RELATIONSHIP BETWEEN

BEHAVIOURAL OUTCOME AND CORTICAL RESPONSES

IN HEARING AID USERS

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Register No. 12AUD006

A Masters Dissertation Submitted in Part Fulfilment of Final Year

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Dedicated to
"Appa & Amma"
they are the first
teachers

&

To all my
"teachers" they
are my second
parents

Certificate

This is to certify that this Masters dissertation entitled '**Relationship Between Behavioural Outcome And Cortical Responses In Hearing Aid Users'** is a bonafide work in part fulfilment for the degree of Master of Sciences (Audiology) of the student with Registration Number **12AUD006**. This has been carried out under the guidance of faculty of this institute and has not been submitted earlier to any other Universities for the award of any Diploma or Degree.

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May, 2014

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Declaration

This Masters dissertation entitled '**Relationship Between Behavioural Outcome And Cortical Responses In Hearing Aid Users'** is the result of my own study and has not been submitted to any other university for the award of any other Diploma or Degree.

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CHAPTER I - INTRODUCTION

Estimation of hearing thresholds through the objective measures, such as auditory brainstem responses (ABRs) or auditory steady-state responses (ASSRs), allow audiologists to decide on whether a child or adult requires a hearing aid or not (Ching &Dillon, 2001; Seewald & Scollie, 2003). Unfortunately, reliable estimation of thresholds or adjustments of the hearing aid poses a challenge in estimating the benefit from a hearing aid. There should be some reliable means of evaluating the adequacy of hearing aid fitting for its maximum benefit.

To establish the efficacy of hearing aid in the population with hearing impairment is the challenging process for the audiologist, especially in children, particularly evaluating the behavioural outcome of the hearing aids (Snik, Neijenhuis, & Hoekstra, 2001). The most common approach for evaluating the efficacy of the hearing aid is through the behavioural evaluation which is highly dependent on the response of the client (Hodgson, 1994).

To overcome the inconsistency with the behavioural measures, especially in the younger clients using hearing aids, electrophysiological technique may also be used as one of the tools for the assessing the efficacy of the hearing aids (Stapells & Kurtzberg, 1991).Recording the aided cortical potentials shows the evidence for detection of speech at the level of the cortical structures in the auditory system. This is more reliable or effective when the presentation level of stimulus is at the conversational level (Rapin & Graziani, 1967).

Currently, there is much interest in the measurement and quantification of hearing aid outcome (Humes, Halling, & Coughlin, 1996; Mueller, 1997). In general, ‘outcome’ refers to the measurable effect, either real or perceived, of the hearing aid on the wearer's hearing disability or hearing handicap (Weinstein, 1997). The outcome can be either positive or negative. That is, the use of a hearing aid by the wearer can either decrease or increase the problems faced due to hearing loss. The subjective outcomes (i.e., using questionnaires and interviews) are available to document the opinions and attitudes of the client or parent.

Subjective measures of performance, on the other hand, rely entirely on the wearer's judgement or opinion and have no external reference for evaluation. Examples of subjective performance measures include loudness judgments whether accomplished by scaling, category rating, or matching, quality judgments (clarity, harshness, spaciousness, etc.), and perceived disability or handicap (questionnaire).

The most common approach to verifying the fit in this young population is to use information gained from behavioural measures, the outcomes of which are highly dependent on the state of infant (Hodgson, 1994. Ewing (1944) pioneered this form of assessment and used a wide variety of noise makers such as bells, rattles, and rustling paper to elicit a response. The technique, in brief, involves the presentation of noise makers in the sound field at known levels and then observation of the infant's response to these sounds. Electrophysiological techniques may also be useful tools for verifying the fit of a hearing aid in infants and toddlers, especially with multiple disabilities. The recording of auditory brainstem response (ABR) thresholds to brief-tone stimuli provides valuable diagnostic information and threshold estimates for hearing aid prescription (Dillon, 2001).

The cortical auditory evoked potentials (CAEPs), which have generators at a higher level in the auditory pathway than ABRs, are more indicative of whether neural signals are reaching the auditory cortex and thus should be more closely related to the perception of sound. Consequently, they are said to be more appropriate for objective assessment of speech and language development as reported by Stapells (2009). This has been shown to be related to speech perception scores and functional measures of hearing ability (Golding, Pearce, Seymour, Cooper, & Ching, 2007; Kurtzberg, 1989).

Therefore, in the current study it is intended to study the relationship between behavioural measure and Cortical Auditory Evoked Potentials in individuals using hearing aids.

Need for the study

There are many behavioural measures which are used for the evaluation of the hearing aids but the effectiveness of all the tests is not similar. The behavioural tests used for evaluating the performance of the hearing aids are similar to those used for evaluating the hearing. They are aided thresholds, speech identification scores, and subjective questionnaires. Golding, Pearce, Seymour, Cooper and Ching (2007) have reported on the relationship between obligatory cortical auditory evoked potentials and functional measure in young infants. They suggested that a significant relationship exists between CAEP and functional outcomes for infants who were aided. This relationship was not seen when ABR/ECochG results were similarly compared with functional performance. This information is likely to complement existing test batteries and assessment tools in the verification of hearing aid fittings, especially in young children.

Assessment of aided speech skills could be a difficult task in young children and infants. Accordingly, there is more need for objective tests such as the aided evoked potentials to effectively establish the efficacy of the hearing aids. This objective evaluation gives the information regarding the performance of the hearing aids. There are many objective tests currently available but having their own merits and demerits as they may or may not give the information on the speech perception or recognition skills.

Though studies have used the measures with behavioural and cortical auditory evoked potentials, more evidence is required to generalize the findings. There is a dearth in literature on the relationship between the behavioural measures, subjective outcomes and the CAEPs. Hence, the present study intends to use different behavioural tests / measures and their relationship with cortical auditory evoked potentials.

Aim and objectives of the study

The aim of the present study was to evaluate the efficacy of the hearing aids using the behavioural measures and objective measures in hearing aid users; and to investigate the relationship between. The specific objectives of the study were -

1. To study the behavioural measures (i.e., AI, SIS, SNR-50, subjective questionnaires) for evaluating the outcome of hearing aid, in adults and children.
2. To study the objective measure (aided cortical potential LLR) for evaluating outcome of hearing aid, in adults and children.
3. To compare the behavioural and objective outcomes of the hearing aids, in adults and children.

Hypotheses

There is no significant relationship between the behavioural outcome and cortical auditory evoked potentials in the individuals using hearing aids.

CHAPTER 2 - REVIEW OF LITERATURE

Hearing aid fitting in the children and the adults requires reliable measures to reflect the benefit obtained by the hearing aid. These measures provide information about the extent of benefit provided by the hearing aids. Such measures are broadly classified as the behavioural measures and the objective measures (Marynewich, Jenstad, & Stapells (2012). There are generally two ways in which hearing aid validation techniques can evaluate the outcomes from the hearing aid fitting process. They include those that focus on subjective outcomes (i.e., using questionnaires and interviews to document the opinions and attitudes of the patient), and those that focus on objective outcomes (i.e., using empirical data to verify improvements in performance) (Cox, 1999). It is essential that the audiologist demonstrates the outcome to the client, either subjective or objective. The literature relevant to the present study has been provided under the following headings.

2.1. Evaluating hearing aid outcomes - Behavioural measures

2.1.1 Subjective outcomes and the hearing aids

2.1.2 Speech Recognition, Identification and Discrimination

2.2. Evaluating hearing aid outcome - Electrophysiological or objective measures

2.2.1. Auditory Brainstem evoked response (ABR)

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2.2.4. Cortical auditory evoked potentials (CAEPs)

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2.1. Evaluating hearing aid outcomes - Behavioural measures

The behavioural measures generally involve active participation of the individuals. The behavioural audiological tests include measures such as unaided and aided sound field warble tone evaluation, speech audiometry, subjective questionnaires or functional outcomes.

2.1.1 Subjective outcomes and the hearing aids

The hearing aid benefit can be defined as the difference between unaided and aided performance. Hearing aid benefit can also be measured subjectively through the use of self-report measures. Because objective tests are completed using a pre-defined external standard, they are tests that are administered within the laboratory or clinic. Therefore, self-report measures of outcome are a useful method of determining real-world benefits of hearing aid performance (Bray &Nilson, 2002). The clients have always provided clinicians with real-world outcome assessments of their hearing aids. (Watson, Tolan, & Davis 1949; Silverman, 1947) emphasized the importance of gathering information from the perspective of the client during the initial trial period with hearing aids in everyday listening environments.

The questionnaires are widely used to monitor the responses to the auditory stimuli; these outcome measures give the more functional aspect and the effective information regarding the hearing aids. There are several questionnaires where the parents or the care takers are involved in the measures (Stelmachowicz, 1999; Arlinger, 2001; Sirimanna, 2001).

