11 to 20 years (Ponton et al. 2000). Sharma et al. (1997) reported a different pattern of development in response to speech. They reported that late negativity (N1b) showed a significant decrease in latency with age and no amplitude effects.

Though the various studies support different ages of maturation of late latency responses, but there are studies which report of CAEPs in preterm infants. Pasman, Rotteveel, De Graaf, Massen and Noterman (1991) measured CAEPs in preterm babies at 35-37 weeks conceptional age and also reported good detectability rates (95%) for CAEPs in infants.

Attention

P1 does not get affected by either attention or awakefullness or sleep state while N1 shows an increase in amplitude of approximately 0.61 μv when the stimulus is attended (Picton & Hillyard, 1974). James, Gordon, Kraiuhin, Howson, and Meares (1989) found that amplitude of the Nl was larger in the attending versus the unattending condition. Similar to Nl, P2 also shows increase in amplitude of about 0.70 μv when stimulus is attended (Freeze, 1990). N2, on other hand show slight increase in latency, increase in amplitude and biphasic peaks in attentive condition (Ford, Roth & Kopell, 1976). The N200 demonstrates equal amplitude in both the attended and unattended condition for complex stimuli, or stimuli where a decision must be made (Ritter, Simson & Vaughan, 1983).

Hearing Loss

There is very small body of literature which studies the relationship of CAEPs and hearing loss. Most of the earlier studies on CAEPs, have reported that deviations in Nl waveform morphology are associated with poor speech perception. Polen (1984) found that moderate to severe sensori-neural hearing loss resulted in prolongation of N1-N2 and P300 latencies and a reduction in N2 amplitude in comparison with results from normal hearing participants. In contrast, Wall, Balebont, Davidson and Fox (1991) studied five individuals with hearing impairment of mild to moderate sensori-neural hearing loss and reported that there were no significant differences in the latencies of waves Nl, P2 or P3 for the normal hearing versus individuals with hearing impairment or in the amplitudes of these peaks, with the exception of Nl.

Later, it was Oates, Kurtzberg and Stapells (2002) who obtained cortical ERPs for /ba/ and /da/ speech stimuli presented at 65 dB and 80 dB ppe SPL from 20 normal hearing adults and 20 adults who have hearing impairment. The degrees of sensori-neural hearing loss varied from mild to severe / profound hearing loss. They reported that the amplitude and latency response changes that occurred with sensori-neural hearing loss were significantly greater for the later ERP peaks (N2/P3) and behavioral discrimination measures (d' and reaction time) in comparison with earlier N1, MMN responses.

During the same time, Rance, Cone-Wesson, Wunderlich and Dowell (2002) found that the development of 'reasonable speech perception performance' in children with auditory neuropathy was correlated with CAEPs of normal latency, amplitude, and morphology whereas the absence of CAEP was associated with poor speech recognition scores. For these reasons, CAEPs are thought to reflect the functional integrity of the auditory pathway involved in processing of complex speech stimuli (Novak et al. 1989, Ostroff et al. 1990, Tremblay et al. 2003).

From the review of literature, it is quite evident that the earlier potentials like ABR, MLR are not efficient tools in assessing the hearing aid benefit. While CAEPs which are elicited by long duration stimuli are better processed by the hearing aid. CAEPs obtained by naturally produced speech have many potential benefits than non-speech evoked CAEPs. As perception of speech is the ultimate aim of fitting an appropriate hearing aid, use of speech stimuli in assessing the hearing aid benefit would be more relevant choice of stimuli. Very few studies have been done using speech stimuli either in normal hearing individuals or individuals with hearing impairment. However, there is dearth of studies assessing hearing aid benefit using ALLR/CAEPs elicited through speech stimuli.

METHOD

The following method was used to investigate the usefulness of ALLR in evaluation of hearing aid benefit and also to develop norms for ALLR for natural speech tokens.

Participants

Two groups of participants were included in the study. Group I included 15 children with normal hearing in the age range of 5 - 7 years and Group II included 10 children with hearing impairment in the age range of 5 - 7 years.

Participant selection criteria

Group I: Participants who met the following criteria were included in this group:

> The hearing sensitivity less than 15 dBHL at octave frequencies between 250 Hz and 8000 Hz.

> Normal middle ear functioning as indicated by immittance evaluation.

> No history of any otologic, neurologic problems.

Group II: Participants who met the following criteria were included in this group

> Pure tone thresholds greater than 70 dBHL and less than 100 dBHL.

> Air- bone gap of less than 10 dB.

> Normal middle ear functioning.

> No history of any otologic and neurologic problems

Instrumentation

Following instruments were used to carry out the study:

> A calibrated 2-channel OB-922 diagnostic audiometer with TDH 39 headphones with MX 14 AR ear cushions, Radio ear B71 bone vibrator, and sound field facility was used to carry out the pure tone audiometry and functional gain measurements.

> A calibrated immitance meter, GSI-Tympstar was used to examine the middle ear functioning.

> Intelligent Hearing System (version 2.39) with matched loud speakers was used to record and analyze the late latency responses (ALLR).

Materials used for testing

Stimuli for recording LLR were natural speech segments -*/i/, /m/, /l/*. These were spoken by a normal adult female Kannada speaker into a unidirectional microphone connected to the computer. The recording was done using Praat software with a sampling rate of 16000 Hz. The stimuli duration was kept constant at 250ms across all the speech sounds. The wave file was then converted to stimulus file for ALLR recording using 'Stim conv' provided by the Intelligent Hearing System (version 2.39).

Test environment

All the measurements were carried out in an acoustically treated double room situation. The ambient noise levels were within the permissible levels according to ANSI (1991).

Test procedure for Group I

Pure tone thresholds were obtained in the sound field for octave frequencies between 250 Hz and 8000 Hz for air conduction using Hughson-Westlake procedure (Carhart and Jerger, 1959). Tympanometry and acoustic reflexes were carried out to rule out any middle ear pathology. ALLR recording was done for the participants who met the selection criteria.

ALLR recording: Participants were comfortably seated in order to ensure a relaxed posture and minimum rejection rate. Loud speaker delivering the stimuli was placed at a distance of one meter and at a 0° azimuth to the test ear. Speech evoked LLR recording was done when the child was awake. 'Mehndi' was drawn on children's hands to ensure that the child is awake and quiet.

