RELATIONSHIP BETWEEN BEHAVIOURAL MEASURES AND AIDED CORTICAL POTENTIAL RESPONSES IN CHILDREN WITH HEARING IMPAIRMENT (6 MONTHS TO 5 YEARS)

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List of Abbreviations

CAEP	Cortical Auditory Evoked Potentials
ABR	Auditory Brainstem Response
AAA	American Academy of Audiology
MMN	Mismatch Negativity
SD	Standard Deviation
RCP	Retro-cochlear pathology
TEOAEs	Transient-evoked Otoacoustic Emissions
VRA	Visual Reinforcement Audiometry
ENT	Ear-Nose-Throat
ACA	Aided Cortical Assessment
SPSS	Statistical Package for the Social Sciences
TDC	Typically Developing Children
CI	Confidence Interval
SP	Statistically Present
SA	Statistically Absent
VP	Visually Present
VA	Visually Absent

Abstract

Assessment of hearing aid benefit in younger children is a challenging procedure. Behavioral assessment of hearing aid benefit in children and young infants with hearing impairment is always difficult and questionable and hence professionals are dependent on more accurate measures like cortical auditory evoked potentials (CAEPs) using speech stimuli. The CAEPs available with HEARLab systems uses three speech stimuli (/m/, /t/ and /g/) which represent different frequency regions, and carried out at three intensity levels (75dBSPL, 65dBSPL and 55dBSPL). The study included 94 children (44 children with normal hearing, and 50 children with severe to profound sensorineural hearing impairment), with the age range of 6 months to 5 years. All the participants in the experimental group were experienced hearing aid users. CAEPs were recorded for 42 children with normal hearing and 49 children with hearing impairment. The effect of three speech stimuli and intensity on the latency and amplitude measures were assessed. Both within and across group comparisons were carried out. The results showed prolonged (poorer) latencies and reduced amplitude of the P1 and N2 in the experimental group. Further, the effect of intensity on amplitude measures showed statistically significant differences in general however latency did not show any significance. In addition, the amplitudes of the peaks P1 and N2 decreased as the intensity was decreased from 75 dBSPL to 55dBSPL. The effect of speech stimuli on the latency and amplitude measures revealed no significant differences in performance across the speech stimuli in both groups except few pairs of speech stimuli. The visual versus the statistical detection of the responses revealed that the intensity had an effect in confidence of detectability of the response. The accuracy of response detection was greater at higher intensities (75 dB) and for control group compared to the experimental group. The correlation between aided behavioral thresholds and latency of P1 and N2 were observed for the speech stimuli [m] and [g], but not for [t], however, no correlation was observed between aided behavioral thresholds and amplitude measures irrespective of any speech stimulus. The present study highlights the significance of CAEPs in estimating hearing aid benefit in younger children with hearing impairment.

Introduction

Infants with hearing impairment are always at risk of delayed speech and language development compared to typically developing infants. The negative impact of hearing impairment on speech and language development can be reduced by initiating intervention and providing appropriate amplification at an early stage. An appropriate and reliable hearing assessment is the first step in hearing aid fitting. Many prescriptive methods require behavioral thresholds to calculate the target gain of the hearing aid. When it is not feasible to obtain reliable and consistent behavioral audiograms, such as in newborns, infants, and young children, it is suggested that the hearing aids should be programmed using the estimated hearing threshold based on electrophysiological measures (AAA, 2003). The auditory brainstem responses (ABR) are the one of the electrophysiological method and its popularity in hearing aid fitting increased during the 1980s. The ABR had its own advantages and disadvantages which limited its usefulness in the hearing aid fitting. The kinds of stimuli (click or brief tone burst) used for ABR recording are too brief to activate a hearing aid's compression circuitry (Brown, Klein, & Snydee, 1999). Since click stimuli have a very high peak level compared to the root mean square level of the stimulus. Due to which, a hearing aid activated by the click stimuli typically used for ABR testing may perform differently than it would be for speech stimulus. Further, the early latency response gets affected due to stimulus artefact which is common problems encountered due to electromagnetic field of the loudspeaker and hearing aid transducer by the recording electrodes In addition, since younger children are usually tested when they are asleep, ABR is a more suitable tool for assessing hearing sensitivity in infants/younger children. However, the usefulness of auditory brainstem responses in hearing aid benefit assessment is a matter of concern. Hence, late latency responses are presumed to be more appropriate in assessing hearing aid fitting in infants/ younger children.

Purdy and Kelly (2001) reported that it is difficult to assess the efficacy of hearing aid benefit using behavioral measures in very young infants. Auditory evoked potentials (AEPs) are electrophysiological tools help in estimating the objective measure of the auditory systems' response to sound. AEPs are considered as a tool that can be used to assess aided as well as unaided auditory function in infants with hearing impairment. Cortical auditory evoked potentials (CAEPs) are the possible substitutes for the ABR which can be effectively used to assess the hearing aid benefit in infants and young children (Purdy & Kelly, 2001). CAEPs is one of the electrophysiological tool used for assessing hearing aids benefits because it is reliably present in infants and can be recorded using relatively long duration stimuli and compatible with digital hearing aid processors (Kraus et al., 1993).

Researchers explained that CAEPs can be recorded in infants and it gives evidence for detection of speech stimuli at the cortical level and there exists a relationship between functional outcomes and CAEPs for aided responses in infants. However, a study done by Golding et al. (2007) did not notice such relationship when ABR/ECochG results were compared with functional performance as (PEACH) scores (Golding et al., 2007). They attributed this result to two reasons. First, it could be because of the delay between the conduct of the ABR/ECochG testing and PEACH administration. Secondly, it could be because of in spite of the higher degree of hearing impairment, all the participants fitted with the same prescription which could lead to under fitting and poor functional performance. It is also reported that a tool used in HEARLab cortical measures i.e. statistical detection of CAEPs which were noticed to be consistent with those of an expert examiner, thus reported to be an alternative and reliable method of response detection by several researchers(Golding et al., 2007, Dun, Dillon & Seeto, 2015; Hoth, 1993). This information is likely to complement existing test batteries and assessment tools in the verification of hearing aid fitting for infants before the age when well-defined responses can be obtained from infants (Moore et al., 1992).

Developmental changes in Cortical Auditory Evoked Potentials (CAEPs)

Purdy and Kelly defined CAEPs as brain responses which are evoked by the presentation of auditory stimuli and processed near the auditory cortex (Purdy & Kelly, 2001). They reported that these measures indicate the sum of time-locked and synchronous neural activity identified at the level of cortex, related to the strength (amplitude) and timing (latency) of a response. For these reasons, CAEPs have been recommended for clinical use in monitoring changes in neural activity in hearing aid users. However, the outcome of CAEPs is highly dependent upon the type of stimulus, recording location and technique, patient age and state (Dun, Carter & Dillon, 2012). Hence, it is reported to be different in morphology and timing and may overlap one another (Hall, 1992).

CAEPs consists of a series of positive and negative peaks (P1/N1 complex) occurring between 80 and 500 ms after stimulus onset. The typical adult response consists of a dominant negative peak (N1) with a latency of 80-120 ms and N2 with the latency 180 to 200 ms. This feature is preceded and followed by positive components, peak P1 has a latency of 50-70 ms, and P2 has a latency of 150-200 ms (Davis, 1965).

The morphology of the CAEPs is mainly dependent on age (Sharma et al., 2002), sleep state (Campbell et al., 2002), attention (Picton & Hillyard, 1974), stimulus (Sharma &Dorman, 1999), presentation parameters (Golding et al., 2006), and electrode recording position (Novak, 1989). Dun, Carter and Dillon in year 2012 reported that in awake and alert children up to the age around 6 years, a reliable cortical potentials can be recorded from the vertex which includes a positive peak ranging from about 250 ms (at birth) to 100 ms(in childhood), followed by a low-amplitude negative deflection ranging from 450-600 ms (at birth) to 200 ms (in childhood).They explained the decrease in the latency ranges is due to the development of the auditory system over time and also could be dependent on the duration a person has been exposed to sound. They also reported that from around the 8th year of age, there is an appearance of an extra negative deflection ‘N1’which separates the positive deflection into peaks P1 and P2. This change continues further until adulthood, where the cortical potentials have a distinct P1-N1-P2-N2 pattern.

It is believed that the generator of ‘P1’is from deeper cortical layers in the lateral portion of Heschel's gyrus and‘N1’from multiple generators in upper cortical layers including primary and secondary auditory cortex sources near the supra temporal plane (Ponton et al., 2002). Ponton et al. (2002) reported that CAEPs maturational changes reflect developmental changes in the cortical layers and suggested that the relatively early appearance of P1 shows the maturity of cortical layers III and IV in young children, NI reflects the maturation of more superficial cortical layers. According to Novak et al., in 1989, it is believed that cortical potential generated at the surface of scalp arise from postsynaptic potentials of pyramidal neurons.

The morphology in terms of shape and magnitude of the cortical responses also varies from individuals to individuals and from time to time, depending on the alertness or drowsiness of the individuals (Picton & Hillyard, 1974; Sharma et al., 2002). This variation can make the identification of cortical responses more challenging. To assist clinicians in using cortical evaluation with infants, a statistical detection technique, based on the Hotellings-T^2 statistic, has been developed. For both normal and hearing-impaired individuals, the technique has been shown to be at least as accurate as an expert examiner in identifying cortical responses using the visual method from random noise arising from other brain activity, muscle activity and external interference (Golding et al., 2006).

Purdy et al (2013) in their study explored the differences between adult and infant auditory evoked potentials for various speech and tonal stimuli and found that there were substantial differences in the morphology of CAEPs between two groups. They reported well-documented P1, N1 and P2 peaks in adults but infant waveforms showed a broad positivity P1 at 202 ms followed by a late negativity at 367 ms on average. They also reported differences in CAEP latencies and amplitudes across stimuli for both adults and infants. Infants CAEP amplitudes were larger than those recorded in adults, and the latencies of the major P1 and N1 peaks are considerably later. However, they noticed ‘P1’ latencies which were obtained from tonal and speech stimuli consistent with those shown in previous studies in infants (Rapin & Graziani, 1967; Gravel et al., 1989; Kurtzberg et al., 1989; Pasman et al., 1999; Sharma et al., 2002).

Numbers of research studies investigating cortical potentials as a reliable tool due to its advantages of objectivity and potential to assess cortical processing of speech stimuli in difficult to test populations (Purdy & Kelly, 2001; Koravand et al., 2012; Dun et al., 2012). Evaluation of hearing sensitivity and fitting of hearing aids has always been challenging in infants and children with hearing impairment. Using objective tests like electrophysiological recording are sometimes difficult since it is affected, up to some extent, by the state of arousal and obtaining these potentials in alert infants are challenging. Hence, research on the processing of speech in these populations may aid in the development of electrophysiological techniques for diagnosing deviated central auditory maturation coincident with speech, language and learning impairments.

Clinical application of CAEPs

Threshold estimation using CAEPs

The threshold obtained using CAEPs are considered well correlates with the behavioral measures of the pure tone audiometry and can be used to assess the functional consequences of auditory deprivation and hearing aid acclimatization (Kolkaila et al., 2012). Kolkaila et al in 2012 evaluated the threshold estimation in normal hearing children and those with hearing impairment using CAEPs. They reported effective estimation of thresholds using CAEPs in both normal hearing and hearing impaired children. They also reported an evidence of central auditory system plasticity in those fitted appropriately with hearing aids compared to other children with the same degree of hearing impairment and not yet fitted with hearing aids.

CAEPs are a dawning tool for evaluation of hearing aid fitting in children who cannot give determined behavioral feedback (Dun, Carter & Dillon, 2012). They showed sign of audibility of a speech sound depends on absence or presence of CAEPs response in children with sensorineural hearing loss. The detection of response might give confidence to a degree commensurate with the detection probability, that a child is detecting the stimulus at presented level. Dun et al.(2012) aimed to find a correlation between perceptibility of short duration speech stimuli at low sensation levels and detectability of cortical responses evoked in infants.