Some common questionnaires that assess hearing handicap include the Self Assessment of Communication (SAC), the Hearing Performance Inventory (HPI, Giolas et al., 1979), the Hearing Handicap Inventory (HHI) for Adults (Newman et al., 1991), and the Hearing Handicap Inventory for the Elderly (HHIE). Some popular assessment tools for measuring hearing aid benefit include the Abbreviated Profile of Hearing Aid Benefit (APHAB, Cox et al., 1995), the Client Oriented Scale of Improvement (COSI) Dillon, James and Ginis (1977) the Glasgow Hearing Aid Benefit Profile (GHABP) Gatehouse(1999)and the Hearing Aid Performance Inventory (HAPI) Walden, Demorest and Helper (1984).

The study was reported on the comparison between the subjective outcome of open set speech recognition in the children with one group of moderately severe to severe hearing loss and other group having profound hearing loss to the performance of the benefit of the device was evaluated using this subjective outcome and other measures this in terms provides the information of the in order to extract the information on early detection will provide the early intervention and better the benefit of the hearing aids (Fitzpatrick, Olds, Gaboury, McCreae, Schramm, & Smith, 2012).

There are many questionnaires which are used for evaluating the benefit of the hearing aids, in case of very young children the information has to be gathered from the parents or care taker which would precisely provide information about the child's performance reported by Stelmachowicz (1999). These functional outcome measures give the effectiveness of hearing aids, the questionnaires such as the Meaningful Auditory Integration Scale (MAIS) there are questionnaires for parents and children, they are used to evaluate the communication skills in the individuals with severe to profound hearing loss, however there are several outcome measures are used to evaluate the effect on responsiveness of the sound if incase the benefit noted to be poorer then if the criteria was not met with the target or better performance was not found , then the appropriateness of the hearing aids were not reached.

There are questionnaires which is given to the parents or teachers to get a more valid report on the children auditory behaviours such as Parent's evaluation of aural/oral performance in children (PEACH) and teacher equivalent of the peach questionnaire (TEACH). This questionnaire probes into different situations such as noisy, quiet and the response to different environmental sounds. It has a 4 points rating scale for each question. The final rating will be summed and converted in to the percentage. There are also normative studies done using the PEACH questionnaire. It is reported that for the children with normal hearing, aged 0.25 to 46 months (Ching & Hill, 2001). Even the validity of the measure is also established by the same authors in the group of children having severe to profound hearing loss using the hearing aids regularly. This gives the information about the functional performance of the children, the mean performance can be compared with those having normal hearing and hearing impairment. It will give more precise information about the auditory performance.

The PEACH questionnaire was also used in the Indian population to evaluate the benefit of the children auditory behaviours in the children with cochlear implantation reported by Kumar, Rout, Kumar, Chatterjee and Selvakumaran (2013). They had compared the functional language performance in Tamil speaking children who were taken in two groups, early implanted and late implanted. The results revealed that children implanted early in age showed better performance than the later implanted children. Hence, this can give the functional performance of the child and gives meaningful information to the parents.

The use of Hearing Handicap Scale as a measure of hearing aid benefit was investigated. The participants are new hearing aid users with bilateral, sensorineural hearing losses ranging from 5 dB HL to 55 dB HL served as subjects. Changes in speech reception threshold, word identification, and Hearing Handicap Scale were derived by comparing data obtained pre- and post- conditions of the hearing aids, following four weeks of hearing aid use. The results showed a significant improvement for all the three measurements and indicated an improvement in word identification presented at conversational level was more related to self-reported hearing aid benefit than was improvement in speech reception threshold, word identification ratings obtained with the stimuli presented at conversation speech level produced a significant correlation with scores obtained on Hearing Handicap Scale (Tannahill, 1979)

Another study similar to the previous study mentioned by the investigators Humes,Wilson,Barlow,Garner and Amos (2002) have also evaluated the longitudinal changes in the hearing aid satisfaction and the usage in the elderly over a period of one or two after the hearing aid fitting. They had evaluated the individuals with the experience of hearing aids in 1 month, 6 months and 12 months using Hearing Aid Satisfaction Survey (HASS), Glasgow Hearing Aid Benefit profile (i.e., GHABP) and Hearing Aid Disability and Benefit Profile (HDABI) were done and concluded that there was a significant improvement, satisfaction changes noted as the duration of the hearing aid use increases reported.

2.1.2. Behavioural measures (Speech Recognition, Identification and Discrimination) and Hearing aids.

There are also studies that reveal the utility of subjective and objective tool for the evaluation of the hearing aids, sensitivity of the speech recognition tasks and whether it can serve as a more valuable tool for demonstrating the benefit. R-SPIN,HINT, and quick SIN and subjectively the hearing aid performance inventory was used for the evaluation and concluded that these objective tests are more sensitive in evaluating the speech perception abilities and better the subjective questionnaire performance would results in the better objective scores in the individuals using hearing aids, Objective documentation of subjective impressions is essential for determining the efficacy of hearing aid fitting. The findings reported here more clearly define the relationship between objective and subjective outcome measures in an attempt to better define true hearing aid benefit, as reported by Mendel (2007).

The outcome of the hearing aid benefit in the elderly population was obtained in the hearing performance after one month of hearing aid fitting, the measured dimensions of CUNY, SNR and CST. This gives the most efficient and valid information regarding the hearing aids across several dimensions this can be used as the valuable tool clinically (Humes, Garner, Wilson, & Barlow, 2001). Once the stability, relevance, and predictability of the hearing aid outcome have been established, it may be possible to propose a battery of hearing-aid outcome measures for clinical use. It has been established in their study that complete picture of hearing aid outcome can be obtained only by assessing performance along and largely independent dimensions of hearing-aid outcome.

In much similar to the above mentioned studies there are also comparisons made between the subjective and the objective measures to rule out the amount of speech intelligibility using Connected speech test as the objective tool and the subjective speech intelligibility test using a rating scale was done between the normals and the severe hearing impaired adults to rule out the relationship between them reported by Cox and Alexander (1991).

The study by Flynn, Dowell, and Clark (1998) showed the aided speech recognition abilities in the subjects with severe to profound hearing loss. The authors have used the closed and open set consonants, vowel identification and the sentences were also used in both the quiet and the noisy conditions at +10 dB SNR the findings revealed that there is a significant decrease in the performance in the presence of the back ground noise. To conclude, from this only threshold cannot be taken in to consideration in support with that performance of the other conditions like noise is needed for establishing the performance of the devices.

2.2 Evaluating hearing aid outcome - Electrophysiological measures

The objective evaluation does not require the individual to actively participate in the testing and include measures such as auditory evoked potentials, real ear measurements and acoustic reflex testing. The objective test is considered as a reliable measure and of these, the auditory evoked potentials are considered as the valuable test in the evaluation of the efficacy of the hearing aids. The objective measures such as auditory brainstem response (ABR) and auditory steady state response (ASSR) are reported to have poor correlation with the subjective evaluation, but other cortical potentials like late latency response (LLR), P300 and Mismatch Negativity (MMN) are documented to have a better correlation with the benefit provided by a hearing aid.

The electrophysiological tests can be used as the hearing aid verification tools in the population where the behavioural test is not very reliable or feasible. The recordings of the ABR and ASSR using the frequency modulation can provide valuable information for the prescription of the hearing aids (Stapells & Kurtzberg, 1991). The Kannada word list was used for the present. The recording of the cortical auditory evoked potential (CAEP) can provide evidence on the detection of the speech at the cortical level in the auditory system. The recording was done at the conversation level can provide the gives more information on the efficacy of the hearing aids.

2.2.1 Auditory brainstem responses (ABR)

The studies on the hearing aid verification and the ABR responses have revealed that the latency and amplitude of the peak V for different frequency can be taken for the consideration of the response in the hearing aids it is up to 75 % to 100% and the early V peak also was indicating the better speech intelligibility in the subjects, when correlated with the routine speech intelligibility battery this was reported by Cox (1995).

The ABR can be considered as the tool for estimating the thresholds in aided as well as unaided conditions. Literature has revealed poor or no correlation with the behavioural testing. The study by Brown, et al., 1995) revealed that there is no correlation between the speech perception and the auditory brainstem response.

There are some limitations for the ABR to be used as the electrophysiological assessment for the evaluation of the hearing aids since it is reported by the authors that electrical energy from the hearing aid as well as the transducer creates the interference with the recordings this would leads to the contamination of the waveform. Since there is a drawbacks on that ABR can give the information more on the thresholds rather than the speech perception abilities .So there are some limitations on ABR for using as the tool for the hearing aids evaluation.