Silver chloride electrodes were placed after cleaning the electrode sites using skin preparation gel. Conducting paste was used while placing the electrodes to improve the conductivity of the signal. The electrodes were secured in place using plasters. Conventional electrode montage was used with the non inverting electrode on Fz, inverting electrode on the mastoid of the test ear and common electrode on the mastoid of the non test ear. It was ensured that the electrode impedance values were less than $5k\Omega$

and the inter electrode difference was less than $3k\Omega$. ALLR were recorded using the test protocol given in Table 1.

Table 1: Protocol used for ALLR recording

Stimuli	/i/, /m/, /ʃ/
Stimulus level	65 dBSPL
Transducer	Loudspeakers at 0° azimuth
Rate	1.1/sec
Polarity	Alternating
Filters	1-30 Hz
Notch filters	On
Number of channels	Single channel
Recording time window	500ms
Amplification	50X
Sweeps	200
Number of repeats	2

Test procedure for Group II

Similar to the procedure used in the Group I, pure tone thresholds, tympanometry and acoustic reflexes were obtained for the participants of Group II. Two digital hearing aids were pre-selected and programmed based on the audiological findings. Functional gain measurements as well as unaided and aided LLR were carried out with pre-selected hearing aids. These two test procedures were used to rate the hearing aids regarding their suitability.

Functional gain measurements: Unaided and aided pure tone thresholds were obtained for FM tones at octave frequencies between 250 Hz and 8000 Hz. The stimuli were presented through the speakers placed at distance of one meter and at 45° azimuth. Conditioned responses were obtained across the frequencies using the Hughson-Westlake procedure (Carhart & Jerger, 1959).

ALLR recording: ALLR were recorded separately for the three stimuli, /i/, /m/, /ʃ/ without the hearing aid as well as with pre selected hearing aids. The procedure used for recording ALLR was same as that used for Group I.

Analysis

The waveforms were analyzed and P1-N1-P2-N2 peaks were identified by two audiologists who were unaware of the test conditions. The audiologists ranked the unaided and aided ALLR obtained for Group II as I, II, III. Latency and amplitude of the identified peaks were noted and suitable statistical analysis was carried out to investigate the aims of the study.

RESULTS AND DISCUSSION

The main aim of the study was to assess the usefulness of P1-N1-P2-N2 responses obtained for naturally produced speech tokens /i/, /m/, /ʃ/, in the validation of most appropriate hearing aid. The present study also investigated whether the naturally produced speech sounds (/i/, /m/, /ʃ/) produce significant differences in the P1-N1-P2-N2 waveforms in children with normal hearing. Robust P1-N1-P2-N2 responses were obtained in all the participants (in Group II with most appropriate hearing aid) for all the three naturally produced speech tokens, /i/, /m/, /ʃ/. The responses were replicable for the same participant in the same session. Earlier it was believed that natural speech stimuli contain highly complex time varying signals that evoke multiple overlapping neural response patterns and hence CAEPs evoked by natural speech tokens might be less stable compared with those elicited by clicks, tones, or synthesized speech. But Tremblay et al. (2003) reported that CAEPs evoked by naturally produced speech stimuli show remarkable test- retest reliability when recorded from the same individual. The results obtained in the present study support that CAEPs evoked by naturally produced speech stimuli can be recorded from individuals with normal hearing as well as those with hearing loss, wearing a hearing aid. The data obtained were analyzed using the SPSS software.

P1-N1-P2-N2 responses in children with normal hearing

P1-N1-P2-N2 responses could be recorded from all the 15 participants for all the three natural speech tokens /i/, /m/, /ʃ/, presented at 65 dBSPL. The data obtained were tabulated and statistical analysis, mixed design ANOV A, was carried out to assess the effect of age and stimuli on latency and amplitude of P1-N1-P2-N2 responses.

Effect of stimuli

The mean and the standard deviation of latencies obtained for the three stimuli, across the three age groups are tabulated in Table 2. It can be observed from the table that the latencies of all the waves are different across the /i/, */m/* and /ʃ/ stimuli. A general trend can also be observed for the latency measures where high frequency stimuli had longer latencies compared to the low frequency stimuli as demonstrated by Table 2. The latencies for the /i/ were shortest while /ʃ/ had the longest latencies and */m/* had latencies in between the latencies of /i/ and /ʃ/ stimuli as observed from Figure 1.