Golding et al. (2008) reported that cortical responses to /m/, /t/ and /g/ sounds can always be detected among babies with normal hearing, provided the babies are awake, alert and physically active. The shape of the cortical responses varies markedly with age, whereas adult cortical responses usually exhibit the well-known P1-N1-P2 response, with three peaks at approximately 60, 100 and 180 ms after the stimulus onset, infant's exhibit a single positive peak centred about 200ms after stimulus onset, and often a late negative about 400ms after stimulus onset. The latency of the positive peak decreases markedly within the first year of life, provided the child has had adequate exposure to sound during this period. Children who do not receive adequate stimulation with sound until many months or a few years after birth have latencies following cochlear implantation closer to that of new born babies (Ponton et al, 1996; Sharma et al., 2002). Latency does not decrease to normal values if the child first receives adequate stimulation after seven years of age, and may not decrease to normal if the first stimulation is after 3.5 years of age (Sharma et al., 2002)

CAEPs in assessment of Hearing Aid benefit

CAEPs have been used to give a purposeful measure of the advantage given by hearing aids (Korzack, Krutzberg & Staplles, 2005). Recording CAEPs can give an idea about the perception of speech stimuli detection at the higher level of the auditory system. Characteristic CAEPs can be seen to verify the audibility of speech stimuli presented at a conversational level in infants and young children fitted with hearing aids (Kurtzberg, 1989; Steinschneider et al., 1992).

An investigation by Hinduja, Kusari and Vanaja (2005) showed that auditory late latency responses in individuals using hearing aids revealed shorter latency and larger amplitude when the aided thresholds were within the speech spectrum than when aided responses were not within the speech spectrum. Further, few studies did show changes in amplitude and latency with auditory experience in children and adult using amplification devices (Kraus et al., 1995; Purdy & Kelly, 2001; Tremblay & Kraus, 2002).

The clinical applications of CAEPs range from their use as an indicator of auditory sensitivity in difficult to test population in the diagnosis and monitoring of various otologic and neurologic disorders (Ruth & Lambert, 1991). The CAEPs responses are passively evoked in which participant is asked just to alert and there is no task to be given to subjects. Since these responses are not influenced by behavioral and performance-related demands, it provides an objective tool to assess cortical auditory function in children.

Further, it is essential to measures the effect on the acoustic content of auditory stimuli with a change in hearing aid signal processing. The signal processing system of the hearing aid can lead to various acoustic alteration of a stimulus that may affect CAEPs.

However, it remains uncertain about the effect of acoustic alteration affect the aided response of CAEP. Further, Aided CAEPs or evoked potentials recorded from hearing aid users can be used to assess the effectiveness of hearing aid fittings and experience-related plasticity connected with amplification devices.

Hassaan (2011) incorporated the aided CAEP testing in hearing aid benefit assessment battery of children with hearing impairment. The tracing of aided CAEPs constituted a valuable tool for assessment of hearing aid benefit. It can introduce valid information about the frequency specific aided hearing thresholds and the speech perception ability. Tracing of cortical potential using free field setting by simple presentation paradigm constituted a valuable tool for the assessment of hearing aid benefit. The enhancement of the physiologic activity of the auditory cortex paralleled the enhancement in the psychophysical tests. It could be a solution to the difficulties encountered in the assessment of hearing aids benefit in infants and very young children. Recording of aided N1 wave threshold revealed good agreement with the behavioral thresholds (Stapells, 2002), which constitute a valuable tool for frequency-specific threshold detection. The total number of emerged waves in the cortical potential revealed more selectivity to cortical function than the latency parameter.

The verified suitable hearing aid gain does not guarantee a benefit from the hearing aid. The aided pure-tone threshold and the speech tests constitute main validation tests, which can be an enigma when dealing with infants and young children. Accordingly, there is growing need for an applicable objective test that represents aided thresholds and cortical processing of amplified sounds.

CAEPs in measuring the auditory maturation

The developmental changes in CAEPs in infants have been measured widely (Kurtzberg et al. 1984; Novak et al. 1989; Ponton et al. 1996; Sharma et al. 1997). Since cortical responses are evoked by various brain regions which include frontal cortex, primary auditory cortex, sub-cortical region and auditory association areas (Stapells, 2002) that develop at different progression, there are complex changes in morphology of waveform, scalp distribution as well as latency and amplitude of the P1-N1-P2 waves with maturation (Cunningham, Nicol, Zecker& Kraus 2000; Ponton et al. 2000).

Koravand, Jutras, and Lassonde (2012) investigates the fashion of neural activity in the central auditory system in children with hearing impairment. They suggested that the low auditory input affects the pattern of CAEPs in children with mild-to-moderately severe hearing loss and suggested deficit and delay in maturation of central auditory processing in children with hearing impairment, as shown by P1 and N2. On the other side, negative MMN finding showed adequate discrimination abilities among children with hearing loss by amplification given by hearing aids. Their findings revealed that low auditory input early in life can affect the development of central auditory processing shown by the specific response of CAEPs. The combination of minimum two factors can also lead to delay in maturation, which can be the reason for the abnormal pattern obtained in children with hearing disability. However, it was observed that sensory hearing impairment has more impact on earlier cortical potential P1 when compared to later potential N2.

The findings have shown that CAEPs are more vulnerable with sensory hearing impairment. The result of CAEPs can be easily interpreted by well-trained audiologists (Koravand et al., 2012). P1 and N2 amplitude measures can be used to check the effectiveness of auditory training program and establish the plasticity of auditory pathway, which helps the Audiologist to confirm whether suitable stimulation is being given by a hearing aid or cochlear implant and based on the outcome, the Audiologist can adjust auditory training program.

The latency of P1 was defined as a biomarker for the development of central auditory pathway in children who received training through cochlear implant or hearing aids (Sharma et al., 2005). They concluded that both latencies, as well as morphology, can be considered as a biomarker for the development of central auditory pathway in children using a cochlear implant or hearing aid. P1 latency can also be used to compare the effectiveness of different auditory training program.

Visual versus objective detection of the CAEP responses

Dun et al(2015) estimated hearing thresholds in hearing impaired adults through objective detection of CAEPs since the available research is not sufficient in assessing the precision of this method with an automated paradigm for the objective detection of CAEPs. They investigated the difference between subjective and CAEP thresholds confirmed with and objective paradigm based on Hotelling's T^2 statistic. The objective method based on Hotelling's T^2 statistic was used to determine the response of CAEPs threshold. To select next stimulus level, a decision tree was used by researchers. The difference between objective (CAEPs threshold) and subjective test (behavioral threshold) was calculated for each audiometric frequency. Researchers observed that subjective pure tone threshold was on average 10dB lower than 40-msec cortical tone-burst thresholds, with an SD of 10 dB.4% of CAEP thresholds were more than 30 dB than their behavioral counterparts. It was summed up that behavioral hearing thresholds can be calculated with an adequate degree of precision using an objective statistical cortical-response detection algorithm in combination with a decision tree to calculate the test levels (Dun, Dillon& Seeto, 2015).

Hoth (1993) stated that confirmation of threshold of hearing from cortical responses basically done by visual inspection of recordings by an experienced professional. Minimum two factors are liable for the modest reliability of such method: first, it gives the response threshold and not the hearing threshold; and second, the outcome of visual inspection depends on subjective factors. Computer-aided evaluation encourages the visual inspection in that various characteristic features are judged numerically. The relationship between the Q value and psychophysical hearing threshold explored by a statistical analysis. The outcome showed that it was possible to predict hearing threshold with the precision of +/- 10 dB (Hoth, 1993).

Chang et al. (2012) investigated the efficacy of objective statistical detection method in CAEP testing to assess audibility in an infant with sensorineural hearing loss. They reported that greater number of CAEP responses detected at higher intensity (sensation) level. They also observed that higher number of CAEP response detected in aided condition compared to unaided condition. However, detection of CAEP responses with amplification device does not necessarily show that amplification device gives effective amplification because the automatic detection method may detect a CAEP response to a signal that is just audible. A speech stimulus which is audible just above the hearing threshold is not enough for adequate speech and language development.

The HEARLab system is developed for clinical use but eye blink response is not monitored. Any epoch with more than +/-110uV got rejected. However, if eye blink response smaller in amplitude might be missed due to amplitude rejection criterion. Thus, eye blink response that was not rejected may contaminate the CAEPs. They also showed that at higher sensation level, the responses becomes more statistically significant and increased detection sensitivity. The absence or presence of CAEPs response as defined by the automatic statistical detection was effective in showing that whether increased sensational levels given be amplification device were enough to reach the auditory cortex.

Need for the study

Recently, there has been an increasing interest in the use of speech evoked cortical potentials to evaluate speech perception abilities in a clinical population. However, there is a need to explore specific electrophysiological measures in terms of its abilities to demonstrate peripheral discrimination skills. Such tests would contribute to the objective evaluation of the participants, who for reasons like age, hearing impairment, lack of auditory, linguistic and/or cognitive pre-requisites for behavioral speech perception tests.

Various studies are reported in the literature which examined the relationship between CAEPs and auditory perception abilities (Kraus et. al., 1993; Purdy et al., 2003; Tremblay et al., 2006). The researcher has also shown that CAEPs correlate well with pure tone audiometric thresholds (Maanen & Stappells, 2005). The presence of identifiable peaks in speech evoked CAEPs inferred that speech stimuli have been detected at cortex level as reported by Hyde in 1997. However, a study has shown that CAEP waveform is affected by changes in speech stimulus parameters (Tremblay et al., 2003). Several researchers do report differences in the CAEP measures in adults population using different speech stimuli suggesting that underlying neural representation of the stimuli differs in these population (Agung, Purdy, McMohan & Newall, 2006; Tremblay et al., 2006). Keeping the above factors in mind, research at National Acoustic Laboratory (NAL) designed a protocol for speech evoked CAEPs using speech sounds [/m/, /t/ & /g/] specifically for paediatric populations and called as HEARLab evoked potential system (Carter et al., 2013; Carter et al., 2010; Chang et al., 2012). Golding et al. (2007) assessed the relationship between functional measures and obligatory cortical auditory evoked potential in young infants with normal hearing using the HEARLab system. They measured cortical potential using speech sounds when babies were awake, alert and not too physically active. They reported a significant correlation between functional measures and CAEP responses for infants who wore a hearing aid. They suggested that a significant relationship exists between CAEP latency and amplitude measures and functional outcomes for those infants who were fitted with hearing aids. Though studies have used behavioral measures and cortical auditory evoked potentials, more evidence is required to generalize the findings. Further, there is a discrepancy exists in the literature on the relationship between the behavioral measures and CAEPs responses.

Since the processing of all the speech sounds which encompasses the speech spectrum is important, studying the single frequency processing may not prove to be sufficient. Hence, the present study explored recording CAEPs using three different speech stimuli i.e. /m/ which is a low-frequency sound, /g/ which is a mid-frequency sound and /t/ which is a high-frequency sound in typically developing children. Further, there is also a need to study the CAEPs in children with hearing impairment using hearing aids since difficult-to-test population can be tapped using objective measures. In addition, the present study also estimates aided thresholds using behavioral measure and their relationship with cortical auditory evoked potentials using the HEARLab evoked potential system. Further, CAEPs in infants and younger children in aided conditions were measured at three intensity levels (75 dBSPL, 65 dBSPL & 55 dBSPL).

Aim of the Study

The aim of the present study was to check the relationship between behavioral measure and aided cortical potential responses in infant/children using hearing aids in the age range of 6 months to 5 years. Further, to compare between unaided responses from children with normal hearing and aided response from children using hearing aids.

Objective of the Study

The specific objectives of the study were to-

1. Compare the cortical responses (Latency and Amplitude) between normal hearing infant/children and infant/children using hearing aids.

2. Check effect of intensity on cortical potential responses (Latency and Amplitude) in infant/children with normal hearing as well as in infant/children using hearing aids.
3. Check effect of speech stimuli on cortical potential responses (Latency and Amplitude) in infant/children with normal hearing as well as infant/children using hearing aids.
4. Obtain the detection power using automatic responses versus visual inspection of the waveform for aided and unaided cortical potential responses.
5. Obtain relationship if any between behavioral aided responses and cortical potential measures in infant/children using hearing aids.