2.2.2Auditory steady state response (ASSR)

The study on ASSR was reported by Picton (1988) evaluated the benefit of the hearing aids and they reported that the response was 13 dB to 17 dB higher than the behavioural thresholds used for the evaluation. Hence, it can be inferred from this that ASSR can be used as the measure for the evaluation of the hearing aids. Kotaiah and Manjula (2005) compared the objective measure (ASSR) and behavioural measure they studied the correlation between real ear insertion gain and the gain obtained through the ASSR, and it was found that the ASSR measure can be used for the selection of the hearing aids in the population were the behavioural measures are difficult as they found the presence of a positive correlation between the two measures.

The ASSR can be contaminated by the artifacts in some conditions where the intensity is very higher, since in the case of severe to profound hearing loss the gain of the hearing aids will be higher. Hence, the precautions must be taken while evaluating the hearing aid through the ASSR was reported by Gorga and Neely, Hoover, Deiking, Beauchaine and Manning (2004).

2.2.3. Middle Latency response (MLR)

There are some studies which have investigated the evaluation of hearing aids through the middle latency response. Firtsz, Chamber, and Kircues (2002) evaluated the speech perception abilities and the middle latency responses (MLR). In their study, speech perception in the quiet and noise conditions, for words and sentences, was measured. It was found that those with better amplitude and lower thresholds on MLR had better speech perception.

However, there is a high possibility of the occurrence of the Post Auricular Muscle artifact while recording MLR.

2.2.4. Cortical auditory evoked potentials (CAEP) Late Latency Response.

The cortical auditory event related potentials (ERPs) are usually classified as two types, obligatory or (exogenous) and cognitive or (endogenous). The obligatory ERPs are those whose presence, latency and amplitude are highly dependent upon the acoustic parameters of the stimulus and the integrity of the primary auditory pathway.

This obligatory potential having three major components they are generated at the level of the primary auditory cortex (PAC) and association areas of the temporal lobe. Obligatory ERPs can be elicited by clicks, tone bursts, tone-complexes and speech sounds. They are reliably recorded in awake, alert adults and also present in newborns and young infants, although their latency, amplitude and scalp distribution undergo significant maturation during the first 6 years of life, proceeding through late adolescence.

The CAEPs have been regarded as most suited to assess the audibility of hearing aid-amplified speech. CAEPs are generated at the highest level of the auditory pathway, and can provide physiological evidence that the speech signal has reached the cortex, and thus potentially audible to the individual (Korczak, 2005). The response that arises from the auditory cortex is much larger, around 5 to 10 microvolts, compared to the amplitude of other electrophysiological measures (ABR or ASSR). Hence, fewer stimulus presentations are needed for a response to be generated (Dillon, 2005).

The cortical auditory evoked potentials will provide information on the neural mechanism underlying the processing of speech when the speech stimuli are being used. The response complex (P1 N1 P2 N2) will evaluate the effect of hearing loss on the neural coding activities for the behavioural detection or the discrimination of sounds and the information related to the processing or the detection of speech with the amplification. From this, one can infer the benefits of hearing aids (Agung, Purdy, Mc Mahon, &Newall, 2006).

A slow obligatory response at the cortical level is recorded as late latency response (LLR) which occurs between the 50 ms to 300 ms after the onset of stimulus. The response is denoted by the peaks (P1, N1, P2, and N2). The cortical potentials are used as one of the important tools in the evaluation of sensitivity of hearing, in both children and adults. This is because, a good agreement between the cortical potentials sensitivity and the audiometric thresholds has been reported (Davis, 1965).

There are abundant applications on the CEAP as the biomarker of the development of the auditory system, which assess the response components such as P1 and N1which reflect the maturation of the central auditory processing. It has been reported that P1 biomarker is having the sensitivity of 89% and specificity of 85% and that it also provides the close correspondence with the behavioural measures. It has been reported that the P1 biomarker can give the appropriate guideline for the direction of intervention in children with hearing impairment (Nash, Sharma, Martin, & Biever, 2003).

2.2.4 Mismatch negativity (MMN)

The CAEPs such as mismatch negativity or P3 are evoked by a change from a frequent "standard" stimulus to an infrequent "deviant" stimulus. Oates, Kurtzberg and Stapells (2002) investigated MMN and P3 discriminative evoked potentials in response to /ba/ and/da/ speech stimuli in adults with mild to severe or profound hearing loss who wore hearing instruments. The sensorineural HL led to amplitude and latency changes for the earlier (N1, MMN) cortical responses.

However, the MMN is smaller in amplitude, generally < 2 μV, in comparison to the majority of the other CAEPs, thus creating a poorer SNR for this response. The MMN is not always reliably elicited in either individual subjects with normal hearing sensitivity or those with varying degrees of sensorineural hearing loss. It is less reliably elicited in children compared to adults (Marynewich et al, 2012).

The cortical potentials such as LLR has advantages (Agung, 2006) and is feasible and thus has been taken as the objective measure for evaluating the efficacy of the hearing aids for this current study. This potential shows higher in amplitude, thus is easy to identify the peaks, and not much affected by the electrophysiological noise compare to all the other electrophysiological tests. These are the possible reasons for choosing the LLR (CAEP) for the evaluation of the hearing aids.

2.2.5 Cortical auditory evoked potentials and maturation in normal hearing children and Adults

Generally, the aspect of maturation deals with the development of the perception. The performance in the behavioural perception task parallels the maturational changes structurally as reported by Eggermont and Ponton (2003).The maturation of the cortical potential (LLR) was reported in infants, children and adult by Wunderlich and Wesson (2006).

Table 2.1

Different components of LLR and the anatomical site of generation of the potential

LLR components	*Anatomical Site of generation*
P1	Late thalamic projections and early auditory cortex. Heschl's gyrus Planum temporal, lateral temporal cortex and hippocampus
N1	Areas in or near superior temporal gyrus (STG).
P2	Lateral frontal supra temporal auditory cortex. Primary auditory cortex, secondary auditory cortex and reticular activating system. Heschl's Gyrus
N2	Supra temporal auditory cortex.

2.2.6 Cortical Auditory evoked potentials in Adults

In the adult population, the CAEP consists of a series of positive and the negative peaks which are noticed after the stimulus presentation of 50ms and till 300ms. Generally, the N1 Peak (N100) and P2 peak are the more prominent. The other peaks include the P1 (P50) and sometimes a small negative peak N2.

The morphology and latency of CAEP, as for any evoked potential, is highly dependent upon the evoking stimulus and acquisition parameters, including the setting of the electrophysiologic filters.

2.2.7 Late latency response (LLR) and the behavioural outcome.

The importance of the P1 latency was considered as the biomarker of the auditory development in the group of children who were using the amplification (Sharma, Martin, Roland, Bauer, Sweeney, Gilley, & Dorman, 2005). They examined the clinical feasibility of using the P1 latency of LLR using the synthesised /ba/ stimulus as an objective tool for evaluating the efficacy of the amplification and found that the more robust P1 peak indicates sufficient stimulation for the auditory system. When this is combined with the traditional behavioural measures of the audiological evaluation, this can provide reliable information on the use of amplification or cochlear implant. This can also be used to monitor the development of the responses once the fitting process is done.

From the birth up to the age of seven years of age, the LLR would be dominated by a large positive (P1) peak. Hence the LLR is a good indicator of hearing and a sensitive electrophysiological tool for the assessment of the hearing aids. The LLR measures can be reliably interpreted in children.

Golding, Pearce, Seymour, Alison Cooper, Ching, and Dillon (2007) evaluated the LLR in young children to provide the evidence of the speech detection ability at the cortical level. They evaluated the relationship between the presence or the absence of the cortical potentials for the speech stimulus and the outcome of the questionnaire administered on parents on performance of children with the hearing aids. It was found that there is a good agreement between the functional outcome and the aided cortical potentials. This cortical potential can provide the alternative and more reliable methods for the evaluation and the verification of the hearing aids in children once the hearing aid is fitted. Generally to consider the better fitment of the hearing aids in the group of the children or other older population usually a direct observation of the responses are carried out such as behavioural tests (BOA, VRA and conditioned play audiometry or parental questionnaires or electrophysiological tests. The outcomes of the behavioural generally taken as measures to establish the efficacy of the hearing aids but the cortical potentials gives the validated results as well as electrophysiological evidence in the establishment of the benefit.

As reported in the previous study, cortical potentials are one of the important tools for the assessment (Chang, Dillon, Carter, van dun, & Young, 2012). In their study, the effectiveness of the objective measure in the assessment of the hearing aids in the young infants with sensorineural hearing loss the stimuli was evaluated. The three presentation levels were 55, 65 and 75dB SPL in both the unaided and aided conditions. They found that higher SLs would be required for the occurrence of the cortical potentials.