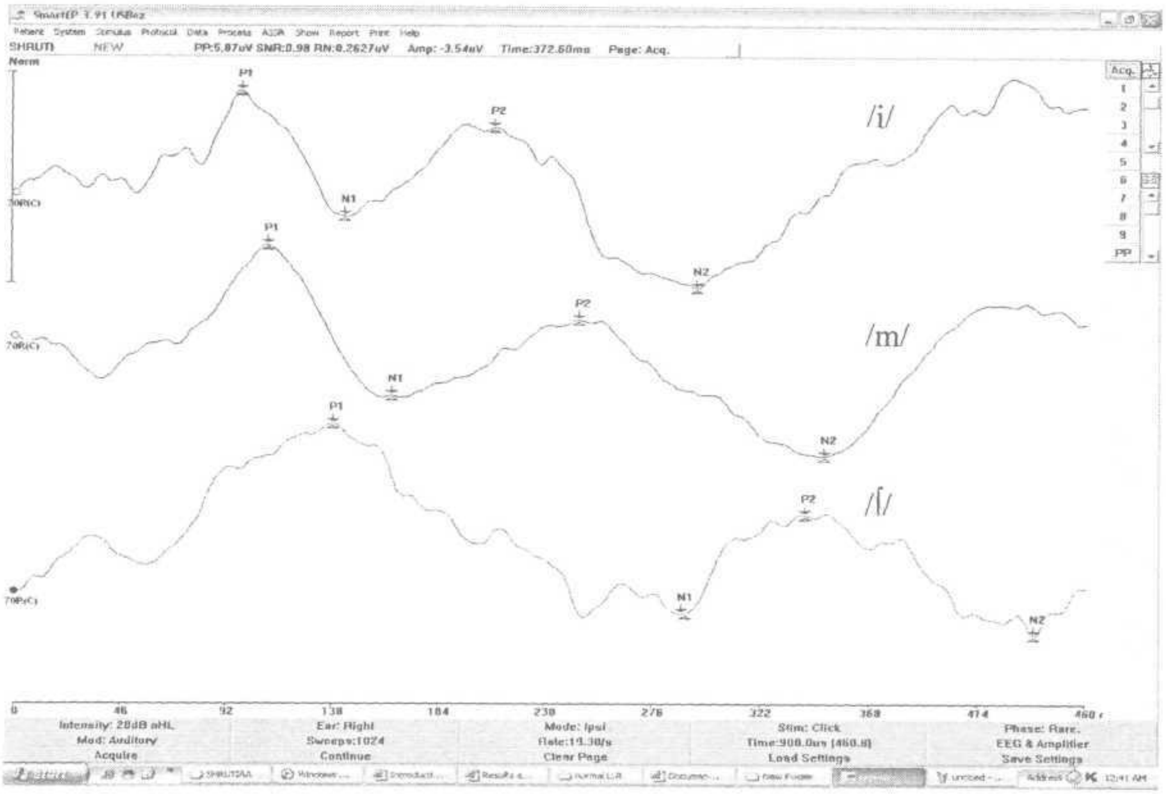

Figure 1: Responses for /i/, /m/ and /ʃ/ stimuli in children with normal hearing.

Table 2: P1-N1-P2-N2 latencies in ms for the three stimuli across the age groups in children with normal hearing.

Peaks	Age	Stimuli					
		/i/		/m/		/ʃ/	
		Mean	SD	Mean	SD	Mean	SD
P1	5-6 years	101.34	16.84	113.40	20.74	131.42	17.94
	6-7 years	97.35	10.24	102.60	6.53	130.42	9.16
	7-8 years	86.22	3.56	93.96	5.27	118.92	19.71
N1	5-6 years	172.94	18.55	199.88	28.21	227.52	30.50
	6-7 years	169.80	14.33	196.55	18.00	216.57	28.53
	7-8 years	152.08	17.14	176.70	25.64	215.02	47.40
P2	5-6 years	226.74	22.79	266.74	24.96	291.76	30.25
	6-7 years	211.63	12.74	255.50	17.52	289.20	28.06
	7-8 years	201.38	31.16	238.86	29.04	283.14	42.57
N2	5-6 years	302.20	32.20	330.24	23.92	394.14	43.02
	6-7 years	278.30	19.39	339.90	13.16	390.03	16.83
	7-8 years	273.56	34.25	312.74	34.99	339.38	45.15

Table 3: F values for the effect of stimuli on children with normal hearing

	F value	Significance
P1 latency	(2, 22) = 18.61	0.00
N1 latency	(2, 22) = 9.53	0.001
P2 latency	(2, 20) = 14.76	0.00
N2 latency	(2, 20) = 17.28	0.00

Repeated measure ANOV A revealed that there was a main effect of stimuli on latency of all the waves. The F value and the significance are shown in Table 3. Bonferroni's multiple comparison test was done to see the pairwise differences between the stimuli. The test results indicate that all three stimuli are significantly different (at 0.01 level of significance) from one another for the P1 and N2 responses. But for N1 and P2 stimuli the results showed that there was a significant difference between /i/ and /m/ and between /i/ and /ʃ/ stimuli at 0.05 level of significance but there was no significant difference between */m/* and /ʃ/.

The N1-P2 responses were the most prominent peaks. Hence, only amplitude of N1-P2 was measured. Table 4 shows the mean amplitude and standard deviation of N1-P2 complex for the three stimuli. According to the Table 4 it can be observed that high frequency stimuli, /ʃ/, had smaller amplitude and stimuli that dominant spectral energy at low frequencies, /i/ and */m/*, had comparatively larger amplitudes. A main effect of stimuli on N1-P2 amplitude was yielded when repeated measures of ANOVA was done ($F(2,35) = 8.82$, $P < 0.05$). Bonferroni's multiple comparison test revealed that there was a significant difference between /ʃ/ and */m/* at 0.05 level of significance but no significant difference was seen between /i/ and */m/* and between /i/ and /ʃ/.

Table 4: N1-P2 amplitude in μv for the three stimuli and across the age groups in children with normal hearing

Amplitude	Age	Stimuli					
		/i/		/m/		/ʃ/	
		Mean	SD	Mean	SD	Mean	SD
N1-P2	5-6 years	3.05	0.83	3.72	0.76	2.30	1.24
	6-7 years	3.35	0.69	3.45	1.98	1.62	1.01
	7-8 years	2.25	0.89	2.31	1.23	1.99	0.81

The present study demonstrates latency difference across /i/, /m/ and /ʃ/ stimuli for the P1-N1-P2-N2 responses. It was found that /i/ had shortest latency followed by /m/ and /ʃ/ had the longest latency. These results are in accordance to the findings of Agnug et al. (2006) where in /i/ had shortest latency, followed by /ɔ/, /m/, /a/, /u/, /s/ and /ʃ/ had longest latency. In the same study, latency differences across the different vowels were studied wherein high front vowel /i/ had earlier latencies than latency for low mid- back vowel /u/. The CAEP for the mid vowel /a/ occurred between these two latencies. Again, through the N1m studies, Obleser, Eultiz and Lahiri (2004) found that the back vowel /o/ resulted in later latency when compared to the latency of the front vowel /ø/. These investigators suggested that front vowels activate a more inferior and anterior source compared to back vowels. Similar results were reported by Makela, Alku, Makinen, Tiitinen (2005) and they concluded that cortical representation of vowels reflects the phonological features of speech. However, phonological features alone do not account for latency differences, as suggested by Agnug et al. wherein they found that in Australian English., /ɔ/ is further retracted than /u/, but still low-back vowel /ɔ/ did not have the latest latency, but occurred at a similar latency to the mid vowel /a/. The investigators accounted this difference to the large F2-F1 differences in the vowels .They explained that large F2-F1 differences as in /i/ and /u/ (~2300 Hz and ~1700 Hz respectively) resulted in larger areas of activation and therefore elicit a response that occurs at a different time compared to a vowel with a small F2-F1 differences such as /a/ and /ɔ/. This is supported by Makela, Alku, Tiitinen (2003), who found that different vowels with equal F2-F1 differences produced N1m peaks that did not differ in latency, although the vowels were found to activate distinctly separate areas in the left hemisphere of the auditory cortex. Thus, F2-F1 differences may account at least in part for the latency differences observed for different vowels (Agnug et al. 2006). This might also be the reason for obtaining differences in latencies for /i/, */m/* and /ʃ/ stimuli. The F2-F1 difference is approximately 700 Hz to 800 Hz for */m/* speech sound and hence might be resulting in response that occurs at a different time compared to the vowel /i/ which has a larger F2-F1 difference. Tremblay et al. (2003) also observed that when the stimuli had an early onset of vocalic portion as in /ʃi/ early P1-N1-P2-N2 latency was obtained than compared to the /si/ stimuli where the vocalic portion had comparatively later onset.