Method

Participants

There were 94 infants/children in the age range of 6 months to 5 years participated in the study. Out of 94 infants/children, 44 infants/children (22 male & 22 female) with normal hearing sensitivity served as control group and 50 infants/children (22 male & 28 female) with severe to profound hearing loss served as a clinical group. The mean (SD) age of the clinical and control group were 3.90 (0.90) and 3.16 (1.06) years, respectively. The mean (SD) aided thresholds for the frequencies 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were 36.14 dB HL (3.46), 38.85 dB HL (4.02), 41.31 dB HL (4.17) and 44.91 dB HL (4.32) respectively in the hearing aid users. All the participants in the clinical group were recruited from the All India Institute of Speech and Hearing (AIISH, Mysore). However, participants for the control group were recruited from the play homes, Pre-schools and kindergartens.

Participant selection criteria

The participants for the control group were selected based on the following criteria.

- Hearing sensitivity within normal limits (≤ 15 dB HL) for octave frequencies between 250 Hz to 8000 Hz for air conduction, and from 250 Hz to 4000 Hz for bone conduction.
- Normal middle ear functioning with ‘A/As’ type tympanogram and presence of acoustic reflexes at 500, 1000, 2000 and 4000 Hz as indicated by immittance evaluation.
- No history of otologic and neurologic problems.

- No illness at the day of testing, no retrocochlear pathology (RCP) ruled out using tone burst and click-evoked ABR (recorded in the Bio-Logic Navigator® pro) and TEOAEs (with the default setting in the Otodynamic echoport ILO V6 software).

The participants for the clinical group were selected based on the following criteria.

- Participants in the clinical group had a pre-lingual severe-to-profound sensorineural hearing impairment (> 70 dB HL).
- Normal middle ear functioning as indicated by immittance evaluation.
- History of no otologic and neurologic problems.
- Retrocochlear pathology was ruled out using TEOAEs.
- The clinical group had an experience of using hearing aids at least for one month and not exceeding one year.
- Aided threshold within speech spectrum at least up to 2000 Hz.

Based on the above criteria, three participants were eliminated from the study, in which 2 participants from the control group for delayed motor milestones as reported by the parents and one from the clinical group because of aided threshold which was out of speech spectrum at 1000 Hz, 2000 Hz, and 4000 Hz. Finally, 42 (20 male and 22 female) infants/children with normal hearing and 49 (21 male and 28 female) infants/children with severe-to-profound sensorineural hearing impairment participated in the study.

Instrumentation

The below mentioned equipment was used in the study. All the behavioral and electrophysiological tests were carried out in a sound treated room as per the guidelines in ANSI S3.1 (1991).

- Calibrated double channel clinical audiometer GSI-61 with the standard loudspeaker (1761-9630),TDH-50 headphone and B-71 bone vibrator was used for visual reinforcement audiometry (VRA) /conditioned audiometry/ pure tone audiometry as well as for aided audiogram and Ling's six sounds (/a/, /e/, /u/, /m/, /s/ & /ʃ/) test.
- Calibrated GSI-Tympstar middle ear analyzer was used for tympanometry and reflexometry evaluation.
- Otodynamic echoport ILO V6 software with the default settings was used for the measurement of TEOAE.
- Biologic Navigator Pro EP (version 7.07) was used for auditory brainstem responses (ABR).
- HEARLab (version 1.0) system was used for recording of speech evoked cortical potentials.

Procedure

Visual Reinforcement Audiometry (VRA)

Visual Reinforcement audiometry was carried out for the children who were below the age of 3 years (20 in control group and 18 in the experimental group). The thresholds were assessed for the octaves 250 to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction. The familiarization session consisted of training the child to orient /look towards the visual reinforcement whenever he/she hears a sound. The children were encouraged to give VRA responses by providing animated visual reinforcements. The visual reinforcement audiometry was carried out in the sound field, with the speaker at the 0^0 azimuths, and the visual reinforcement screen was located at the extreme right side to the participant. A visual reinforcement was presented following a tonal stimulus at different frequencies.

The conditioned play audiometry

The conditioned play audiometry was done for the children between the age ranges of 3 to 5 years (22 in control group and 31 in the experimental group). Air conduction testing was carried out through headphones, and bone conduction was assessed using the bone vibrator. The children were conditioned to put down the block whenever they hear a puretone or warble tone and were conditioned to respond even for the slightest sound they hear through the headphone or bone vibrator.

Immittance evaluation

Immittance evaluation was carried out using GSI-Tympstar to assess middle ear function. Appropriate sized and sterilized probe tips were selected to obtain an adequate hermetic seal. Caution was taken while testing so that the child was not physically moving. Once the hermetic seal was achieved, the tympanometric testing was started to get the tympanometric peak pressure, static admittance and physical volume of the ear canal. Ipsilateral and contralateral acoustic reflex thresholds were measured at 500, 1000, 2000, and 4000 Hz. All the participants in the control group showed 'A/As' type of tympanogram with the presence of acoustic reflexes in between 500 Hz to 4000 Hz. However, experimental group participants showed 'A/As' type tympanogram with the absence of acoustic reflexes in between 500 Hz to 4000 Hz.

Auditory Brainstem Response (ABR)

The click-evoked ABR was administered in 18 infants/children (7 in control group and 11 in the experimental group) to verify the hearing sensitivity of the participants. During the recording of ABR, the participants were seated in a reclining chair or made to sleep on a pediatric bed. Infants/children were sedated whenever they were not cooperative for the ABR testing since it is not affected by the sleep. The skin surface at the two mastoids (M1, M2) and forehead (Fz) were cleaned with skin abrasive, to obtain skin impedance of less than 5 kΩ for all electrodes. The electrodes were placed with the help of skin conduction paste and surgical plaster was used to secure them tightly in the respective places. Children were made to relax and to reduce extraneous body movements by playing silent cartoon movies. The testing was carried out monaurally for both the control and experimental groups. Recording of ABR started with the level of 50dBnHL for the control group and the intensity was reduced in 10dB steps. The lowest level at which the ABR was observed was considered as the threshold of ABR. The ABR was present (presence of peak V at 30 dBnHL for click stimuli) in all the participants of the control group. However, ABR for click stimuli was absent in all the 11 participants in the experimental group at the intensity of 90 dBnHL. Table 1 shows the protocol used for the click-evoked ABR.

Transient Evoked Otoacoustic Emissions (TEOAEs)

Transient evoked otoacoustic emissions were performed on both groups to rule out retrocochlear pathology using Otodynamic echoport ILO V6 software with the default settings. The testing was carried out in a sound-treated room, and care was taken while recording to make sure that the infants/children were not moving physically and the ambiance was quiet. It was observed that the TEOAEs were present (at least for three consecutive frequencies with an SNR of >6dB) in all the participants of the control group, whereas TEOAEs were absent in all the participants of the experimental group.

Aided Audiogram in experimental group

Aided audiograms were obtained for the experimental group participants with their own hearing aids as prescribed by qualified Audiologist. The hearing aids of the participants were optimized and programmed to make sure that the aided thresholds are within speech spectrum at least for the frequency 500, 1000 and 2000Hz. Aided thresholds were obtained for the frequencies 500, 1000, 2000 and 4000Hz. The testing was carried out with the loudspeaker kept at 0^0 angles and participants were seated at one meter away from the loudspeaker.

Cortical Auditory Evoked Potentials (CAEPs)

The Cortical auditory evoked potentials (CAEPs) were recorded using HEARLab (version 1.0) evoked potential system with the aided cortical assessment module default settings (Table 1). The CAEPs were recorded only for the participants who passed the selection criteria, for both control and experimental group. The participants were seated at the test position with their head approximately 1 meter from the loudspeaker positioned at 0^0 azimuths. Disposable self-adhesive button electrodes were used for the CAEP recording.

The CAEP recording displays averaged neural responses for the speech stimuli, at the specified intensity level. Each recorded waveforms for different speech stimuli were colour coded (red for /m/, blue for /t/ and green for /g/). The HEARLab instrument provides the statistical analysis results in a separate window which are displayed in the detection ‘p’ plots. The statistical processing of detection of responses is achieved through the Hotelling’sT^2 (Flury & Riedwyl, 1988; Harris, 2001). Hotelling’sT^2 uses the averaged responses, which calculates the probability (p) by comparing the mean value of any linear combination of variables, which are significantly different from zero. The resultant p-value is represented graphically, which are color coded. The detection of p-values indicated the probability that the response is significantly different than noise. A p-value of less than 0.05 indicated the presence of responses (Figure 1).

Figure1: Hotelling's T^2 for the statistical detection of the responses.

Table 1: *Parameters for click-evoked ABR and speech evoked cortical potential*

Parameters	Click-evoked ABR	Speech-evoked cortical potential
Stimulus	Click (100 µs duration)	/m/ (30 ms), /g/ (30 ms) and /t/ (30 ms)
Electrode Placement	Reference - M1 Active - Fz Ground- M2	Reference: M1/M2 Active: Cz Ground: Fz
Intensity	90 dB nHL	55 dB SPL, 65 dB SPL, and 75 dB SPL
Transducer	Insert earphones	Loudspeaker
Transducer Position	None	0 degree azimuth
Ear	Monaurally	Monaurally
Polarity	Alternating	Alternating
Filter setting	100 - 3000 Hz.	1-30 Hz
Repetition rate	11.1/s	1.1/sec
Total no. of sweeps	1500	200
Impedance	< 5 kΩ	< 5 kΩ
No. of Channels	One	One
Analysis Time	10ms	500 ms

Statistical analysis

All statistical analyses were carried out using the software Statistical Package for the Social Sciences (SPSS, version 21). Descriptive statistics were used for obtaining mean, median and standard deviations. The amplitude and latencies of the peaks P2 and N2 were noted down, for all speech stimuli (/m/, /t/ & /g/) at different intensity levels (75 dBSPL, 65 dBSPL & 55 dBSPL) for both the groups. Since the data were not uniformly distributed, non-parametric tests such as Kruskal-Wallis and Mann-Whitney U were done to compare between two groups. The non-parametric tests i.e. Friedman and Wilcoxson signed rank tests were done to make within group comparison. Further, Spearman correlation analysis was also done to study the relation between behavioral aided threshold and CAEPs measures.

The waveforms of CAEPs recorded for control and experimental group was inspected both statistically and visually. For visual inspection, screenshots of the waveforms at each intensity level were taken, for both the control and experimental group. The images were later cropped to remove the statistical information, and only the waveform information which was color coded with red, blue and green for the stimuli /m/, /t/ and /g/, respectively, were given to three experienced audiologists working in the area of cortical potentials. They were instructed to mark the peaks P1 and N2 on each waveform in addition to the identification of responses in both the groups. The waveforms inspected by the Audiologists were later compared with the automatically identified waveforms by the HEARLab system.

Results and Discussion

The latencies and amplitudes of the peaks P1 and N2 of the cortical auditory evoked potentials were measured. The mean and standard deviations (SD) of peaks P1 and N2 were calculated using the descriptive statistics, for latency and amplitudes measures, for all the three speech stimuli ([m], [t] & [g]) and at three intensity levels (75 dB SPL, 65 dB SPL & 55 dB SPL). Effect of intensity, as well as the effect of speech stimuli on the latency and amplitudes of the P1 and N2, was assessed using Mann-Whitney U test for between group comparison and Friedman non-parametric tests for within group comparison. Further, Wilcoxon pairwise comparison test was done wherever Friedman test showed significant differences within each group. In addition, Pearson's correlation analysis was done to check the relationship between the aided behavioral thresholds and aided cortical auditory evoked potentials.

In the present study, the morphology of the CAEPs recorded from the control group was observed to be better in comparison to the experimental group (Figure 2 & 3). The Figures 2 and 3 shows a sample waveform as the visual representation of the recorded waveforms of the CAEPs for three speech stimuli at three different intensity levels. The figures also give information on the automatic statistical detection of the responses, where a '√' mark is an indicative of a positive response and a '-' mark is an indicative of the absence of response. As it can be noted from the figures, there is a positive response to all the three speech stimuli at all intensities in the control group (Figure 2). However, the responses were detected at only three recordings in the experimental group (Figure 3). It can also be noted that there are differences in overall morphology obtained from both the groups.