The cortical auditory evoked potentials are used as the tool for the validation of the hearing aids was reported by Hassaan (2011) the hearing aid fitting can be validated with the help of behavioural tests but in the case of children it is enigma so, the additional use of objective evaluation will give more valid information on benefit of the hearing aid. In his study, aided cortical evoked potential was used for the assessment of benefit from the hearing aids. They had taken children with moderately severe hearing loss. The stimulus was tone burst of 500 Hz and 4000 Hz, and speech stimuli /ga/ and /wa/. The aided speech recognition in Arabic kindergarten bisyllabic and phonetically balanced monosyllabic words in the live mode of presentation was done in quiet and noise using the open set speech recognition. They had taken P1-N1 and P2-N2 complex for the consideration of the peaks. They found the peaks in all the subjects with the parallel relationship with the speech recognition tasks. The 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 physiological 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. Recordings of aided N1 wave threshold revealed good agreement with the behavioural one, which may constitute a valuable tool for frequency specific threshold detection. The total number of emerged waves in the potential revealed more selectivity to cortical function than the latency parameter.

Kolkaila, Emara, and Gabr (2012) reported the use of aided LLR in hearing aid users and reported that this can be used for the assessment of the functional consequences of the auditory deprivation and the acclimatization of the hearing aids using. They concluded that these can be used for the estimation of the hearing thresholds. Further, the impact of hearing aid on the cortical processing of complex or simple stimuli was also evidenced to reveal the central auditory plasticity in the hearing aid fitted group. Thus, LLR can be used as an indicator of the development.

The study on slow cortical potentials and the amplification similar to the above mentioned content was reported by Marynewich et al. (2012). This report can be used in the fitting of the hearing aids, both analog and digital hearing aids. However, the occurrence of the peak in the slow cortical potentials are indicating that the response or the stimuli reaching the auditory cortex. In the adult population, the CEAPs are used for the evaluation of neural encoding of speech sounds (Agung et al., 2006). This helps in evaluating the normal and the impaired auditory system.

The effect of sensorineural hearing loss and the hearing aids were evaluated using the cortical event related potentials and the behavioural measures of the speech sound processing (Peggy, Korczak, Kurtzberg, & Stapells, 2005). They investigated the effect of the severe to profound hearing loss sensorineural hearing loss and the prescribed hearing aids using the N1, MMN, N2b potentials using speech discrimination tasks. Thus, the use of personal hearing aids can improve the detectabilty as well as discrimination. It is also said that the degree of the hearing impairment is important for interpreting the findings.

Similar to the previous study the MMN and P300 were used for the evaluation of the hearing aids in the two individuals by Kraus and McGee (1994). The subject who had good discrimination behaviourally for /ta/ and /da/ showed the presence of MMN and P300; but the subject with poorer discrimination revealed absence of MMN and P300. From this it can be inferred that there is a positive relationship between the behavioural and the cortical responses.

The cortical potentials (P1, N1, P2) will be used for the assessment of evaluating capacity of the auditory cortex ability to detect the auditory stimuli. This provides the electrophysiological evidence and the functional outcome measures for the evaluation of hearing aids (Martin & Boothroyd, 1999).

The study by Thabet and Said (2012) gives the valuable information on the maturation of the auditory system, benefit of the amplification and the aural rehabilitation in children hearing impairment. Majority of the children had moderately severe to severe hearing impairment. The aided cortical potentials were measured using the /da/ stimulus presented through loudspeaker. The speech recognition tests were also performed. They concluded that P1 latency of children was prolonged who had received the inadequate rehabilitation and the P1 latency was correlating with the duration the hearing loss. The CAEP was found to have a negative correlation with the speech discrimination (PBKG and ESP). In this study, it is concluded that there is no significant correlation between aided thresholds and P1 latency. Hence, the behavioural thresholds can always provide a sensitive indicator so the alternative choice of cortical auditory evoked potentials can be used.

2.2.8 Cortical auditory evoked potentials reflects the effect of speech in noise

The CAEP is vulnerable to the effects of noise on speech perception, and it is commonly acknowledged that failure of central auditory processes can lead to these difficulties with speech-in-noise (SIN) perception as reported by Anderson, Chandrasekaran, Yi, and Kraus (2010). However, little is known about the mechanistic relationship between central processes and the perception of SIN. The authors have studied the effect of central encoding of the speech through the cortical auditory evoked potentials and to evaluate the relationship between the cortical potential and the behavioural indices of the speech in noise. The /da/ stimulus was used for the recording in the quiet and in the presence of multi talker babble. The cortical amplitudes in the top SIN group remained stable between conditions, whereas amplitudes increased significantly in the bottom SIN group, suggesting a developmental central processing impairment in the bottom perceivers that may contribute to difficulties in encoding and perceiving speech in challenging listening environments. These findings demonstrate a relationship between higher-level perception and obligatory cortical activity and, specifically, demonstrate that a greater N2 response magnitude in noise is associated with poorer SIN perception.

Since several reports in literature are on cortical potentials, subjective outcome, and speech recognition thresholds individually. The intent of the current study is to evaluate the relationship between the behavioural outcomes and the cortical potentials in the hearing aid users and evaluate which of the behavioural measures is having a better correlation with the cortical potentials.

CHAPTER 3 - METHOD

The present study was conducted to investigate the relationship between behavioural outcome measure and aided late latency response in children and adults using hearing aids.

3.1 Participants

The participants had Kannada as their mother tongue. The test ears of the participant had severe degree of sensorineural hearing loss. A total of 25 ears were included for data collection. Two groups of participants were taken for the study. Group I included 15 ears of 10 children having a severe degree of hearing loss, i.e., PTA of >70dB HL in the test ear. Group II comprised of 10 ears of 7 adults having a severe degree of hearing loss, i.e., PTA of >70dB HL in the test ear. The AIISH ethical committee guidelines were followed in the study.

3.1.1 Inclusion criteria

The participants in this study were diagnosed to have severe hearing loss on pure tone audiometry with 'A' type tympanogram in the test ear in Group I. Their age ranged from 4 to 12 years with a mean age of 6.6 years. Their aided closed set speech identification scores (SIS) was not less than 60%. Written consent was obtained from the parents of the participants prior to data collection. All the children had congenital hearing impairment. All of them used the hearing for atleast a period of one year.

Group II comprised of participants with the age ranging from of 20 to 50 years with a mean age of 57.1 years. They had post-lingually acquired hearing impairment with adequate speech and language. The aided thresholds of the test ear were within speech spectrum, and the aided open set SIS was not lesser than 60%.

3.1.2 Exclusion criteria

Individuals having middle ear infections, neurological disorders and cognitive deficit were excluded from the study.

3.1.3 Test environment

The entire audiological tests were conducted in an air-conditioned sound treated single/double room, with noise levels within the permissible limits.

3.1.4. Equipment & tools

The following equipment and tools were utilized in the study.

1. A calibrated sound field audiometer (Madsen Orbitor 922, version 2) was used for the study with the loudspeaker was positioned at 0^0 Azimuth and at a distance of one meter away from the participant. This arrangement facilitated to establish the audiogram, speech identification score in the aided condition.
2. A computer was connected to auxiliary input of the audiometer for the presentation of the recorded speech material
3. A calibrated immittance meter (GSI tympstar version 2) was used to rule out the middle ear pathology.
4. HEAR Lab ACA was used to record the aided late latency response (ALLR) in both the groups, the loudspeaker was calibrated and participant is made to sit one meter away from the loudspeaker.
5. The test material included the PB word lists in Kannada for children (Vandana & Yathiraj, 1998) and PB word lists in Kannada for adults (Yathiraj & Vijayalakshmi, 2005). These were used for measuring the speech identification scores. The PB word

lists in Kannada for adults Manjula, Geetha, Antony and kumar (2013) were as used for measuring the signal to noise ratio - 50 (SNR-50).

6. **Parent's evaluation for aural oral performance of children** (P.E.A.C.H) (Ching & Hill, 2001): This was used to evaluate the effectiveness of the hearing aid in children in terms of the child's functional performance in everyday life situations. This questionnaire consists of 13 questions. Of these, the first two questions were pre-interview questions; third to thirteen questions were taken for scoring. The six questions (i.e., question nos. 3, 4, 7, 8, 11, & 12) were questions to assess performance in quiet condition. The questions included were on responding to name call, following verbal commands, following stories, involvement in conversation, recognizing voices and conversation over telephone. The other five questions (i.e., question nos. 5, 6, 9, 10, & 13) were on the same topics but in the presence of noise.