In the present study, the natural speech tokens dominated by high frequency spectral energy, /ʃ/, elicited P1-N1-P2-N2 responses with smaller N1-P2 amplitudes than speech sounds that had dominant spectral energy in the low frequencies. These findings are consistent with the results of Agnug et al. (2006), wherein, the low frequency dominant stimuli *(/m/, /a/, /u/, /i/)* had higher amplitudes compared to the high frequency dominant stimuli (/s/, /ʃ/). Similar findings have been reported for the tonal stimuli, with low frequency tones eliciting larger cortical response amplitudes than high frequency tones (Jacobson, Lombardi, Gibbens, Ahmad, Newman, 1992). Shestakova, Brattico, Soloviev, Klucharev, Hotiliainen (2004) recorded N1m for exemplars of /a/, /i/, and /u/ categories. It was found that amplitude and source locations differed between the vowel categories and vowels with similar spectral envelopes had closer cortical representations than those where spectral differences were greatest. The physiological reasons for difference in CAEP responses for low and high frequency stimuli was investigated using fMRI studies by Yeltin, Roland, Chriestensen, Purdy (2004). These investigators reported that cortical areas that respond to the low frequency auditory information are located more superficially (i-e closer to the surface of scalp) than cortical regions for high frequencies. Hence, the low frequency stimuli may activate more superficial cortical regions and produce larger amplitude CAEPs than high frequency speech sounds, when surface scalp electrodes are used. But, as it is known, the complexity of speech stimuli are not based solely on frequency effect, as found by Agnug et al. (2006), where /ɔ/ (dominated by lowest frequency spectral energy) produced N1-P2 amplitudes that were not significantly different from /s/ and /ʃ/ response amplitudes.

The results of the present study and the earlier reports indicate that the latency and amplitude of waves depend on the stimulus used for evoking the responses and the latency and amplitude probably depend on the spectral content of the stimuli used.

Effect of Age

A general trend can be observed from Table 1 wherein there is a decrease in latency from 5 to 8 years of age for all the four peak latencies (P1-N1-P2-N2). However, mixed design ANOVA revealed that age did not have a main effect on the latency and amplitude measures (P > 0.05 level of significance). No age related trend was observed for the N1-P2 amplitude and results of mixed design ANOVA revealed that there was no main effect of age on the amplitude of N1-P2. The results of significance of latency and amplitude across ages are tabulated in the Table 5. Also, no significant interaction between age and stimuli was observed. Though not statistically significant even in the present study there was a decrease in latency of all the peaks with increase in age.

Table 5: F values for latency and amplitude across ages in children with normal hearing

	F value	Significance
PI latency	(2,11)= 5.38	0.45
Nl latency	(2,11)= 1.31	0.35
P2 latency	(2,10)= 0.27	0.54
N2 latency	(2,10)= 1.28	0.31
N1-P2 amplitude	(2,35)=0.98	0.47

Previous studies also report maturational changes during the early childhood. Ceponiene, Rinne and Naatanen (2002), reported that children's ERPs are dominated by P1 and N1 peaks, and the N1 emerges between 3 to 4 years of age. In the study a long preponderance of the N2 potential was noted. Mc Pherson and Starr, (1993), also reported that P!-N1-P2-N2 decrease in latency from birth up to 5 years of age. The N2 demonstrates a greater negativity in this age group than the older age groups. It was also reported that peak amplitudes and latencies for P2 and N2 remain relatively constant for ages between 5 to 16 years (Mc Pherson and Starr, 1993). Again with advancing age there is decrease in amplitude and increase in latency (Cranford & Martin, 1991). The maturational progression of decrease in latency and amplitude with increase in age has been supported by Cunningham et al. (2000). This was attributed to increase in myelination and improvements in synapse efficacy (Kraus et al. 1993).

The present study demonstrates a more pronounced decrease in latency and amplitude for P1 than for Nl, P2, and N2 responses. This is consistent with investigations by Sharma, Martin, Roland, Sweeny, Gilley and Dorman (2005), who revealed that P1 latency is the biomarker for the development of auditory pathways in children with hearing impairment who received intervention through conventional hearing aids and cochlear implants. The reason for not finding statistical significance across ages might be because of small sample size considered for each age group (5 participants in each age group). The effect of age needs to be further investigated by a larger sample size.

P1-N1-P2-N2 responses in children with hearing impairment

P1-N1-P2-N2 responses were recorded for natural speech tokens /i/, /m/, *lSl,* in both unaided and aided condition, at 65 dBSPL for 10 children with hearing impairment.

P1-N1-P2-N2 responses in unaided condition

P1-N1-P2-N2 responses were absent in the unaided condition for all the participants. This is probably due to severity of hearing loss. The participants had hearing loss that ranged from severe to profound (71-90 dBHL and >91 dBHL), but the stimuli were presented at normal conversational level (65 dBSPL) as the aim of the study was to assess the benefit of the hearing aid at conversational level. The responses were absent in unaided condition in all the participants. Polen (1984) found that moderate to severe sensori-neural hearing loss resulted in prolongation of N1-N2 and P300 latencies and a reduction in N2 amplitude in comparison with results from normal hearing participants. But the effect of hearing loss needs to be further investigated.