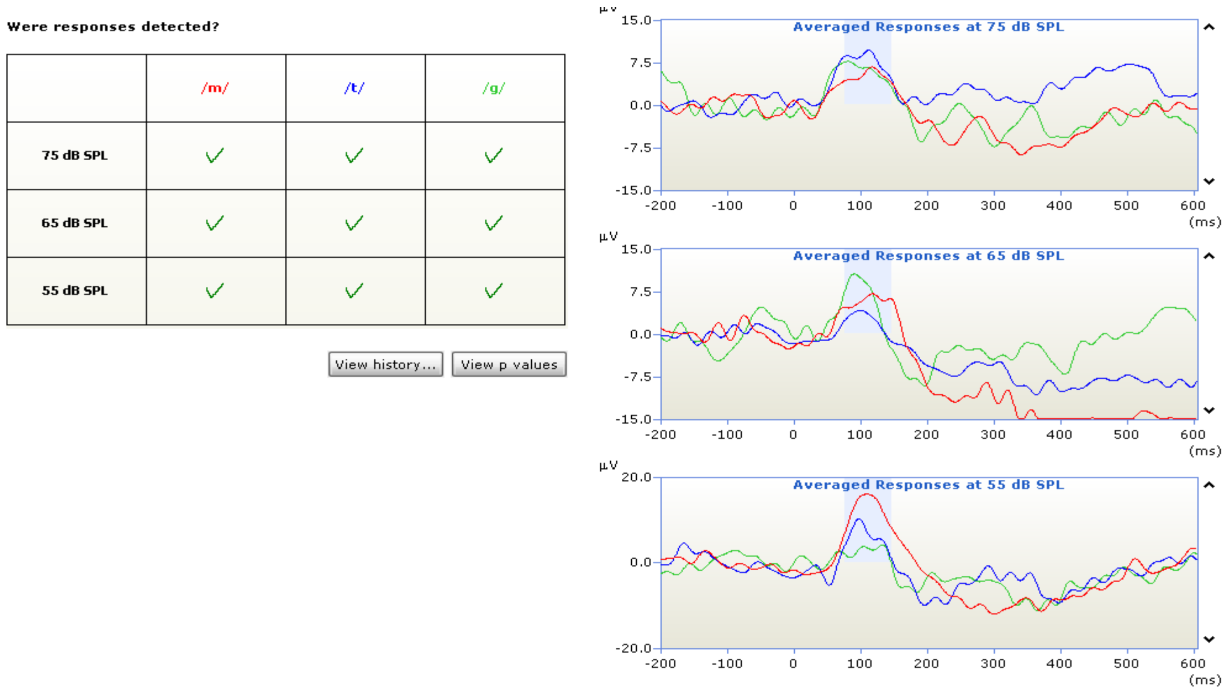


Figure 2: *A sample waveform of the recorded CAEP responses in HEARLab system from a participant of the control group.*

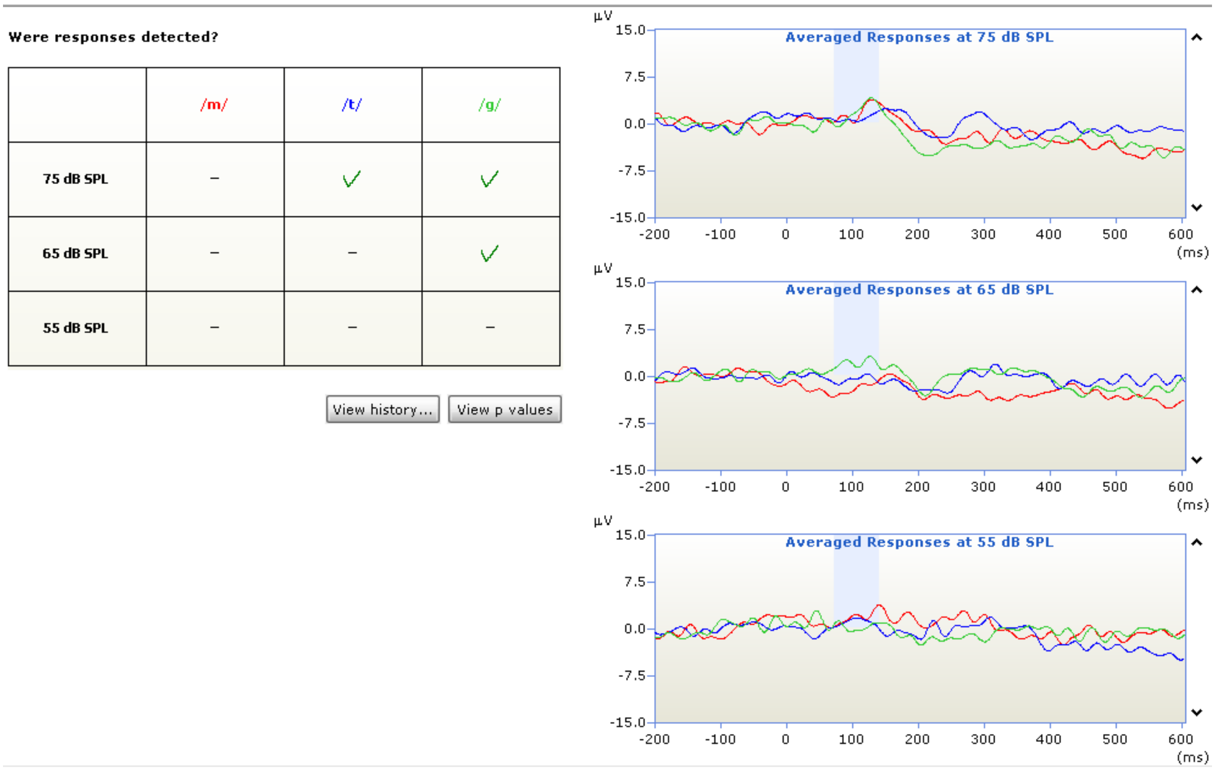


Figure 3: *A sample waveform of the recorded CAEP responses in HEARLab system from a participant of the experimental group.*

As reported in literature, in infant and younger children a reliable CAEP shows biphasic responses i.e. a positive peak (P1) in the range of 100 ms to 250 ms followed by a low-amplitude negative deflection (late negativity or N2) ranging from 200 ms to 450 ms (Dun, Carter & Dillon, 2012., Purdy & Kelly, 2001). Studies reported decrease (better) in latency which could be because of the development of the auditory system over time in younger children (Sharma, Dorman, &Spahr, 2002). Studies also reported decrease in latency could be due to duration of use of amplification devices in an individual exposed to the sound (Ponton, Don, Eggermont, Waring, Kwong& Masuda, 1996; Bauer, Sharma, Martin, & Dorman, 2006).

Effect of intensity on the latency and amplitude measures in each group

The mean latency with 95% confidence interval (CI) of the peaks P1 and N2, at different intensities in both control and experimental group for [m], [t], and [g] are given as Figures4, 5 and 6 respectively. From the figures, it can be observed that the latencies of the P1 and N2 in TDC with normal hearing are shorter (better) compared to children using hearing aids.

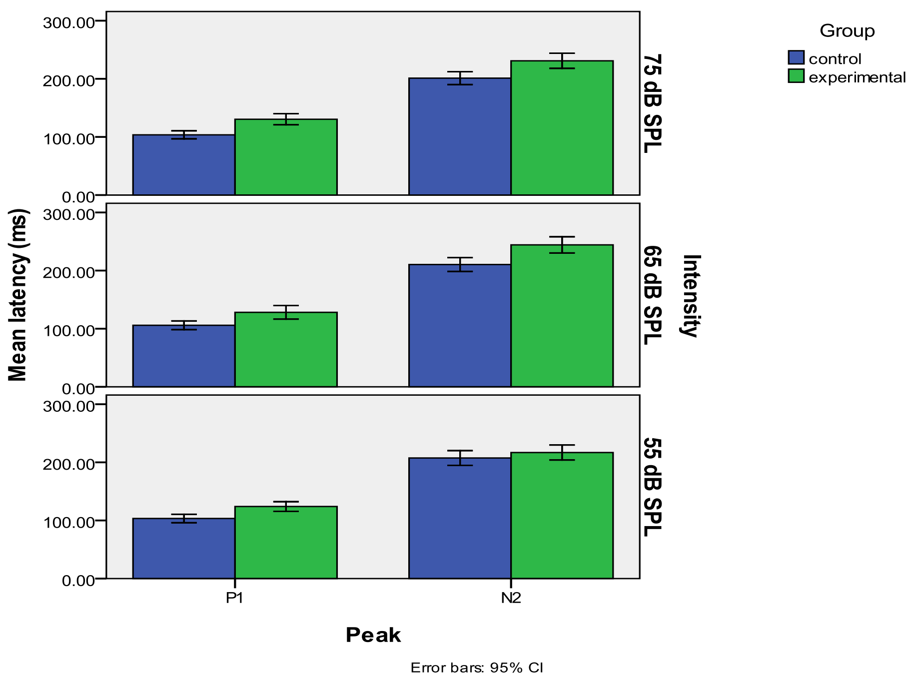


Figure 4: *Mean latency and 95% CI of latency of the peaks P1 and N2 at different intensity levels for [m] speech stimulus in both control and experimental groups.*

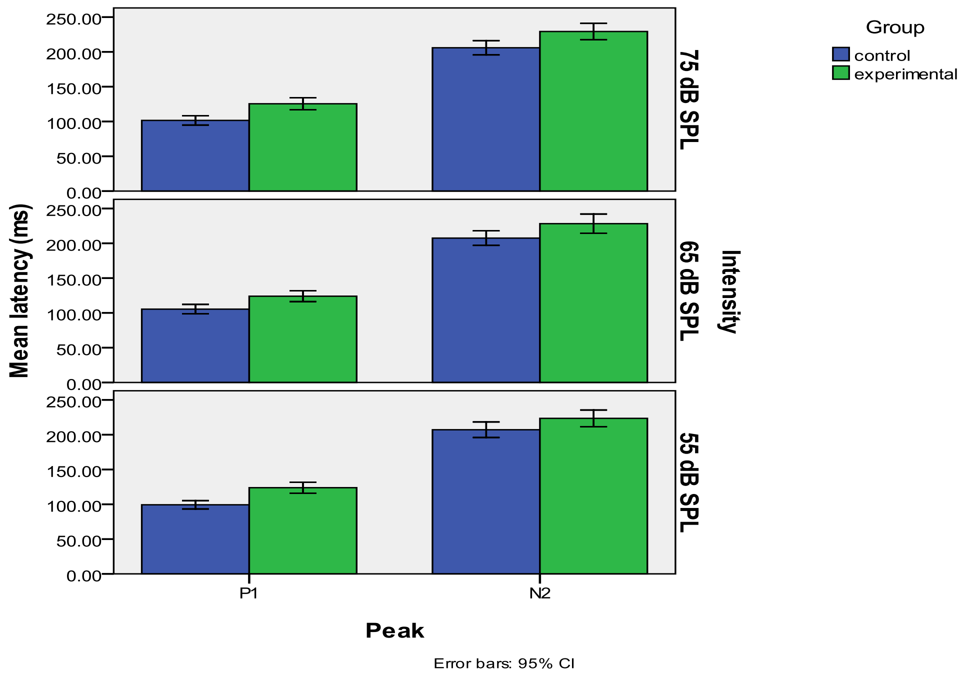


Figure 5: *Mean latency and 95% CI of latency of the peaks P1 and N2, at different intensity levels for[t] speech stimulus in both control and experimental groups.*