   This questionnaire used a of 5-point rating (0-4 points), where i.e., 0 (0% of time) means 'never', 1 (1-25%) means 'seldom', 2 (26-50%) means 'sometimes', 3 (51 -75%) means 'often', 4 (75% -100%) means 'always'. The scoring was done separately for quiet, noise and overall performance (i.e., quiet and noise combined). The 5 point rating scores for each question were summed up and it was taken as the raw score. The total raw score was 24 for the quiet condition; 20 for the noise condition and 44 for the overall performance. Later, this was converted in to the percentage by taking the sections of quiet environment (raw score in quiet / total score*100); noise environment (raw score in noise /total score*100); and overall score of both the environments were taken as sum of both quiet and noise (total raw score/total score*100).

7. **Self-assessment of Hearing Handicap** (SAHH) (Vanaja, 2000) : This scale is to identify the performance of hearing aids in different situations in adults. This scale

consists of a set of 15 questions. The eight questions (i.e., question nos. a, b, c, d, e, f, g, h) were questions to assess performance in quiet condition with hearing aids in different situations like comprehending speech, following the conversations with the family members, conversation with the male and female speakers at different distances, watching TV. The other seven questions (i, j, k, l, m, n, o) are for listening to radio, conversing in the shop, co-passenger, talking to a family member without visual cues. The scoring was done separately for quiet, noise and overall performance (i.e., quiet and noise combined). The 5 point rating scores for each question were summed up and it was taken as the raw score. The total raw score was 32 for the quiet condition; 28 for the noise condition and 44 for the overall performance. Later, this was converted in to the percentage by taking the sections of quiet environment (raw score in quiet / total score*100); noise environment (raw score in noise /total score*100); and overall score of both the environments were taken as sum of both quiet and noise (total raw score in quiet and noise/total score*100).

8. The AI was computed using the computer software program. The aided thresholds at nine frequencies i.e., 250 Hz, 500 Hz, 750 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz, 4000 Hz and 6000 Hz were considered to obtain the AI.

3.3. Procedure

The preliminary procedure was initiated with a detailed audiological evaluation. The audiometric testing was done using a calibrated sound field audiometer. The pure tone audiometric thresholds were obtained using modified Hughson-Westlake procedure (Cahart & Jerger, 1965) across octave frequencies from 250 Hz to 8000 Hz for air-conduction and 250 Hz to 4000 Hz for bone-conduction. The minimum intensity at which the response was elicited was considered as the threshold. Tympanometry was done to ensure normal middle ear functioning. Speech audiometry was done to obtain the speech recognition threshold (SRT), speech identification scores (SIS) and uncomfortable level (UCL) for speech.

For the purpose of evaluating the objectives, the data collection process was done in three phases. Phase I included the programming and optimization of the participant's own digital BTE hearing aid. In this phase, all the participants underwent optimization of hearing aid using the Ling's six sounds.

Phase II comprised of administration of P.E.A.C.H questionnaire for Group I and SAHH questionnaire for Group II. It also involved establishment of SIS in quiet for both the groups; and SNR-50 for Group II.

Phase III involved objective assessment by recording aided LLR. The aided LLR was administered for participants from both the groups. Figure 3.1 illustrates the test procedures administered for data collection.

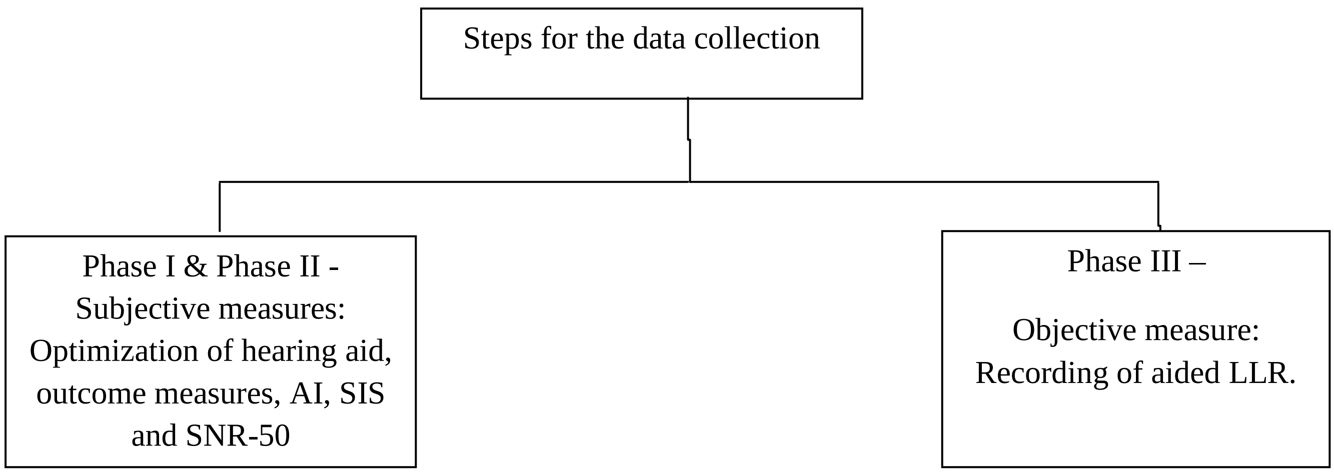


Figure 3.1. Flow Chart of III Phases Followed in the Study for Data Collection.

3.3.1 Phase I: Hearing aid programming and optimization.

In this phase, the participants from both Group I and Group II were involved. Optimization of their hearing aids was performed by using Ling's six sounds. After optimization of the hearing aid, aided audiogram testing was done for both the groups, from 250 Hz to 6000 Hz. The participants were made to sit one meter away from the loudspeaker, with the loudspeaker positioned at 0^0 Azimuth. Their aided thresholds were within speech spectrum. This phase was proceeded by Phase II of the study.

3.3.2 Phase II: Behavioural measures.

Phase II involved administration of questionnaire on parents for evaluation of aural oral performance of children with the hearing aid (PEACH) or Self-assessment of hearing handicap (SAHH) to measure the hearing aid benefit for adults. This phase also involved computation of AI and SIS test in quiet for children and adults; and establishment of SNR-50 measure for adults.

3.3.2.1 Parent's evaluation for aural oral performance of children (PEACH).

The participants from Group I were administered with the P.E.A.C.H. questionnaire. The participants and the caretaker were made to sit comfortably and the questionnaire was administered in Kannada language in the form of interview. This was administered in order to know the performance of a child with the hearing aid. The questions were asked on two different sections as it is mentioned under the 'Equipment and tools' section (3.2.3). This quantified the performance of the child in everyday life situations and this gives the outcome on efficacy of the hearing aid.

3.3.2.2 Self-assessment of hearing handicap (SAHH)

The participants from Group II were made to sit comfortably and interviews on the performance of the hearing aids in Kannada language was done based on the SAHH questionnaire.

3.3.2.3Articulation Index (AI)

The AI was computed by feeding the aided thresholds at 250 Hz, 500 Hz, 750 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz, 4000 Hz and 6000 Hz. The AI values were calculated automatically as the data was entered in to the excel program sheet.

3.3.2.4 Speech identification score in quiet (SIS)

The aided speech identification score in quiet were obtained for Group I and Group II. The participant was seated in the calibrated position one meter away from the loudspeaker at 0^0 Azimuth. Group I was presented with the PB-word list (vandana, 1998) which consisted of 25 words. The words were presented through monitored live voice mode and the presentation level was 45 dB HL. The VU meter monitoring was done to ensure that it did not exceed the average deflection.

The SI scores for Group I was obtained through picture identification or closed-set task. The picture book consisted of four pictures in a page. The child was instructed to point to the target picture. The participants were instructed and given practice items prior to the actual testing. The scoring of the test words was done by counting the number of correct words identified correctly. Each correct identification was given a score of ‘1’. The maximum score was 25 as there were 25 words in the PB word list.

For Group II, the aided SIS in quiet was obtained through recorded mode of presentation. The laptop with the CD having the recorded PB wordlists (2 nos.) in Kannada for adults (Manjula et al.2013) was connected to the auxiliary input of the audiometer. The stimulus was presented at an intensity of 45 dBHL. The participants were instructed to repeat the words heard. Each word correctly identified was given a score of ‘1’. The maximum score was 25 as the number of word in the list was 25.

3.3.2.5 Signal to Noise Ratio-50 (SNR-50)

The SNR-50 was performed only for Group II. The signal to noise ratio (SNR) required for 50% performance is termed SNR-50 (Fabry, 2005). The participant was made to sit comfortably on a chair, in the calibrated position, in the sound treated room. The recorded PB word lists were presented, from the CD loaded in the laptop computer, to the loud speaker, through the auxiliary input of the audiometer. The speech was presented at 45 dB HL, through the loudspeaker which was kept in front of the participant at 0^o Azimuth and one meter distance. The level of speech stimuli was kept constant at 45 dB HL. Later, speech noise was introduced through the same loud speaker, the level was set at 30 dB HL. The level of noise was increased, in 5-dB steps, till the participant repeated two out of four words correctly, i.e., 50% of the words being presented. From this level, the noise was varied in 2 dB steps in order to obtain a more precise level of speech noise at which 50% of the words are correctly repeated. At this point, the difference in intensity of speech and the intensity of speech noise, in dB, was noted as the SNR-50.