Effect of amplification

Speech evoked P1-N1-P2-N2 responses were reliably recorded in children who wore hearing aid. Effects of amplification were analyzed statistically by comparing aided and unaided responses for latency and amplitude measures. Based on the functional gain measurements the hearing aids were ranked as I and II, where benefit from amplification was greater for the hearing aid ranked as I when compared to hearing aid ranked II. The mean and the standard deviation across the stimuli for two hearing aids are tabulated in Table 6. From the Table 6, it can be observed that, similar to that obtained in children with normal hearing, /i/ has the shortest latency followed by */ml* and /ʃ/ has the longest latency for both the hearing aids. Figure 2, 3,and 4 represent the unaided, aided response for rank II hearing aid and response for rank I hearing aid for the three stimuli, /i/*, /m/* and /ʃ/, respectively.

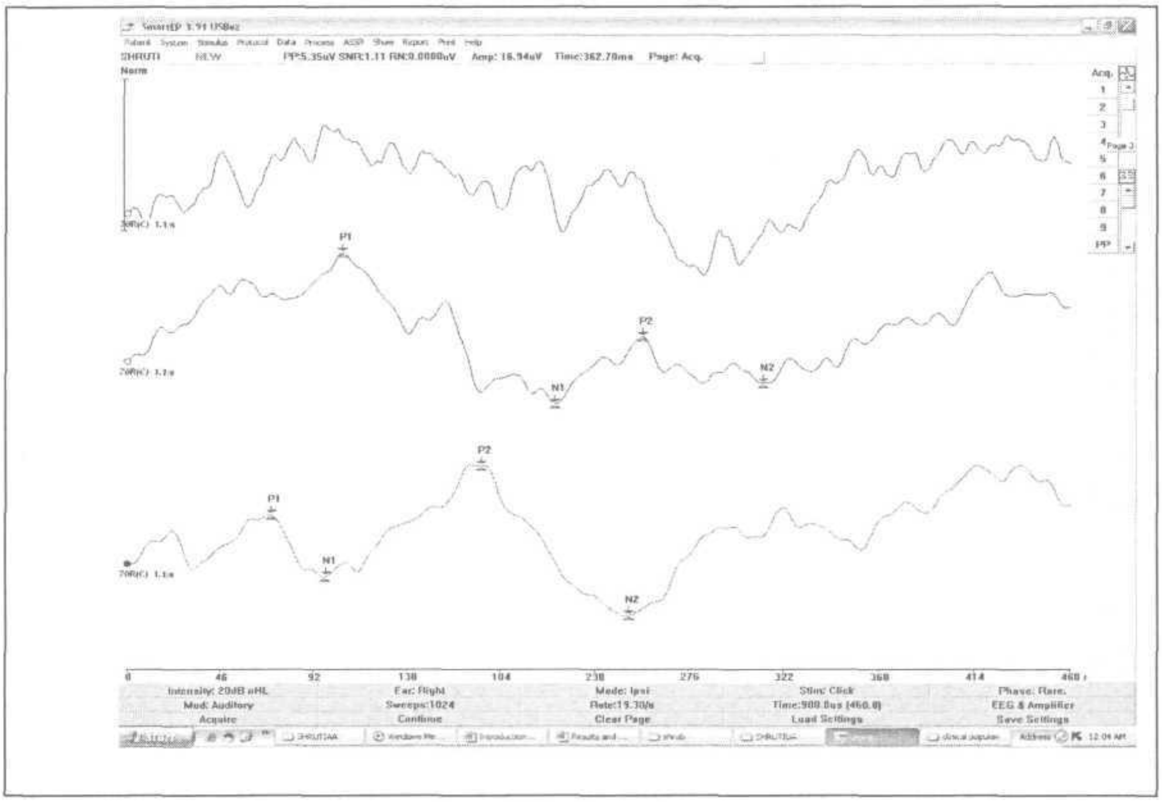

Figure 2: Responses for /i/ stimuli in unaided , rankII and rankI hearing aids

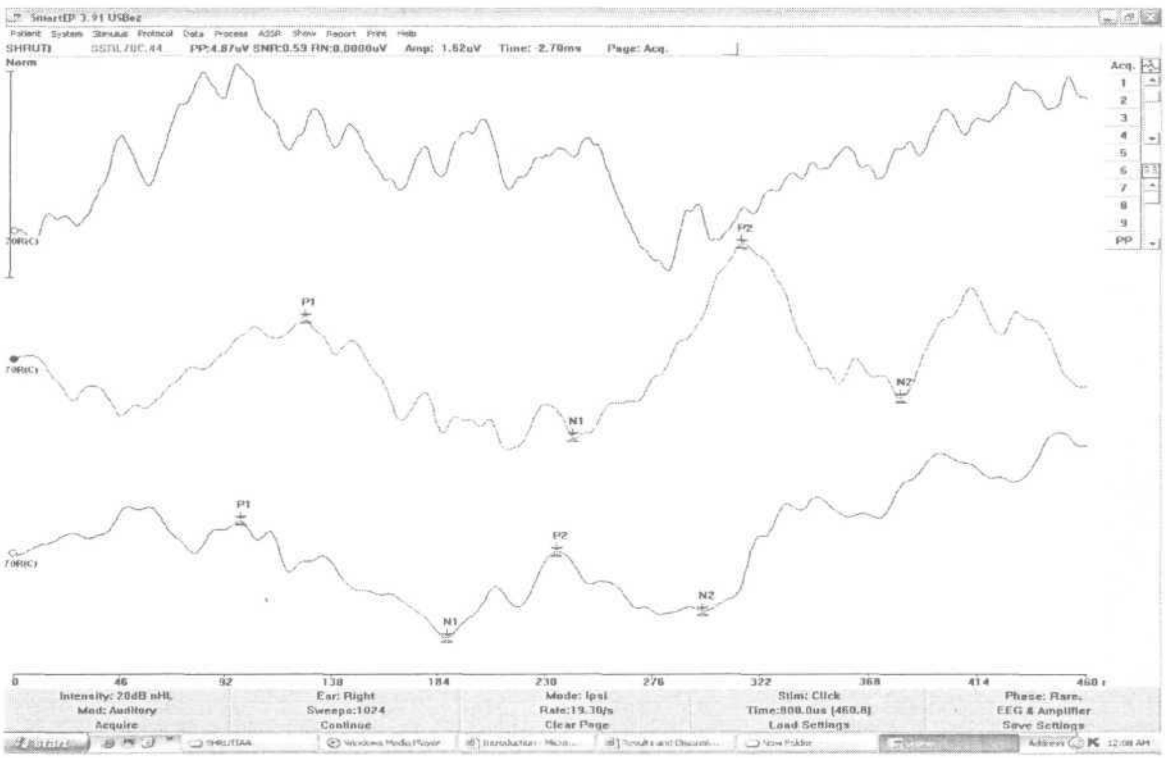

Figure: 3 Responses for /m/ stimuli, in unaided , rankII and rankI hearing aids

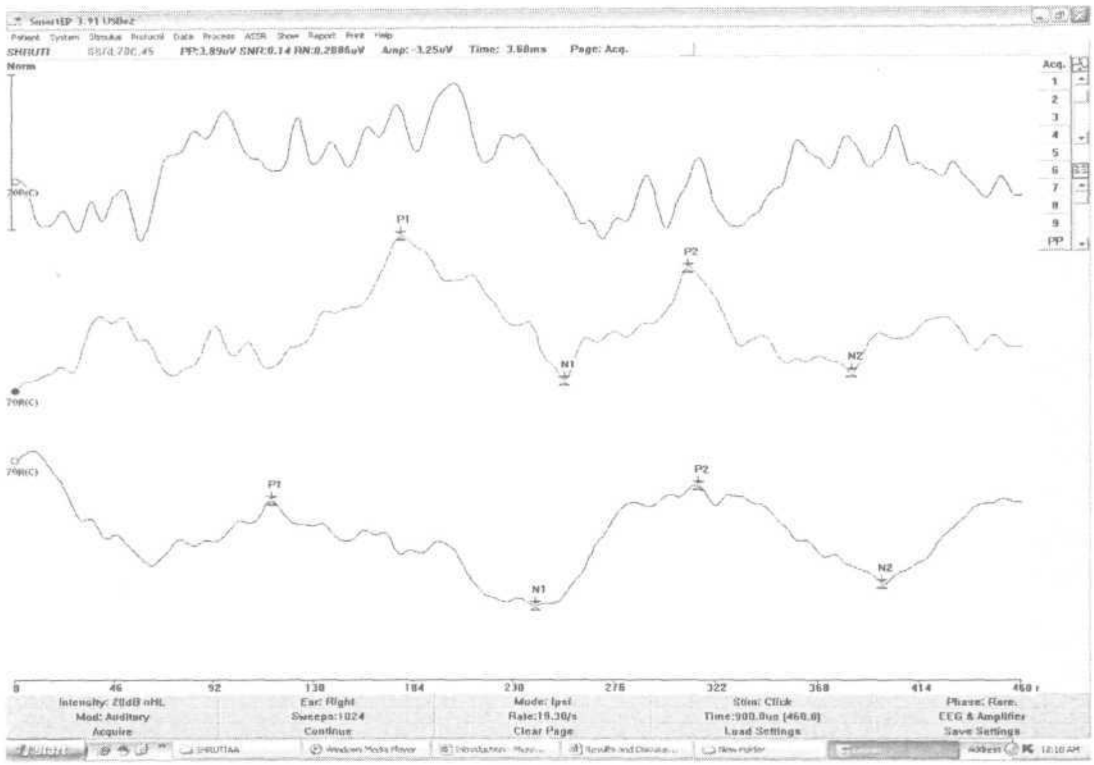

Figure 4: Responses for /ʃ/ stimuli in unaided , rankII and rankI hearing aids

Repeated measure ANOVA revealed that there was no main effect of stimuli on P1, P2, and N2 response latencies but there was a main effect of stimuli on latency of N1. Bonferroni's multiple comparison test showed that there was significant difference between /i/ and /m/ and between *lil* and /ʃ/ ($P< 0.05$) for latency of N1, while no significant difference was found between /m/ and /ʃ/ for the rank I hearing aid. In contrary, for the rank II hearing aid no effect of stimuli was observed for P1-N1-P2-N2 responses.