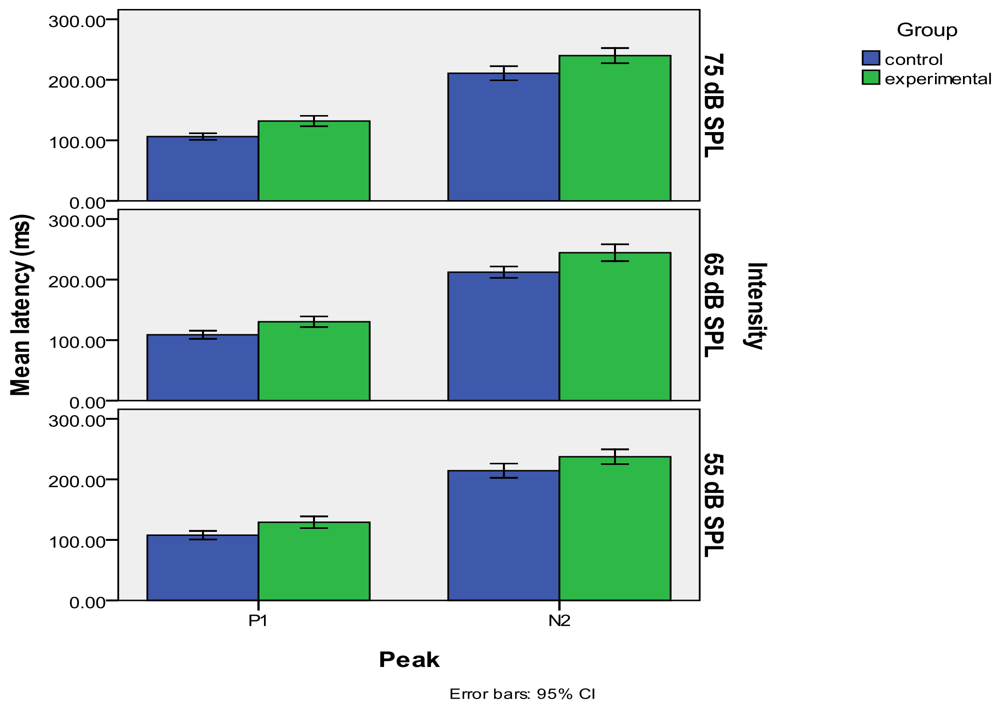
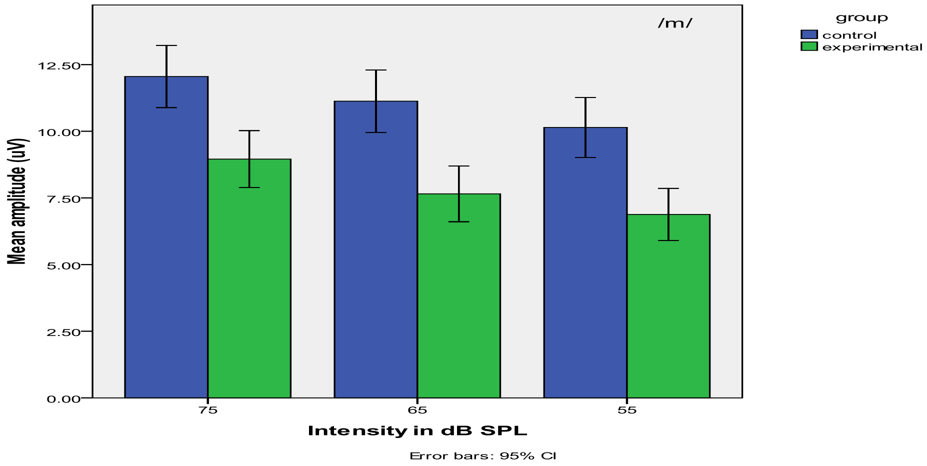
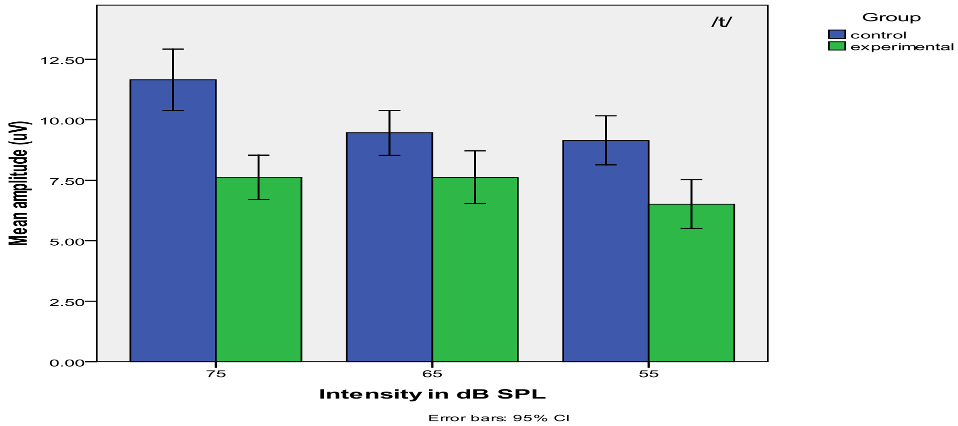


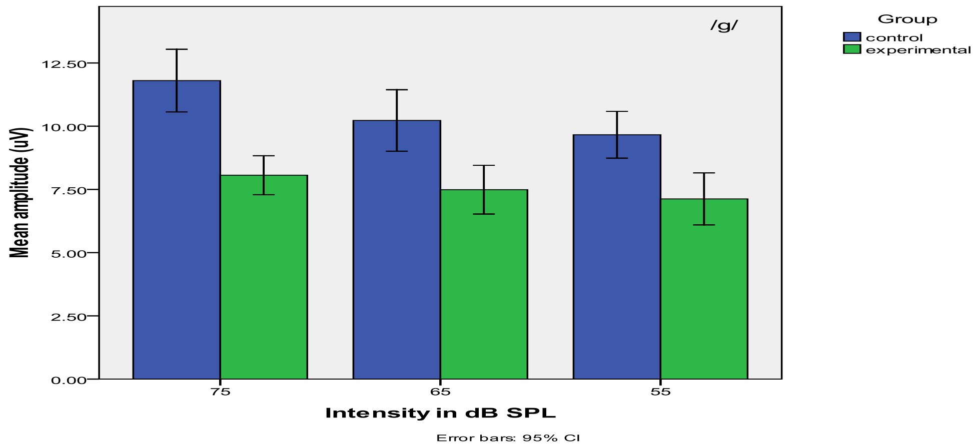
Figure 6: *Mean and 95% CI of latency of the peaks P1 and N2 at different intensity levels for [g] speech stimulus in both control and experimental groups.*



(7A)



(7B)



(7C)

Figure 7: *Mean and 95% CI of the amplitude of the peaks P1- N2 complex, at different intensity levels, for the stimuli [m], /t and [g] in the figures A, B, and C respectively for both the groups.*

Similarly, the Figures 7A, 7B, and 7C graphically represent the mean and 95% confidence interval (CI) for the peak-to-peak amplitude of the P1-N2 complex for different speech stimuli in both control and experimental group. It can be noted from the figure 7A, 7B and 7C are that the amplitudes of the P1-N2 complex are lesser (poorer) in the hearing aid users in comparison to TDC with normal hearing irrespective of any speech stimulus and intensity levels. Further, it was also noticed that as intensity decreases from 75 dB to 55 dB, the P1-N2 complex amplitudes also reduced for both the groups irrespective of any speech stimulus.

Friedman test was done to check the effect of intensity in each group i.e. TDC with normal hearing and hearing aid users at each speech stimulus on latency and amplitude measures. In addition, *Wilcoxon pair-wise comparison* was done wherever there were significant differences observed in Friedman test at each speech stimulus and at each intensity level (Appendix 1).

Table 3: *Effect of Intensity on each speech stimulus in control and experimental group (Friedman Test outcomes)*

		TDC with NH		Hearing aid users	
Speech stimuli	Peaks	Chi-square-Latency	Chi-square-amplitude	Chi-square-Latency	Chi-square-amplitude
/m/	P1	0.08	1.30	2.36	2.45
	N2	0.48	**8.13***	0.08	**7.40***
/t/	P1	3.67	1.16	3.56	**10.35***

	N2	0.51	**15.17***	0.58	1.35
/g/	P1	**6.59***	**8.23***	2.59	3.70
	N2	0.31	5.78	1.98	2.11

**p<0.05; TDC: Typically developing children; NH: Normal Hearing*

From the table 3 it is observed that effect of intensity on latency and amplitude measures in TDC with normal hearing did not show any significant differences at each speech stimulus except for latency and amplitude of peak P1 of /g/ speech sound and only amplitude of peak N2 of /m/ and /t/ speech stimuli. However, peak-to-peak amplitude of P1-N2 did show significant effect of intensity for /m/ (χ^2 =6.63), /t/ (χ^2 =16.23) and /g/ (χ^2 =21.49) speech stimuli among TDC with normal hearing.

Effect of intensity on latency and amplitude measures in hearing aid users did not show any statistically significant differences at each speech stimulus except for amplitude of peak N2 of /m/ and peak P1 of /t/ speech stimuli. However, among hearing aid users, the peak-to-peak amplitude of P1-N2 did show a significant effect of intensity only for /m/ (χ^2 =19.05) and /g/ (χ^2 =7.82) speech stimuli.

The results of *Wilcoxon pair-wise comparison test* revealed that in TDC with normal hearing, both latency and amplitude measures of peak P1 and N2 did not show statistically significant differences between different intensity levels at each speech stimulus except P1 latency (65 dB versus 55 dB) and amplitude (75 dB versus 55 dB) for [g] speech stimulus and N2 amplitude for [m] at (75 dB versus 55 dB; 65 dB versus 55 dB), and [t] at (75 dB versus 65 dB; 75 dB versus 55 dB; 65 dB versus 55 dB) speech sound. Similarly in hearing aid users, both latency and amplitude measures of peak P1 and N2 did not show statistically significant differences between different intensity levels at each speech stimulus except amplitude of P1 for [t] (75 dB versus 55 dB) and amplitude of N2 for [m] (75 dB versus 55 dB; 65 dB versus 55 dB) speech stimuli (Appendix 1) .

The effect of intensity on the peak-to-peak amplitude of the P1-N2 complex was also analyzed. The results revealed statistically significant differences across different intensity levels on P1-N2 complex among TDC with normal hearing for [m] at (75 dB versus 55 dB) [g] at (75 dB versus 65 dB; 75 dB versus 55 dB) and [t] at (75 dB versus 65 dB; 75 dB versus 55 dB) speech sound. However, children using hearing aids showed statistically significant differences only for [m] at (75 dB versus 65 dB; 75 dB versus 55 dB; 65 dB versus 55 dB) and [g] at (75 dB versus 55 dB) speech sounds. The significant differences were not noticed for [t]speech sound for any combinations of intensity levels in hearing aid users. The above outcomes very clearly indicate that children with normal hearing do have the ability to reflect the minute changes in intensity in terms of change in slope (P1-N2 complex) of cortical potentials at any frequency region (low, mid and high). However, such changes are not reflected well in hearing aid users in cortical potential measures though fitting of appropriate hearing aids with optimum gain was done. In spite of the optimum gain provided to hearing aid users, changes in P1-N2 complex well reflected only at low and mid frequency region and not very clearly reflected at the high-frequency region. This can be attributed to the fact that even though hearing aids compensate for the hearing impairment, the CAEP still does not reflect the detection of minute changes in intensity (difference of 10 dB) at cortical level specifically with high-frequency sounds.

Billings, Tremblay, Souza and Binns in 2007 have found that as intensity increases the latency of the peaks P1, N1, P2 and N2 decreases (better) and the amplitude increases (better). Oates et al (2002) found similar results where the amplitudes of the N1 were larger for the stimulus intensity of 85 dB SPL than at 65 dB SPL. Recently, Dun, Carter, and Dillon (2012) also observed that the statistical detection of the CAEP responses increased significantly as the intensity was raised in 10 dB steps from 55 dB SPL to 75 dB SPL using HEARLab evoked potential system in infants with sensorineural hearing impairment. Similarly, in the present study, it is observed that the amplitude increases and the latency reduce (better) as intensity levels increases from 55 dB SPL to 75 dB SPL in 10 dB steps though these changes were not statistically significant for each speech stimulus. Effect of intensity in terms of changes in latency and amplitude was observed in both TDC with normal hearing as well as children using hearing aids.