3.3.3 Phase III Objective measure

The participants from both the groups were recorded with aided cortical auditory evoked potential (LLR), the participants were made to sit comfortably in the air conditioned room, the electrode placement sites were cleaned with the Neuprep gel using a piece of cotton. The disposable electrodes were placed on the test sites. The vertical montage included the upper forehead, lower forehead and mastoid). It was ensured that the impedance was within 5 kOhms. The ongoing EEG activity was monitored to prevent the contamination of the response or high rejection. For Group I, eye blink was monitored by playing the muted movie or cartoon while recording. The CAEP recording was repeated to check for replicability. The protocol for measuring aided CAEP-LLR is given in the Table 3.1 below.

Table 3.1*: The Protocol Used for Recording Aided LLR*

Parameters	***Settings***
Test type	Cortical Auditory Evoked Potentials – LLR
Aided/unaided	Aided
Transducer	Loudspeaker
Position of the loudspeaker	1 metre distance with the Azimuth of 90^0 (side of the hearing aid worn).
Electrode sites	Active – vertex upper forehead(Cz) Reference –non test ear mastoid Ground – forehead
No. of epoch	200
Intensity level	65 dB SPL
Stimulus used	Three recorded speech sounds in low frequency /m/ (30 ms) in mid frequency/g/ (20 ms) in high frequency /t/ (30 ms)
Filter settings	0.16-30 Hz
Polarity	Alternating

3.3.3.1 Procedure Analysis of Latency and amplitude of aided LLR

The latency and the amplitude of the LLR wave form were visually inspected by extracting the latency and the amplitude information and the subjective note on peaks were inspected by three expertise audiologist in the department, they were instructed to mark the presence and the absence of peaks and to rate the presence of peaks on a 5 point rating scale. This was created using the code in the MATLAB program. After the complete evaluations, the scores from all the phases were tabulated and subjected for statistical analysis.

3.4 Statistical analysis

The data from different phases were tabulated and subjected to the appropriate statistics using Statistical Package for Social Science (SPSS version 17.0). The analyses of the parameters

I. The behavioural measures (SIS, SNR50, subjective questionnaires) for evaluating outcome of hearing aid in adults and children.

II. The objective measures (aided cortical potentials) for evaluating outcome of hearing aid in adults and children.

The analysis of the behavioural and the electrophysiological measures were done. Descriptive statistics (Mean, S.D & Range) were used for the evaluation of the outcome of the hearing aids in children and adults.

III. To compare the behavioural and objective outcomes of the hearing aid in adults and children.

The behavioural and the electrophysiological measures were compared and correlated. To find out the relationship between behavioural measures and CAEP (i.e., LLR). Mixed ANOVA and MANOVA were used to find out the significant difference between the children and adult group.

CHAPTER 4 - RESULTS AND DISCUSSION

The aim of the current study was to evaluate the relationship between behavioural outcome measures and cortical auditory evoked potentials in individuals using hearing aids. The three specific goals of the study were:

i) To study the behavioral measures for evaluating outcome of hearing aid in children and adults

ii) To study the objective measure of aided cortical potentials for evaluating outcome of hearing aid in children and adults.

iii) To compare the behavioural and objective measures of hearing aid in children and adults

The data were collected from two groups of test ears. They were 15 ears of 13 children, and 10 ears of 7 adults using hearing aids. The data for objective measure included the electrophysiological measure cortical auditory evoked potentials (CAEP). An attempt was made to compare the behavioural and objective measures. The data on behavioural and objective measures were tabulated and analyzed using SPSS for Windows (version 17).

4.1 Aided Behavioural Measures

The data from the behavioural measures included AI, SIS, and subjective questionnaire for both children and adult groups. In addition to these subjective measures, SNR-50 was also included for adults. These data were tabulated and analyzed.

Table 4.1 provides the mean, SD and range values of the subjective measures in adults and children.

Table 4.1

Mean, SD and range of AI, SIS, SNR-50, and questionnaire response in children and adults.

Behavioural measures	***Children***		***Adults***	
	Mean (SD)	***Range***	***Mean (SD)***	***Range***
AI (Range=0-1)	0.68 (0.053)	1-1	0.740 (0.085)	1-1
SIS (Range=0-25)	17.80 (1.656)	16-21	18.60 (1.349)	15-22
SNR-50	-	-	8.00 (2.055)	5
Questionnaire				
Quiet (Range= 0-100%)	76.27% (6.660)	70-85	79.30% (5.438)	65-88
Noise (Range= 0-100%)	63.67% (10.93)	60-75	65.70% (4.692)	35-75
Overall (Q+N) (Range= 0-100%)	70.00% (8.203)	65-80	73.10% (4.771)	50-81

4.2 Electrophysiological measures

The data in terms of latency and amplitude of aided cortical auditory evoked potentials, i.e, aided LLR, in children and adults were tabulated for analyses and comparison

4.3 Comparison of behavioural and objective outcome measures of the hearing aid in children and adults.

The data collected on behavioural and electrophysiologic measures were tabulated and subjected correlational test and test of significant difference between the means. The results are discussed under the following headings.

4.1 Aided behavioural measures in children and adults.

4.2 Aided electrophysiological measures in children and adults.

4.1. Aided behavioural measures

The mean, SD and range values of the behavioural measures such as AI, SIS, PEACH/SAHH questionnaire in quiet, noise and overall conditions, in children and adults, were tabulated and subjected to statistical analysis. In addition to these, SNR-50 was also analyzed in adult group. Details of statistical analyses are provided separately for children and adults.

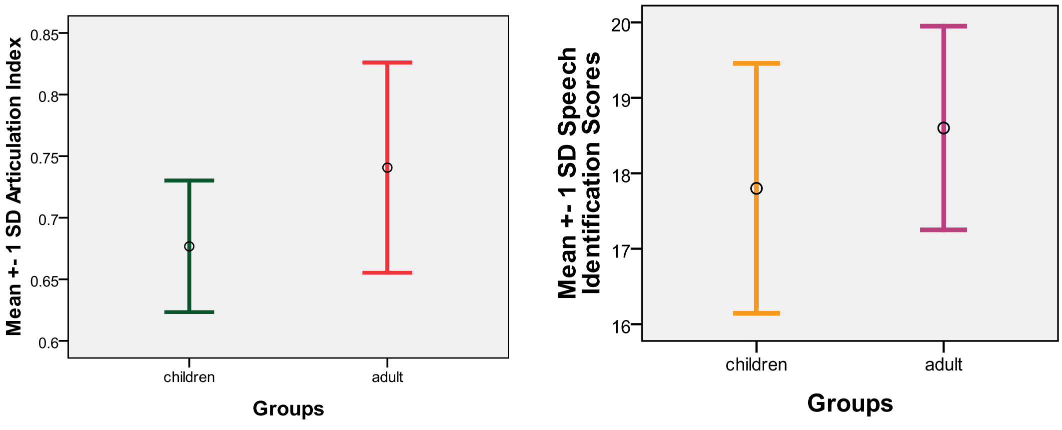
4.1.1 Behavioural measures in children and adults.

The articulation index (AI) was computed for each participant and tabulated. The data on SIS for PB word list in quiet; subjective questionnaire, i.e., performance in quiet, noise and overall conditions; and the SNR-50 were evaluated for the adult group. In children, except for SNR-50, data on these other measures were subjected to statistical analyses. Descriptive statistics was used to compare the mean, standard deviation and range for all the behavioural measures, in children and adults.

It can be inferred from Table 4.1 that the two groups are slightly different in terms of the mean values of behavioural measures of the adult and children groups.

The mean values of AI, SIS, and questionnaire with the hearing aid are higher in the adult group compared to that of children group.

In addition, it was noted that there was a low SD in both the adult and children groups suggesting that the groups were homogenous.



A *B*

Figure 4.1 *Error bar graph showing the mean and SD values of the behavioural measures of AI (as in A) and SIS (as in B) of Adult and Children Groups.*

The Figure 4.1 (A & B) represents the mean and SD of AI and SIS, in the children and adult groups. This indicates that the adult group is having higher mean values for AI as well as SIS than in children. This clearly indicates that there is a difference in performance between adult and the children groups.