Table 6- P1-N1-P2-N2 latencies for the stimuli for children with hearing impairment wearing hearing aid

Latency	Stimuli	Rank I hearing aid		Rank II hearing aid	
		Mean	SD	Mean	SD
P1	/i/	92.70	20.42	119.92	42.15
	/m/	104.73	30.34	119.97	39.64
	/ʃ/	127.56	36.23	145.76	37.33
Nl	/i/	159.17	28.87	214.87	48.67
	/m/	189.77	18.98	216.10	42.48
	/ʃ/	221.55	50.11	233.53	42.17
P2	/i/	237.82	25.87	276.61	23.92
	/m/	270.0	35.92	284.91	52.31
	/s/	284.17	53.18	333.58	40.27
N2	/i/	308.13	48.11	365.10	33.35
	/m/	339.41	43.42	374.34	44.84
	/ʃ/	366.41	45.25	411.50	17.58

Table 7:F values for the latencies for the two hearing aids

	F value		Significance	
	RankI hearing aid	RankII hearing aid	RankI hearing aid	RankII hearing aid
P1 latency	(2,14) =1.42	(2,14) = 0.77	0.27	0.48
Nl latency	(2,12) = 8.20	(2, 14) =0.66	0.006	0.93
P2 latency	(2, 14) = 2.86	(2, 14) = 2.86	0.09	0.65
N2 latency	(2,14) = 3.17	(2, 14) = 3.33	0.07	0.89

The N1-P2 amplitude was also analyzed for the rank I and rank II hearing aids. The mean and standard deviation for N1-P2 amplitude with two hearing aids is tabulated in Table 8. It can be observed from the Table 8 that /ʃ/ has the lowest amplitude compared to *IV* and /m/ and *IV* has better amplitude than */ml* but there was no effect of stimuli on amplitude of N1-P2 complex for both the hearing aids, as revealed by repeated measure ANOVA (P>0.05), and these findings are similar to findings in the normal hearing children. But for rank II hearing aid it was seen that the amplitude of N1-P2 complex was reduced and the overall morphology was poor when compared to rank I hearing aid.