Chang et al in 2012 investigated the detection of CAEPs and estimated the audibility in infants with hearing impairment. The CAEPs were recorded in both aided and unaided conditions. They found that greater number of CAEPs was recorded at higher sensation levels in these infants. Further, in aided condition, CAEP responses were better compared to unaided condition. In addition, significantly more number of CAEP responses was noticed for the speech stimuli [g] and [t] sounds in aided than the unaided condition. However, CAEP responses using [m] sound did not elicit more detection in aided than the unaided condition. Further, they demonstrated that the statistically significant CAEP responses as revealed by the automatic statistics are mostly recorded to speech stimuli with higher sensation levels in aided condition. Hence, there is an effect of intensity on the latency and amplitude of CAEP responses. However, using the HEARLab system, the present study did not find a significant effect of speech stimuli on CAEP at different intensity levels in each group.

Effect of speech stimuli on the latency and amplitude measures in each group

Friedman test was done to check the effect of different speech stimuli on each intensity level in TDC with normal hearing as well as on hearing aid users (Table 4). The results did not show the statistically significant effect of different speech stimuli at each intensity level on latency and amplitude measures of peak P1 and N2 except P1 latency at 65 dB SPL and amplitude of P1 at 75 dB and N2 amplitude at 65 dB SPL in TDC with normal hearing. However, peak-to-peak amplitude showed the statistically significant effect of different speech stimuli at 65 and 55 dB SPL in TDC with normal hearing. Similarly, hearing aid users also did not show the statistically significant effect of speech stimuli at each intensity level for both latency and amplitude measures except N2 latency and amplitude at 75 dB SPL. In addition, peak-to-peak amplitude also did not show a significant effect of speech stimuli at any intensity level.

Table 4: *Effect of speech stimuli on each intensity level in each group (Friedman Test outcomes)*

		TDC with NH		Hearing aid users	
Intensity level	Peaks	Chi-square-Latency	Chi-square-amplitude	Chi-square-Latency	Chi-square-amplitude
75 dB SPL	P1	2.32	**6.63***	5.19	2.05
	N2	0.94	5.07	**6.17***	**8.82***
65 dB SPL	P1	**7.28***	5.43	3.03	0.84
	N2	0.70	**13.30***	3.38	1.64
55 dB SPL	P1	0.84	1.91	3.95	1.00
	N2	0.00	2.63	5.25	0.48

**p<0.05; TDC: Typically developing children; NH: Normal Hearing*

Wilcoxon pair-wise comparison was done to check the effect of speech stimulus on the latency and amplitude measures in control and experimental group. The pair-wise comparisons were made between the speech stimulus i.e. [m] versus [t], [g] versus [t], and

[m] versus [g] for each group and at each intensity level. The results revealed that there were no statistically significant differences across speech stimuli at each intensity level in both TDC and hearing aid users. However, sporadically there were difference observed in each group i.e. TDC with normal hearing shows differences for latency of P1 ([m] versus [t]; [m] versus [g]) at 65 dB; amplitude of P1 ([g] versus [t]) at 75 dB; amplitude of N2 ([m] versus [g]) at 65 dB. Similarly in hearing aid users, the different combination of speech stimuli showed significant differences only for latency of N2 at 75 dB SPL for [m] versus [g] speech stimuli as well as for amplitude of N2 at 75 dB for [m] versus [t] and [g] versus [t] speech sounds. Further, Wilcoxon pair-wise comparison for the peak-to-peak amplitude of the P1-N2 complex revealed no significant differences between different speech stimuli at each intensity level among both groups of children, except for the pair [m] & [t] at 65dBSPL and 55 dB SPL for the control group (Appendix 1).

Dun, Carter, and Dillon in 2012 found that there was no significant effect of speech stimuli ([m], [t] and [g]) on the latency and amplitude measures of the P1 and N2 in the hearing impaired infants. In contrast, Golding et al in 2006 reported that the speech stimuli [t] elicited significantly larger amplitude in comparison to speech stimuli [m] and [g]. Purdy et al in 2004 found that the differences in amplitudes existed for the speech stimuli pair [m] & [t] and [t] & [g] in the infants using hearing aids. Studies have demonstrated that the aided responses for the stimuli [m] were better than for the [t] and [g] (Gravel et al., 1989; Sharma et al., 2005; Golding et al., 2006). The reason for obtaining such results can be due to the fact that the speech stimulus [m] is a low-frequency speech syllable. Chang et al in 2012 found that the CAEP responses were better for the speech stimuli [t] and [g], than for [m], in the infants who were fitted with hearing aids. In the present study, in contrary to the above studies and in accordance with Dun, Carter, and Dillon (2012), it was observed that there was no significant effect of speech stimulus on the latency and amplitudes of CAEPs. The significant differences observed for the effect of the stimulus on the latency and amplitude measures at few intensity levels could be attributed to chance factors, since there were no clear trends noticed in the present study. The another reason could be that present study explored CAEP in children having severe to profound degree of hearing impairment fitted with hearing aids.

Comparison of latency and amplitude measures of the peaks P1 and N2 between two groups

Descriptive statistics shows mean and standard deviation (SD) for latencies and amplitude measures of peaks P1 and N2, across three different speech stimuli ([m], [t] & [g]) at three intensity levels (75 dB SPL, 65 dB SPL & 55 dB SPL) for both control and experimental group (Table 5). From the Table-5, it is observed that the latencies of the CAEP peak P1 and N2 in the hearing aid users were prolonged (poorer), for all the three speech stimuli and at all three intensity levels in comparison to typically developing children (TDC) with normal hearing. It can also be observed that the amplitudes of the CAEPs peaks P1 and N2 were reduced (poorer) in hearing aid users, for all three speech stimuli, at each intensity level in comparison to the TDC with normal hearing. In addition, the SD for the latency and amplitude of the peak N2 were noticed to be higher, both in control and the experimental group. The variation in latency and amplitude of the peak N2 depend on multiple factors which includs the age of the participants, auditory maturation, and duration of hearing aid use. The higher SD of peak N2 can be attributed to the fact that, the present study assessed children between the age ranges of 6 months to 5 years for both the groups. Further, among hearing aid users, the experience with the hearing aids was restricted from 1 month to 1 year. These two reasons probably could be attributed to the higher SD of peak N2 in the latency and amplitude of the CAEPs.

Table 5: M*ean (SD) of latency and amplitude measure of the peaks P1 and N2, for control and experimental groups.*

		Latency (ms)					
		Control group			Experimental group		
		75dBSPL	65dBSPL	55dBSPL	75dBSPL	65dBSPL	55dBSPL
[m]	P1	106.20 (21.36)	107.80 (27.34)	108.83 (25.85)	131.86 (32.91)	129.15 (34.51)	130.34 (27.98)
	N2	212.23 (36.24)	210.85 (45.21)	214.31 (45.57)	244.40 (53.48)	239.96 (44.42)	237.39 (38.77)
[t]	P1	103.58 (26.72)	103.40 (28.11)	105.86 (29.28)	130.40 (35.89)	124.02 (29.26)	128.15 (33.09)
	N2	210.40 (45.77)	201.16 (42.63)	207.48 (48.93)	244.23 (52.35)	230.94 (45.77)	216.84 (36.40)
[g]	P1	101.55 (25.84)	99.30 (23.37)	105.40 (26.17)	125.44 (32.01)	123.88 (27.77)	124.00 (22.51)
	N2	207.48 (40.51)	205.93 (39.72)	207.15 (43.18)	228.23 (51.65)	229.30 (41.18)	223.51 (34.85)
		Amplitude (microvolt)					
[m]	P1	5.15 (3.57)	4.84 (3.52)	4.96 (3.35)	3.05 (3.86)	2.39 (2.19)	2.41 (2.87)
	N2	-6.61 (3.60)	-5.98 (4.14)	-4.79 (3.93)	-5.37 (5.05)	-5.25 (3.96)	-4.17 (3.69)
[t]	P1	4.69 (3.45)	3.92 (2.28)	4.19 (2.76)	3.77 (3.49)	2.86 (2.49)	2.01 (2.75)
	N2	-6.83 (4.30)	-5.51 (3.39)	-4.45 (4.16)	-3.54 (4.21)	-4.51 (3.70)	-4.38 (3.38)
[g]	P1	5.69 (3.64)	5.18 (3.75)	4.72 (3.09)	3.13 (2.95)	2.71 (2.75)	2.38 (3.06)
	N2	-5.72 (3.83)	-4.78 (3.20)	-4.73 (2.93)	-4.92 (3.70)	-4.35 (3.87)	-4.62 (4.33)

The peak-to-peak amplitude of P1-N2 complex is an important domain which reflects the changes occurring due to the development of auditory system at cortical levels in TDC with normal hearing and in hearing aid users. It was observed that P1-N2 amplitude was also poorer (reduced) in the hearing aid users compared to the TDC for all speech stimuli at each intensity level. Table 6 summarizes the peak-to-peak amplitude of the P1-N2 complex, for three different speech stimuli at each intensity level, for both control and experimental group.

Table 6: *Mean (SD) of the peak-to-peak amplitude of the P1-N2 complex for control and experimental groups.*

		Control group			**Experimental group**		
		75dBSPL	65dBSPL	55dBSPL	75dBSPL	65dBSPL	55dBSPL
[m]	P1-N2	12.05 (4.51)	11.12 (4.53)	10.14 (4.35)	8.95 (4.09)	7.65 (3.72)	6.87 (3.10)
[t]	P1-N2	11.65 (4.89)	9.46 (3.58)	9.14 (3.92)	7.62 (3.44)	7.61 (3.84)	6.51 (2.83)
[g]	P1-N2	11.80 (4.80)	10.23 (4.70)	9.66 (3.57)	8.06 (2.87)	7.48 (3.38)	7.12 (2.99)

Non-parametric Mann-Whitney U test was administered to compare the latency as well as amplitude measures of the peaks P1 and N2 between both the groups for different speech stimuli at each intensity level. The results of this are given in the Table 7. It is observed that there is a significant difference between both groups for latencies of the peaks P1 and N2 for different speech stimuli at each intensity level except peak N2 for the stimuli [t] at 55 dB SPL. Similarly, the absolute amplitude of peaks P1 and N2 shows significant differences for different speech stimuli at each intensity level between groups except at 75 dB

SPL, for P1 and N2 peaks for speech stimuli [t] and [g] respectively, and N2 peaks for all the three speech stimuli at 65 dB SPL and 55 dB SPL (as shown in the Table 7).

Table 7: *Mann-Whitney U test for between groups comparison for latency and amplitude measures.*

			Latency		**Amplitude**	
			Z	p value	Z	p value
75dBSPL	[m]	P1	-4.80	**0.00***	-3.91	**0.00***
		N2	-3.64	**0.00***	-2.26	**0.02***
	[t]	P1	-4.57	**0.00***	-1.75	0.07
		N2	-4.22	**0.00***	-3.88	**0.00***
	[g]	P1	-4.39	**0.00***	-4.03	**0.00***
		N2	-2.40	**0.02***	-1.55	0.12
65dBSPL	[m]	P1	-3.52	**0.00***	-4.41	**0.00***
		N2	-3.15	**0.00***	-1.23	0.21
	[t]	P1	-0.94	**0.00***	-2.83	**0.00***
		N2	-3.32	**0.00***	-1.58	0.11
	[g]	P1	-4.58	**0.00***	-3.52	**0.00***
		N2	-2.87	**0.00***	-0.81	0.41
55dBSPL	[m]	P1	-3.90	**0.00***	-4.19	**0.00***
		N2	-2.30	**0.02***	-1.31	0.18
	[t]	P1	-3.11	**0.00***	-3.36	**0.00***
		N2	-1.02	0.30	-0.02	0.97
	[g]	P1	-3.10	**0.00***	-3.29	**0.00***
		N2	-1.77	0.07	-0.76	0.44

$^*p<0.05$

In addition to absolute amplitude, even peak-to-peak P1-N2 complex was also analyzed between two groups using Mann-Whitney U test at each intensity level for different speech stimuli. The results showed statistically significant differences between two groups for each speech stimulus at each intensity level as given in the Table 8. It indicates that the slope of the P1-N2 complex was different between two groups i.e. hearing aid users and TDC with normal hearing.