The outcome measure obtained through the PEACH and SAHH questionnaires to measure the performance in quiet, noise and the overall (quiet and noise) conditions are depicted in Figure 4.2. It can be seen that the mean performance of the adult group is higher than the children group, in all the situations.

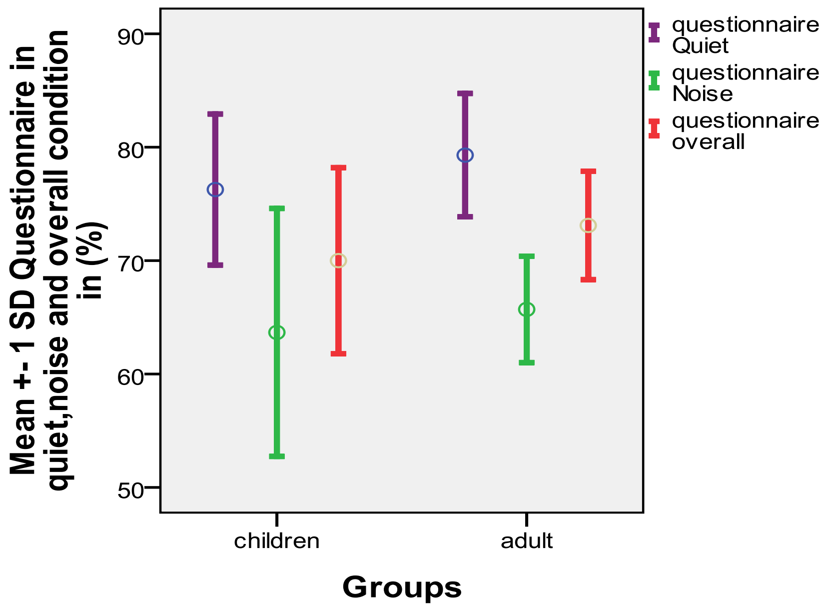


Figure 4.2. *Error Bar Graph Showing the mean and SD of Performance on questionnaire, in Adult and Children Groups.*

The performance of adult group in noise, i.e., SNR-50, revealed that they require speech to be at a higher level compared to noise. This present finding supports that of Lee and Humes (1993) where in individuals having severe impairment required higher SNR than normal hearing individuals. The possible support from the study reported that the degree of hearing loss and presence of noise will still reduces the audibility. This will result in the requirement of higher SNR in the individuals having severe hearing loss. The finding from the present study is in support with the study discussed, the SNR -50 of the adult group had poorer performance in the presence of noise.

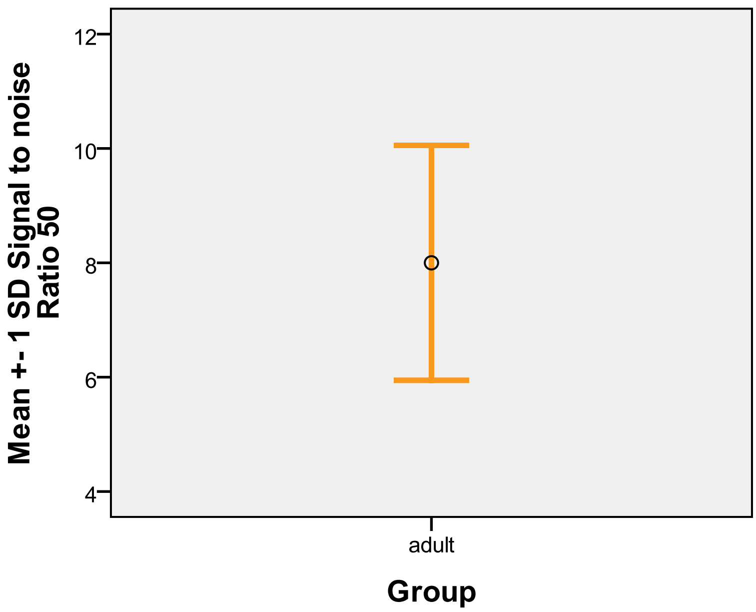


Figure 4.3 *Error plot on Mean Score of the Behavioural Measures of SNR-50 in Adult Group*

4.2 Aided CAEP measures in children and adults

The data on the CAEP (Aided LLR) involving latency, amplitude and slope of the LLR components (P1, N1, P2, N2) were tabulated and analyzed. The results of the statistical analyses of the aided LLR will be discussed.

The data on the latency, amplitude and slope were tabulated and analyzed. The results of the statistical analysis will be discussed. Tables 4.2 and 4.3, and are representing the mean, SD and range for the latency, amplitude and slope of aided LLR for the three different stimulus, i.e., /m/ , /g/ and /t/. The findings in the present study show that the mean value of the latencies was prolonged in children compared to that of adults.

Table 4.2 *Mean, SD and Range of Latency, Amplitude and slope of aided LLR in Children*

Aided LLR	Latency(ms)		Amplitude in (µV)	
	P1	N1	P1-N1	Slope of P1-N1
	Stimulus /m/			
Mean (SD) Range	115.80 (12.83) 92-132	203.46 (31.49) 142-272	6.01 (2.87) 3.17-13.9	-0.61 (0.028) -0.12 - -0.03
	Stimulus /g/			
Mean (SD) Range	117.06 (19.69) 94-158	192.26 (31.26) 151-268	5.67 (2.29) 2.38-9.05	-0.87 (0.05) -0.2 - -0.2
	Stimulus /t/			
Mean (SD) Range	116.66 (16.28) 94-148	202.13 (20.81) 157-244	5.52 (2.09) 2.89-9.43	-0.71 (0.03) -0.16 - -0.03

This findings is possibly in support with the study done on the maturation of CAEP in infants and children reported by Wunderlich et al. (2006) were the prominent of the peaks and prolonged in the latency are generally noted in the children group when compared to adults, also this finding in support with a study on vowel evoked CAEP in the children found that a large positive P1 around the latency 130ms and the two negative peaks were noted around 250 ms and 450 ms which in the positive support with the study by Ceponiene et al. (2003)

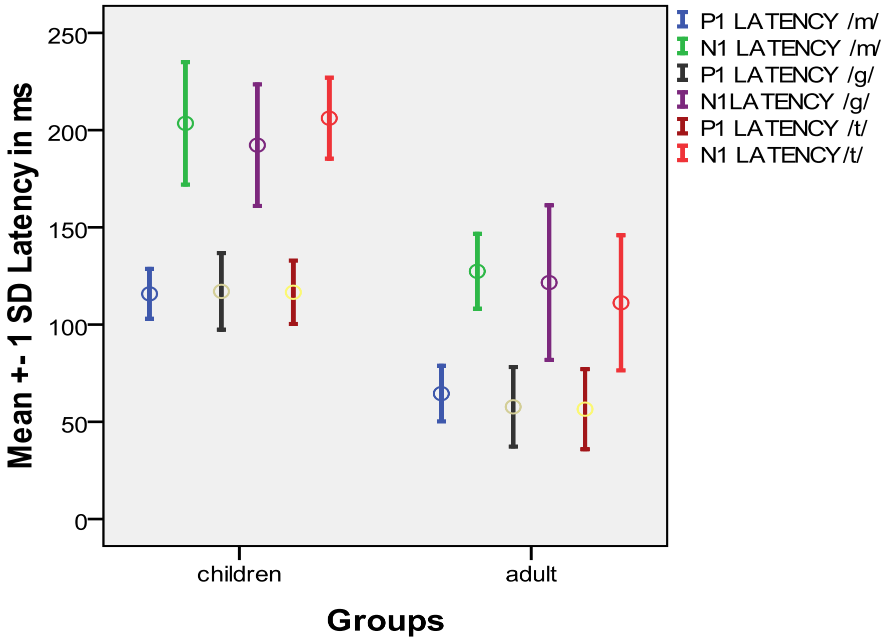


Figure 4.4*: Error bar graph depicting mean and SD of P1, N1 of the three different stimuli for children and adult groups.*

The finding of the present study supports that reported by Cunningham, Nicol, Zecker, and Kraus (2000). Even in their study it was observed that there was generation of the positive and the negative peaks initially soon after the hearing aid was fitted. Once the auditory system is stimulated and with the maturation, there is possible reduction in the amplitude of P1 and reduction in latency of P1 which signifies maturation.