Table 8: N1-P2 amplitude for children with hearing impairment wearing hearing aid

uv	Stimuli	Rank I hearing aid		Rank II hearing aid	
		Mean	SD	Mean	SD
N1-P2 amplitude	*IV*	5.04	2.44	4.2	2.96
	/m/	4.76	2.25	3.5	1.25
	/ʃ/	2.97	1.32	2.5	1.98

The results from the present study indicate that P1-N1-R2-N2 can be recorded from children with hearing loss wearing a hearing aid. The poor responses for /ʃ/ stimuli might be because of reduced frequency responses of the hearing aids. Better performance with /i/ and */m/* stimuli might be because the hearing aid output affects least the vowels and the nasals, as reported by Souza and Jenstad (2005). Kiessling (1982) also reported that shape of the acoustic stimuli is distorted considerably by many hearing aids. For one participant, for whom, P1-N1-P2-N2 responses were poor in morphology even with the rank 1 hearing aid, though the functional gain measurement showed that aided thresholds were better than the unaided thresholds. Hence, P1-N1-P2-N2 response demonstrates that the child may not benefit with the hearing aid but may need alternative rehabilitation.

Comparison between unaided and aided performance

Whereas in unaided condition the P1-N1-P2-N2 responses were absent for all the participants with hearing loss, but in aided condition the responses were present for all the three stimuli for all the participants for both the hearing aids. This suggests that the children are benefited from the use of hearing aid.

Comparison between rank I and II hearing aids

The two hearing aids were compared for latency and amplitude measures across the stimuli using independent paired't' test. The results are tabulated in Table 9. The results revealed that there is a significant difference between the N1-P2 amplitudes and a significant difference was found for N1 and P2 latencies for /i/ stimuli but no significant difference was found for the P1, N2 latencies. The results hence reveal that N1, P2 latencies are critical in demonstrating the usefulness of amplification across the speech stimuli. This has also been supported by various investigators who have used N1 latency and N1-P2 amplitude for assessing the usefulness of P1-N1-P2-N2 responses in fine discrimination tasks (Sharma et al. 2003, Agnug et al. 2006).

Table 9: Results of paired Samples Test for latencies and amplitude across the two hearing aids for the three stimuli

	Stimuli	t values	Significance
PI latency	/i/	2.08	.07
	/m/	1.18	.27
	/ʃ/	1.41	.20
Nl latency	/i/	3.11	.01
	/m/	.99	.35
	/ʃ/	.68	.51
P2 latency	/i/	2.54	.04
	/m/	.32	.75
	/ʃ/	.97	.08
N2 latency	/i/	4.22	.06
	/m/	.24	.81
	/ʃ/	2.95	.06
N1-P2 amplitude	/i/	2.56	0.03
	/m/	2.78	0.02
	/ʃ/	1.33	0.04

From the results thus obtained it can be observed that amplitude measure is more sensitive in differentiating between rank I and rank II hearing aid. In the present study the testing was carried at a constant SPL for both the hearing aids. More the gain offered by the hearing aid, higher is the output delivered to the ear and the higher level reaching the cochlea probably activated more number of fibers which in turn resulted in larger amplitude. It has been reported that the amplitude of auditory evoked potentials depend on the number of fibers responding (Hall, 1992). But the latency depends on the processing time and not on the number of fibers responding and probably the difference in processing time across the participants did not result in significant difference for the two hearing aids for the latency measure. It has been reported that the effect of intensity on latencies of ALLR is not significant at moderate levels (Hall, 1992).

Comparison between children with normal hearing and children with hearing impairment wearing most appropriate hearing aid

The latencies of P1, N1, P2, N2, and amplitude of N1-P2 peaks of the two groups of participants were statistically compared using independent paired't' test. The results reveal that children with hearing impairment with most appropriate hearing aid (rank I hearing aid) had responses that were not statistically different from the normal hearing children. Hearing aids compensated for loss of audibility and there was no neural involvement, hence there was no significant difference between the two groups of participants. Also, the group II participants were hearing aid users since 2 years and are receiving auditory training. These results are supported by Ponton et al. (1996), who reported that when deaf children were fitted with cochlear implant, P1 latency showed same rate of maturation in normal hearing children and children who were fitted with the implant. Purdy et al. (2001) concluded that CAEP responses change in latency, amplitude, and overall morphology with auditory experience in deaf children with cochlear implant and in listeners with normal hearing receiving auditory training. Similar results have been reported by Tremblay et al. (2006), where reliable speech evoked responses were obtained in adults during hearing aid use. Since the hearing aid can alter the speech sounds, it was noted that when the CV boundary was preserved by the hearing aid, it could also be detected neurally, resulting in different neural patterns for /si/ and /ʃi/. There is a need to investigate whether similar results can obtained with naive hearing aid users.

Efficacy of CAEPs/ALLR in ranking hearing aid benefit

Two judges who were unaware of the test conditions were requested to rate the hearing aids based on ALLR responses. The agreement between the two judges was analyzed. It was observed that there was 80% agreement between the two judges for the response /i/ stimuli. There was only 50% agreement between the two judges for the response /ʃ/ stimuli. The response for stimuli /m/ showed 60% agreement between the judges. It was also observed that as the waveform morphology became poorer, agreement between the judges reduced. The probable reason might be that one of the judges was more experienced in judging the speech evoked ALLR than the other judge.

For investigating the efficacy of ALLR in hearing aid validation the ranking of hearing aids based on ALLR was compared with the ranking done based on functional gain measurement. A third audiologist judged the ALLR whenever there was a discrepancy between the two judges and the ranking was carried out based on the decision of the majority of the judges. Comparison of the ranking using ALLR and functional gain measurements showed that there was 80% agreement for the /i/ stimuli, followed by */m/*, which demonstrated 70% agreement and lowest agreement was found for /ʃ/ stimuli. The reason for not finding high agreement for all the stimuli might because the functional gain was based on thresholds for tonal stimuli. Behavioural aided and unaided responses were not obtained for the three stimuli (/i/, /m/, /ʃ/) and hence clearer information about the perception the stimuli could not be obtained.