Table 8: *Comparison between two groups for the peak-to-peak amplitude of P1-N2 complex (Mann-Whitney U test outcomes).*

		Z	**p-value**
75dBSPL	[m]	-3.88	**0.00***
	[t]	-4.27	**0.00***
	[g]	-4.51	**0.00***
65dBSPL	[m]	-4.13	**0.00***
	[t]	-2.88	**0.00***
	[g]	-3.38	**0.00***
55dBSPL	[m]	-4.30	**0.00***
	[t]	-3.62	**0.00***
	[g]	-3.46	**0.00***

***p<0.05**

Purdy and Kelly (2001) have pointed out that the verified suitable hearing aid gain does not guarantee a benefit from the hearing aid. All the behavioral assessment of hearing aid in children uses tonal stimuli and the spectral properties of these stimuli are different. Hence, it has been outlined earlier that the hearing aid assessment through speech stimuli are more meaningful measures. Though the detection of CAEPs indicates that the speech stimulus has been detected at the level of cortex, it does not guarantee that the children with the severe-to-profound hearing impairment will perform similarly to that of the age-matched children with normal hearing. A study done by Tejaswini in 2014 reported that CAEPs responses could be traced at intensity levels (75, 65 and 55 dB) in all hearing aid users with HEARLab evoked system. These participants were having moderate to moderately-severe sensorineural hearing impairment. However, the present study did not get CAEP responses at lower intensity level i.e. 55 dB SPL, in all hearing aid users having severe to profound hearing impairment. In spite of providing appropriate amplification, it is difficult to acquire CAEPs in these children particularly at the lower intensities since the frequency resolution is observed to be poorer in these individuals.

Studies have shown that the latencies of the cortical potentials depend on the adequate exposure to sound during the early childhood. The latency of the positive peak decreases (better) markedly within the first year of life provided the child has adequate exposure to sound during this period (Ponton et al., 1996; Sharma et al., 2002). Since the severity of the hearing impairment was more, it can be presumed that the natural stimulation of the auditory system in these children was not adequate in early age until fitted with appropriate hearing aids. The above factor could be one of the reasons for the delayed/prolonged (poorer) latencies and reduced amplitudes of the peaks P1 and N2 for different speech stimuli at each intensity level. Though children were fitted hearing aids early, the duration of hearing aid use was not sufficient for the auditory system to develop, like that of an age-matched TDC with normal hearing (Sharma et al., 2002). Studies have shown the significance of experience with hearing aids as a contributing factor to the latency and amplitude measures of the CAEPs in hearing aid users (Kraus et al., 1995; Purdy & Kelly, 2001; Tremblay & Kraus, 2002).

Dun et al. (2012) evaluated the relationship between the sensation level of speech sounds and the detection sensitivity of CAEPs in infants with sensorineural hearing impairment in the age range of 8 months to 30 months. The age of first hearing aid fitting was at 5.5 months and the length of hearing aid use was 13.4 months. Speech stimuli used for CAEPs were [m], [g], and [t] stimuli using HEARLab evoked system. Results revealed that there were no significant differences between speech stimuli for both amplitudes and latencies of CAEPs. There were no significant interactions found between speech stimuli and sensation level in these infants. Regression analysis showed weak but highly significant positive relationship between sensation level and P1 amplitude. Similarly, the weak significant negative relationship was observed for sensation level and N2 amplitude. For sensation level and P1 latency, the weak negative significant relationship was observed. However, no significant regression was encountered between sensation level and N2 latency. For sensational levels above 0, 10 and 20 dB, the detection sensitivities were equal to 72%, 75%, and 78% respectively. Hence, they concluded that as sensation level increases the detection rate of CAEP increases in infants with hearing impairment.

Visual versus statistical detection of the CAEP responses

The recorded waveforms were visually inspected by three experienced Audiologist working in the area of auditory evoked cortical potentials. The visually inspected waveforms were then compared with the statistically detected waveform. Based on the comparison made between the statistical and visual detection of waveforms, Table 9 summarizes the outcome of matrices. There were 4 possible ways the responses could be determined. They were visually present (VP), visually absent (VA), statistically present (SP) and statistically absent (SA). The responses which fall under the matrix visually present (VP)-statistically present (SP) and visually absent (VA)-statistically absent (SA) are the confident and accurate responses, whereas responses falling under the visually present (VP)-statistically absent (SA) and the visually absent (VA)-statistically present are the two types of errors, where the discrepancies are observed. The errors occurred where the response detected differently by visual inspection and statistical detection. By analyzing the Table 9, it can be observed that the errors were more while detecting the responses in the experimental group than in the control group. Further, the errors in response detection increased as the intensity reduced from 75 dB SPL through 55 dB SPL, in both control and experimental group, but more errors occurring in the experimental group.

Table 9: *Matrices of the visual detection and statistical detection of the responses for three speech stimuli at three intensity levels in the control group.*

		Control group						**Experimental group**					
Intensity levels/ Speech stimuli		[m]		[t]		[g]		[m]		[t]		[g]	
		VP	VA	VP	VA	VP	VA	VP	VA	VP	VA	VP	VA
75dBSPL	SP	58	**2**	57	**2**	58	**2**	52	**6**	50	**6**	52	**5**
	SA	**0**	0	**1**	0	**0**	0	**2**	1	**3**	2	**2**	2
65dBSPL	SP	57	**2**	56	**2**	56	**2**	50	**6**	47	**6**	48	**6**
	SA	**1**	0	**2**	0	**2**	0	**2**	3	**4**	4	**3**	4
55dBSPL	SP	55	**3**	55	**3**	56	**2**	39	**6**	35	**6**	36	**7**
	SA	**2**	0	**2**	0	**2**	0	**6**	10	**6**	14	**3**	15

Note: *VP: Visually Present; SP: Statistically Present; VA: Visually Absent; SA: Statistically Absent.*

The statistical detection of the presence or absence of the CAEP responses is an alternative tool available in the HEARLab instrument, which determines responses based on Hotelling T^2 techniques. It has been shown in the literature that statistical detection of CAEP responses was consistent with those of an expert examiner identifying responses through visual inspection, thus providing an alternative and reliable method of response detection (Golding et al., 2007; Dun, Dillon & Seeto, 2015; Hoth, 1993). This information is likely to complement existing test batteries and assessment tools in the verification of hearing aid fitting for infants for whom well-defined responses cannot be obtained (Moore, Thompson & Folson, 1992). In the present study, an attempt was also made to compare the statistical detection of the response with that of the visual detection by the expert examiners. It was observed that the mismatch between the two modalities of the response exists more (higher) in hearing aid users than in TDC with normal hearing. Further, similar discrepancies noted more at lower intensity level (55 dB SPL) in comparison to higher intensity level (75 dB SPL) irrespective of speech stimulus ([m], [t], & [g]). The above finding is supported by Chang et al in 2012, where they also reported that the objective detection of the CAEP responses was greater at higher sensation level, and detection of CAEPs are easier in normal children than in the clinical population (Carter et al., 2010).

Objective CAEP response detection (Carter et al. 2010; Golding et al, 2009) does not rely on a template derived from an average waveform obtained from a large number of participants. This is just opposite with the subjective interpretation by a professional, who generally trust on similarities between a template and an individual's waveform for identification. Carter et al (2010) predicted that a 10 dB increase in the sensation level leads to an improve in response detectability. They observed that the response sensitivity index increased as the sensation levels (SL) increased for both the composite examiner condition and for Hotelling's T^2. They suggested that the examiner's cumulative experience is likely to be an important determinant in detection sensitivity of CAEP responses. The Hotelling's T^2 statistics is a statistical tool which enables experimenters obtaining normal hearing infant CAEPs at stimulus SLs of 10 to 30 dB with a detection sensitivity index equal to that of the more experienced examiners. Providing an automatic detection of cortical responses appears to have the promising clinical utility of CAEP testing. The inclusion of automatic response detection in clinical equipment may increase clinician's confidence in using the CAEP technique, in interpreting results, and thus make an electrophysiological form of hearing aid fitting evaluation more accessible to the pediatric population.

Golding et al. (2007) found reasonably good agreement between the examiner and the statistical measure. They suggested that a significant relationship existed between CAEP and functional outcomes in the aided condition. The statistical detection of CAEP responses was consistent with those of an expert examiner. Carter et al., in 2010, demonstrated that the automated statistical detection of cortical responses from normal infants, based on the Hotelling's T^2 statistic was at least as accurate as detection based on the average of three expert examiners. Chang et al.(2012) reported that the sensitivity of the statistical detection of the CAEP responses increased as the sensation level increased. The present study also noticed similar results, where the number of the statistical detection and visual detection of the responses increased as the intensity level of the speech stimulus increased. Further, detection sensitivity was higher for the control group in comparison to the experimental group.

Relationship between the aided behavioral measures and the cortical auditory evoked potentials

In hearing aid users, aided threshold with their own hearing aids was obtained behaviourally at octave frequencies from 500 Hz to 4000 Hz. The mean aided threshold was noticed to be within speech spectrum at all frequencies though threshold was elevated at high frequencies (Table 10). Further, from the Table 10, it is noticed that as the frequency increased from 500 Hz to 4000 Hz, the behavioral aided thresholds also increased from 36.15 to 44.91 dB. The SD also followed a similar trend, which indicates that the variability in individual thresholds was more at higher frequencies. The elevated aided thresholds at higher frequency i.e., at 2000 Hz and 4000 Hz could be because of higher degree of hearing impairment i.e., severe-to-profound hearing impairment among these children. Since the majority of the hearing aids provide lesser gain at higher frequencies, it may not be feasible to provide optimum gain at higher frequencies. However, there is few important speech sounds such as fricatives and affricates for which good hearing at higher frequencies is essential.

Table 10: M*ean and SD of the aided thresholds of the experimental group.*

Frequency	Mean (dB)	SD
500 Hz	36.15	3.46
1000 Hz	38.85	4.02
2000 Hz	41.31	4.17
4000 Hz	44.91	4.32

Spearman's rho correlations were carried out to check the relationship between the aided behavioral thresholds and the latency and amplitude measures of the cortical auditory evoked potentials.

Table 11: *Correlation of the aided behavioral thresholds with the latency and amplitude measures of the cortical auditory evoked potentials.*

	Latency																	
	[m]						[t]						[g]					
	75		65		55		75		65		55		75		65		55	
	P1	N2	P1	N2	P1	N2	P1	N2	P1	N2	P1	N2	P1	N2	P1	N2	P1	N2
500 Hz	0.18	**0.31***	**0.30***	0.27*	0.15	-0.04	0.08	0.08	**0.32***	0.12	0.12	-0.00	0.02	0.08	**0.31***	**0.39****	**0.36***	0.07
1000 Hz	0.25	**0.29***	0.26	**0.30***	0.22	-0.05	0.19	0.21	0.11	0.04	0.04	-0.07	0.07	0.10	0.24	**0.39****	0.28	0.07
1000 Hz	0.25	**0.28***	0.24	0.26	0.12	0.05	0.19	0.21	0.25	0.09	0.12	0.08	0.10	0.05	0.26	**0.37****	**0.53****	**0.34***
4000 Hz	**0.32***	0.22	**0.31***	**0.28***	0.29	0.03	0.22	0.19	0.26	0.02	0.22	0.27	0.16	0.02	**0.31***	0.25	**0.64****	**0.41***
	Amplitude																	
500 Hz	0.06	0.07	0.21	**0.35***	0.19	0.19	-0.17	0.03	0.04	0.00	-0.09	0.08	0.21	**0.38****	0.09	0.23	0.21	0.29
1000 Hz	0.10	0.25	-0.09	0.13	0.19	0.14	-0.22	0.15	-0.18	-0.05	-0.10	-0.03	0.09	**0.31***	-0.15	0.07	0.04	0.02
2000 Hz	0.03	0.07	0.06	0.07	0.01	-0.02	-0.11	0.13	-0.09	0.11	-0.04	-0.01	0.01	0.23	0.10	0.25	0.13	0.13
4000 Hz	**0.26***	0.15	0.09	-0.01	0.09	0.04	0.02	0.17	-0.07	-0.07	0.24	0.11	0.22	**0.34****	0.03	0.10	0.13	0.07
	Peak-to-peak amplitude																	
	P1-N2		P1-N2		P1-N2		P1-N2		P1-N2		P1-N2		P1-N2		P1-N2		P1-N2	
500 Hz	-0.09		-0.22		-0.04		-0.23		-0.01		-0.13		-0.24		-0.13		-0.2	
1000 Hz	-0.23		-0.11		0.04		**-0.29***		-0.05		-0.03		**-0.31***		0.02		0.05	
2000 Hz	-0.07		-0.04		-0.02		-0.09		-0.1		0.03		-0.23		-0.08		-0.01	
4000 Hz	0.11		0.12		-0.18		-0.01		0.02		0.14		0.10		0.01		0.16	

From the Table 11, it can be observed that there was a significant correlation of the 500Hz aided threshold with the latencies of N2 at 75 dB SPL, P2 at 65 dB SPL, for the speech stimuli [m], P2 at 65 dB SPL for the stimuli [t], and P2 and N2 at 65 dB SPL and P2 at 55 dB SPL for the speech stimuli [g]. A significant correlation of the 1000 Hz was seen with N2 at 75 dB SPL and 65 dB SPL for the speech stimuli [m], and N2 at 65 dB SPL for the speech stimuli [g]. The significant correlation of the aided threshold of 2000 Hz was seen for the N2 at 75 dB SPL for the speech stimuli [m], N2 at 65 dB SPL, P2 and N2 at 55 dB SPL for the speech stimuli [g]. Similarly, a significant correlation was seen for the aided threshold of 4000 Hz with P2 and N2 at 65 dB SPL for the speech stimuli [m], P2 ate 65dBSPL, P2 and N2 at 55 dB SPL for the speech stimuli [g].