From the above results it can be observed that ALLR responses can be recorded for the speech stimuli in children with normal hearing and children with hearing impairment wearing a hearing aid. The responses obtained for the three stimuli, /i/, and /m/, /ʃ/, resulted in distinct responses indicating that the stimuli are coded differently in the auditory system. Among the three stimuli, /i/ resulted in better morphology, shorter latency and high amplitude than /m/ and /ʃ/ stimuli, indicating that the vowels are better coded than the consonants. But this needs to be investigated with different stimuli also. A trend of decreasing latency with increase in age indicates that probably maturation is occurring at this stage. With most appropriate hearing aids the responses were present for the /i/, */m/*, /ʃ/ stimuli and they were not significantly different from that of children with normal hearing, demonstrating the usefulness of the hearing aid. The hearing aid which was not suitable according to the functional gain measurements, also showed poor responses in the ALLR recording, hence indicating the usefulness of the ALLR responses in differentiating between the more suitable and less suitable hearing aid.

SUMMARY AND CONCLUSION

The increased emphasis on early identification and remediation of hearing loss, has resulted in considerable interest in using the cortical potentials to assess clinical populations in whom behavioural measures, speech detection and discrimination are difficult to obtain (e.g., infants, children and difficult to test population). From the review of literature it is evident that early potentials like ABR and AMLR are not efficient tools in assessing the benefit from a hearing aid. The investigations done using ASSR demonstrates the usefulness of ASSR in hearing aid selection, but there are certain disadvantages, like presence of artifacts at higher intensities, that limit the usefulness of ASSR in validation of a hearing instrument. The major limitation of all these potentials is that all these potentials are elicited best using the clicks and tonal stimuli and these tonal stimuli give very limited information regarding speech perception. Since the aim of fitting a most appropriate hearing aid is to enhance speech perception in individuals with hearing loss, it necessitates the use of speech stimuli during validation of the hearing aid. The need of physiological measures is more for those individuals who have limited behavioural repertoire due to developmental delay or other disabilities. Thus the need for using the CAEPs recorded using speech stimuli in the hearing aid selection is accentuated. To date only a few studies have used the CAEPS/ ALLR in evaluating hearing aid benefit through the naturally produced speech stimuli. There are only a few studies where CAEP/ALLR was recorded for speech stimuli in adults with normal hearing. There is a dearth of literature on CAEPs/ALLR recorded in children with normal hearing and children with hearing impairment. Hence, the present study aimed at investigating the following objectives:

- comparing the CAEP waveform obtained for naturally produced speech tokens, */i/*, */m/* and /ʃ/ in children with normal hearing.
- evaluating the usefulness of CAEPs for naturally produced speech tokens, /i/, */m/* and /ʃ/ in validation of appropriate hearing aid.

The study consisted of two groups of participants. Group I included 15 children with normal hearing and Group II included 10 children with hearing impairment, both in the age range of 5 - 7 years. CAEPs/ALLR were recorded for Group I participants for three naturally produced speech sounds, /i/, */m/*, /ʃ/. presented at 65 dBSPL in the sound field condition. For Group II participants, functional gain measurements were done for two pre selected hearing aids, and then CAEPs were recorded for the /i/, */m/*, /ʃ/, stimuli, at 65 dBSPL with the participants wearing a hearing aid.

The CAEPs (P1-N1-P2-N2) were analyzed for peak latencies and amplitude of N1-P2 complex. SPSS software (version 10) was used for the statistical analysis. Mixed design ANOVA was used for analysis. The results were separately analyzed for Group I and Group II participants. The results were analyzed in terms of effect of age, effect of stimuli and the interaction between age and stimuli. For the group II, along with effect of age, effect of stimuli and the interaction between age and stimuli, comparison between aided and unaided performance, between rank I and II hearing aids were analyzed.

Efficacy of the most appropriate hearing aid was assessed by comparing the functional gain measurements and aided ALLR recordings, based on the ratings by the judges.

The results revealed that CAEPs could be reliably recorded in all the participants, for all the three stimuli. All the three stimuli elicited waveforms that were distinct from each other. Significant effect of stimuli was demonstrated, with *HI* having shortest latency and /ʃ/ had the longest latency and /m/ had the latency between /i/ and /ʃ/. This trend was seen for children with normal hearing and children with hearing impairment wearing a hearing aid. Significant effect of age was not observed, though a trend of decrease in latency was noted for children with normal hearing. No interaction effect was seen between stimuli and age. Comparison between aided and unaided conditions revealed that in unaided conditions the responses were absent, but the responses were present in the aided condition. Comparisons made among the latencies and amplitude values obtained with the two hearing aids showed that rank II hearing aid resulted in prolonged latencies and reduced amplitudes compared to the rank I hearing aid. There was no statistically significant difference between the latencies and amplitude of CAEP/ ALLR peaks for the two populations when the children with hearing impairment were wearing rank I hearing aid. This suggests that the hearing aids are beneficial to the children with hearing impairment and also demonstrates the usefulness of CAEPs in assessing the hearing aid benefit.

There was high agreement between the two judges for identifying the unaided responses. But the agreement between the judges for the aided responses varied across the stimuli. There was 80% agreement for the /i/ stimuli, it further reduced to 60% for /m/

stimuli and it was least, 50% for the /ʃ/ stimuli. The comparison between the functional gain measurement and aided ALLR findings revealed that there was 80% agreement for the /i/ stimuli, followed by /m/ with 70% agreement and 60% for /ʃ/ stimuli. This highlights the finding that P1-N1-P2-N2 responses are efficient in reflecting the benefit of hearing aid at a gross level, but it may not be an efficient tool in fine grained tasks. The other finding that emerges from the study is that, N1 response is a critical potential in determining the usefulness of speech evoked CAEPs in clinical population and as well as normal hearing population.

Future directions

- The ALLR responses can be recorded for a range of stimuli like stops, vowels, fricatives, nasals, and a comparison across may enhance the knowledge of speech encoding in the auditory system.
- Different degrees of hearing loss can be studied independently to study the effect of hearing loss on the P1-N1-P2-N2 responses.
- Developmental changes can be monitored by studying the CAEP responses across different age groups.
- Usefulness of speech evoked response measures can be assessed for threshold estimation.
- Speech evoked CAEPs can be assessed for whether they are instrumental in demonstrating changes after auditory training in individuals with hearing impairment and in individuals with central auditory processing problem.

• Norms need to be developed for speech evoked ALLR for various stimuli through different transducers i-e headphones, insert receivers and through the loud speakers, as it has been shown that ABR latencies vary with the transducers.

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