Similarly, the correlation of the aided threshold of 500 Hz was seen for the amplitude measure of N2 at 65 dB SPL for the speech stimuli [m] and N2 at 75 dB SPL for the speech stimuli [g]. The correlation of the aided threshold of 1000 Hz was seen with N2 at 75 dB SPL for the speech stimuli [g]. The correlation of the aided threshold of 4000 Hz was seen with P2 at 75 dB SPL for the speech stimuli [m] and N2 at 75 dB SPL for the speech stimuli [g]. When the aided thresholds were correlated with the peak-to-peak amplitude it was observed that the correlation existed only at the 75 dB SPL for the speech stimuli [t] and [g]. From the above table, it can be inferred that the aided thresholds did not correlate well with the both latency and amplitude measures of the cortical auditory evoked potentials with all the stimuli. The correlations observed for the latency of speech stimuli [m] and [g] can be attributed to the fact that these two speech stimuli represent low and mid frequency ranges of the speech spectrum. For the speech stimuli [t], the correlation was observed only with 500 Hz aided threshold for P2 at 65 dB SPL, which can be said as a chance factor. However, a similar trend was not observed with the correlation of the aided threshold with both absolute and peak-to-peak amplitude measures.

In addition, the correlation between the aided thresholds and the latencies of the peaks P1 and N2 are more for the speech stimuli [m] and [g], and no correlation was observed for the speech stimuli [t], except at 500 Hz for the peak P1 at 65 dB SPL.As mentioned earlier, the speech stimuli [m] and [g] represents the low and mid frequencies in the speech spectrum, and the behavioral thresholds were better for the lower frequencies than the higher frequencies.

Purdy et al. (2004) suggested that the CAEPs can be used as an objective tool to guide the fine tuning of the hearing instrument, however, research should be conducted to validate it. A simple way of using CAEPs to guide the fine tuning of amplification device is to increase low-frequency gain if CAEPs response is absent for low-frequency speech stimulus such as /m/, or to increase the gain for high frequency if CAEPs responses for high-frequency speech stimulus such as /t/ is absent. This method cannot reveal an excessive gain of amplification devices, but this may be possible in future as researches would be conducted on input-output characteristics of CAEP in children with normal hearing sensitivity. In future, research should be conducted to determine hearing instrument performance with behavioral and CAEP assessment in the same children to cross-validate the methods, it will give efficacy of CAEPs measures for fine tuning of the hearing instrument.

A study done by Korczack (2005) showed that even though the use of hearing aid leads to enhancement of both the electrophysiological and behavioural measures of speech perception, even though the individual with hearing impairment process speech in a less accuracy and less effective manner while wearing their hearing aid when compared to normal hearing individual mainly at lower intensity. Hassaan (2012) found that there was a reasonable correlation between the aided behavioral thresholds for the pure tones 500 Hz and 4000 Hz and the aided CAEPs for the speech stimuli [ga] & [wa] in children having mild to moderate sensorineural hearing loss and they were a regular hearing aid users. They concluded that recordings of aided N1 wave threshold revealed a good agreement with the behavioral one, which may constitute a valuable tool for frequency-specific threshold detection.

In the present study, it was observed that the there was no correlation between the aided behavioral thresholds and the amplitudes of the CAEP responses. However, the correlations were observed between the aided behavioral thresholds and the latency measures of CAEPs, particularly for the speech stimuli [m] and [g], which represents the low and mid frequency region of the speech spectrum. This trend was not observed for the speech stimuli [t], which represents the high-frequency region of the speech spectrum. Kolkaila et al.(2012) state that the amplitudes of the CAEPs do not play a major role, whereas the latencies are the more sensitive indicators of the hearing aid acclimatization, particularly for the children with hearing impairment, for whom the behavioral assessment is a difficult task. As pointed out by Hassaan (2012), the speech evoked CAEPs gives frequency-specific information. It can be considered as use of speech stimuli has a significant benefit over the tonal stimuli. The correlation observed in the present study for the speech stimuli [m] and [g] with the aided behavioural thresholds for the frequencies 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz with latency measures, which clearly explains that the speech stimuli with low and mid frequency region have frequency specific information among children with severe to profound sensorineural hearing impairment. However, similar trends were not observed in the amplitude measures.

Summary and Conclusion

The present study was aimed to find the relationship between the behavioral measures and the aided auditory cortical potentials in the children with the severe-to-profound sensorineural hearing loss. The participants were in the age range of 6 months to 5 years. Participants in the control group were children having hearing sensitivity within normal limits and the participants in the experimental group were children having a severe-to-profound sensorineural hearing impairment, who were experienced hearing aid users. The cortical auditory evoked potentials were recorded using the HEARLab instrument with the default settings. The latency and amplitude measures of the peaks P1 and N2 were analyzed. Descriptive statistics revealed that the latency of the P1 and N2 peaks were prolonged and amplitudes were decreased (poorer) in the experimental group in comparison to the control group. Overall, the experimental group performed poorer compared to the age-matched TDC with normal hearing. Within the group, comparisons were made to find the effect of intensity and speech stimulus on the latency and amplitude measures of the cortical auditory evoked responses. It was observed that the intensity had a significant effect on peak-to-peak amplitude in general for both the groups, i.e., as the intensity was increased the amplitude was also increased (better). However, in general latency of P1 and N2 did not show a significant effect of intensity in both the groups. Similarly, the effect of different speech stimuli on the latency and amplitude of peak P1 and N2 showed no significant differences in both the groups. However, the significant effect of speech stimuli was noticed only for peak-to-peak amplitude at 65 and 55 dB SPL in TDC with normal hearing.

The statistical versus the visual inspection of the presence or absence of the responses revealed that the accuracy of the response detection reduced as the intensity decreased from

75dBSPL to 55dBSPL. It was also observed that the difficulty in response detection was more in the experimental group compared to the control group. A response which is visually as well as statistically detected as positive response gives greater confidence to the Audiologist. Similarly, a response which is visually and statistically detected as a negative response also gives the Audiologist a feedback that the stimulus has not been detected at the level of the cortex, so that the rehabilitation process can start. Both the conditions are the accurate response detection. There are two more conditions, where the response detected by visual inspection as positive and statistically negative, and vice versa, which puts the Audiologist in dilemma. However, chances of obtaining these kinds of errors can be reduced by providing appropriate amplification and following the standard test protocols. The correlation between the aided behavioral thresholds and CAEPs responses revealed that the aided behavioral thresholds had a greater correlation with the latencies of the speech stimuli [m] and [g], which represents the lower and mid frequency region of the speech spectrum. The cortical auditory evoked potentials can always be recorded, provided the children are awake, alert and physically not moving. Based on the results obtained from the cortical auditory evoked potentials, it is easy for an Audiologist to monitor the auditory rehabilitation of the children using hearing aids, by providing proper amplification and with regular follow-up of the children with hearing impairment.

The cortical auditory evoked potentials are the one of the vital electrophysiological procedure for assessing the hearing aid benefit in the infant and younger children from whom it is difficult to obtain the behavioral responses. The HEARLab instrument is a unique instrument in terms of the stimuli and intensity levels adopted for recording CAEPs. However, still, there is a scope for improving the technology and making the assessment and rehabilitation of the hearing impaired individuals an easier task. There is more opportunity to explore further in this vast area of cortical auditory evoked potentials.

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Appendix 1

Table A: Wilcoxon pair-wise comparison for each speech stimulus on the latency and amplitude measures, in control and experimental groups.

			Experimental group				**Control group**			
			Latency		Amplitude		Latency		Amplitude	
			Z	P	Z	P	Z	P	Z	p
	75 vs 65	P1								
	dBSPL	N2			-1.12	0.26			-1.06	0.28
	75 vs 55	P1								
[m]	dBSPL	N2			-3.01	**0.00***			-2.98	**0.00***
	65 vs 55	P1								
	dBSPL	N2			-2.55	**0.01***			-2.84	**0.00***
	75 vs 65	P1			-1.36	0.17				
	dBSPL	N2							-2.35	**0.01***
	75 vs 55	P1			-3.76	**0.00***				
[t]	dBSPL	N2							-3.60	**0.00***
	65 vs 55	P1			-1.77	0.07				
	dBSPL	N2							-2.11	**0.03***
	75 vs 65	P1					-0.79	0.42	-1.73	0.08
	dBSPL	N2								
	75 vs 55	P1					-1.62	0.10	-2.24	**0.02***
[g]	dBSPL	N2								
	65 vs 55	P1					-2.82	**0.00***	-0.84	0.39
	dBSPL	N2								

$^*p<0.05$

Table B: Wilcoxon pair-wise comparison for peak-to-peak amplitude in control and experimental group.

		Experimental group		**Control group**	
		Z	p-value	Z	p-value
[m]	75 vs 65 dBSPL	-2.69	**0.00***	-1.72	**0.08***
	75 vs 55 dBSPL	-4.64	**0.00***	-3.77	**0.00***
	65 vs 55 dBSPL	-2.50	**0.01***	-1.90	**0.06**
[t]	75 vs 65 dBSPL			-3.71	**0.00***
	75 vs 55 dBSPL			-3.82	**0.00***
	65 vs 55 dBSPL			-1.44	0.14
[g]	75 vs 65 dBSPL	-1.86	0.06	-3.23	**0.00***
	75 vs 55 dBSPL	-2.43	**0.01***	-3.56	**0.00***
	65 vs 55 dBSPL	-1.69	0.09	-1.41	0.15

$*p<0.05$

Table C: Outcome of the Wilcoxon pair-wise comparison test for control and experimental group.

			Experimental group				Control group			
			Latency		Amplitude		Latency		Amplitude	
			Z	P	Z	p	Z	P	Z	p
75 dB SPL	[m] vs [t]	P1							-0.37	0.70
		N2	-0.47	0.63	-3.23	**0.00***				
	[g] vs [t]	P1							-2.55	**0.01***
		N2	-1.52	0.12	-2.18	**0.02***				
	[m]vs [g]	P1							-1.30	0.19
		N2	-2.10	**0.03***	-0.35	0.72				
65 dB SPL	[m] vs [t]	P1					-2.28	**0.02***		
		N2							-1.15	0.24
	[g] vs [t]	P1					-1.18	0.23		
		N2							-1.75	0.08
	[m]vs [g]	P1					-2.87	**0.00***		
		N2							-2.58	**0.01***

***p<0.05**

Table D: Wilcoxon pairwise comparison for peak-to-peak amplitude at each intensity for control and experimental groups.

		Control group	
		Z	p-value
65dBSPL	[m] vs [t]	-3.29	**0.00***
	[g] vs [t]	-0.12	0.90
	[g] vs [m]	-1.62	0.10

	[m] vs [t]	-2.09	**0.03***
55dBSPL	[g] vs [t]	-1.29	0.19
	[g] vs [m]	-1.44	0.14

***p<0.05**