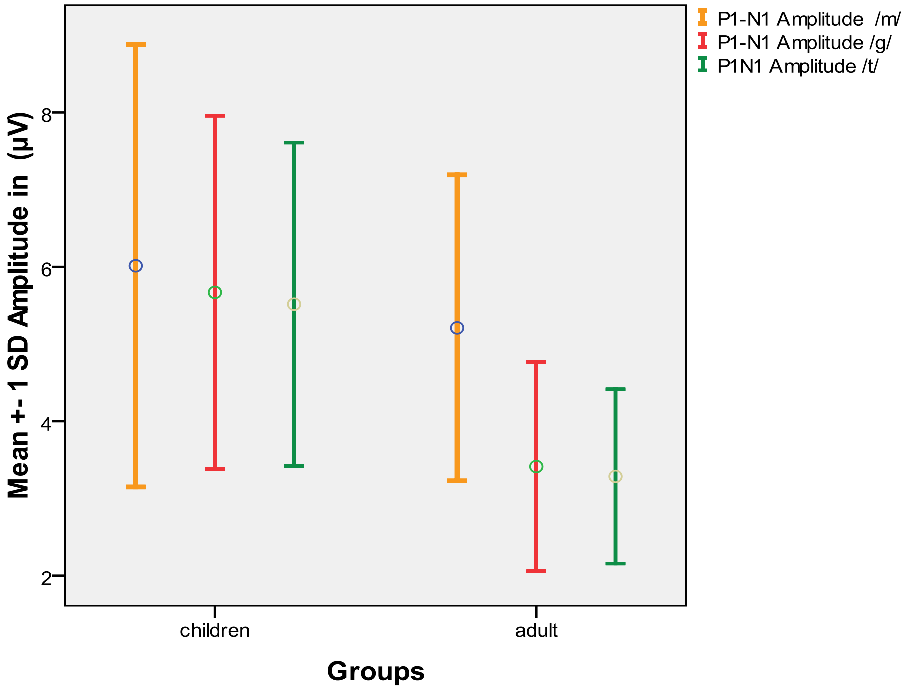


Figure 4.5*: Error bar graph showing the mean and SD of amplitude P1-N1complex of the three different stimuli for Children and adult group*

The Figure 4.5 depicts the amplitude of P1-N1 of the stimulus /m/, /g/ and /t/. This indicates that the children are having greater mean amplitude than the adult group. In this figure, it can also be noted that the variability in amplitude is more in children as reflected by the SD values.

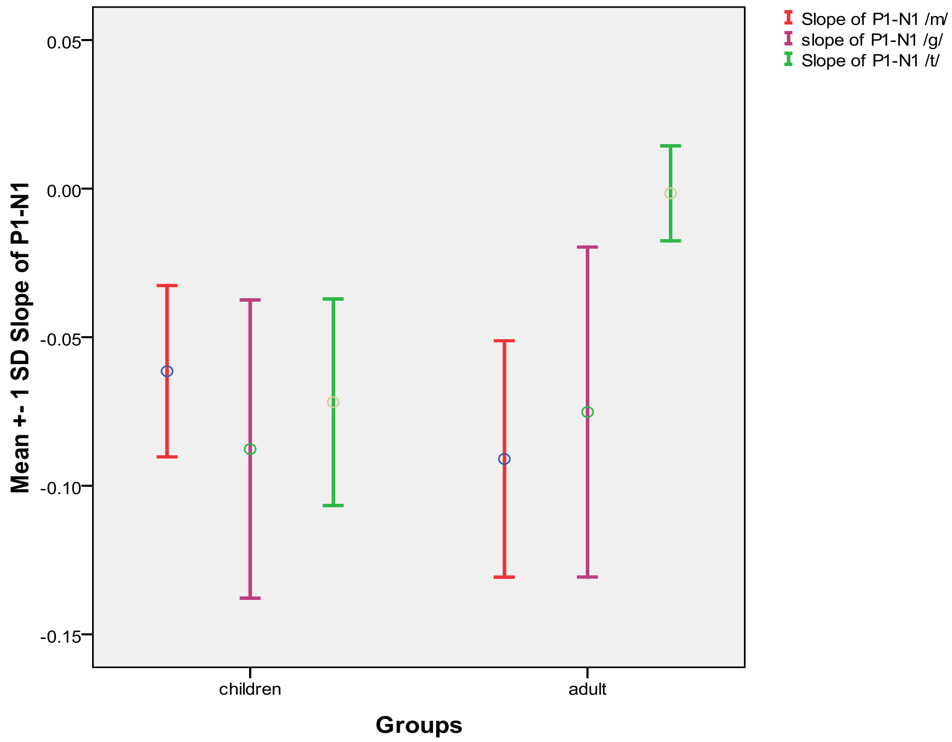


Figure 4.6 *Error bar graph showing the mean and SD of slope of P1-N1, for the three different stimuli, in Children and Adult Groups.*

The children group is having higher mean amplitude for the P1-N1 for the stimulus /g/. This pattern is similar to that mentioned in the previous stimulus section i.e., for /m/. The prominent presence of N1 peaks reported was less and this signifies the developmental changes. As the age increases, the N1 peak latency decreases or prominence of the peaks increases by the changes in the amplitude component. There may be a possibility that the N1 peak can be absent or even if it is present the prolongation of latency will take place over 100 ms to 150 ms as reported by Cunningham, Nicol, Zeker and Kraus. (2000). In the current study too, the presence of prominent N1 peak with prolongation of latency probably reflects the maturation, for all the three stimulus which is used in the study.

Table 4.3 *Mean, SD and Range of Latency, Amplitude and Slope of LLR components in Adult Group.*

Aided LLR	Latency in (ms)				Amplitude in (µV)			
	P1	N1	P2	N2	P1-N1	N1-P2	P2-N2	Slope P1-N1
	Stimulus /m/							
Mean **(SD)** **Range**	64.50 (14.28) 44-94	127.40 (19.25) 112-172	226.60 (8.93) 217-214	374.33 (10.96) 368-387	5.209 (1.98) 2.74-9.48	6.091 (4.73) 1.52-13.1	8.348 (0.26) 8.19-8.64	-0.191 (0.39) -0.18- -0.03
	Stimulus /g/							
Mean **(SD)** **Range**	57.70 (20.46) 39-101	121.60 (39.76) 66-167	199.20 (12.29) 186-212	364.00 (15.52) 349-380	3.413 (1.36) 1.65-5.44	3.533 (2.08) 0.08-6.68	5.915 (0.45) 5.67-6.43	-0.075 (0.05) -0.22 –0.02
	Stimulus /t/							
Mean **(SD)** **Range**	56.50 (20.59) 39-100	111.20 (34.74) 66-167	231.40 (21.76) 212-265	349.33 (24.82) 335-378	3.285 (1.12) 2.03-5.18	4.210 (2.134) 1.17-7.11	7.220 (0.70) 6.46-7.85	0.016 (0.015) -0.16- -0.02

The Table 4.3 depicts the descriptive statistics in terms of the mean, SD and range of latency, amplitude and slope of the components of aided LLR in adults. This finding in adults supports that reported by Wunderlich et al. (2003). In their study, it was reported that as the age increases, there is a reduction in the latency of the P1 and N1. In the present study too, the mean of the P1 and N1 peaks showed a reduction of the mean latencies for the adult group compared to that in the children group. This systematically shows a difference due to maturational aspect in the children group.

In the present study, it is clearly observed that the mean amplitude of the P1-N1 of adults is lesser when compared to the mean amplitude of N1-P2 complex, as depicted in the Table 4.3. This is in support with the findings reported by Sharma et al. (2002). The peaks P2 and N2 were prominently observed in the adult group, and were not present in the children group.

4.3 Comparison of the behavioural and objective outcomes of the hearing aid in adults and children.

In order to evaluate the third objective of the study to compare the behavioural and objective outcome of the hearing aids in adults and children, the results will be discussed under two headings:

4.3.1 Relationship between behavioural and objective outcomes in children and adult.

4.3.2 Significance difference between behavioural and objective outcomes in children and adult.

In order to evaluate the above, the correlation statistics i.e., Pearson's correlation, and Mixed ANOVA and MANOVA were used to extract the information on the main effect of conditions and groups and interaction between them.

4.3.1 Relationship between behavioural and objective outcomes in children and adult:

The Pearson's correlation was used to evaluate the relationship between the behavioural measures and the aided LLR.

i) The correlation between AI, SIS, questionnaire in quiet, noise and overall conditions with aided LLR, in children.

ii) The correlation between AI, SIS, SNR-50, and questionnaire in quiet, noise, overall with aided LLR, in adults.

Table 4.4

Correlation between behavioural measures and CAEP (Aided LLR) children (A)

Aided LLR components	Behavioural measures	r (correlation coefficient)			*p (*Significance)		
		/m/	/g/	/t/	/m/	/g/	/t/
P1	AI	0.220	-0.531**	0.220	>0.005	<0.005	>0.005
	SIS	0.133	0.028	0.140	>0.005	>0.005	<0.005
	Questionnaire in quiet	0.146	0.166	0.140	>0.005	>0.005	>0.005
	Questionnaire in noise	0.119	0.249	-0.119	>0.005	>0.005	>0.005
	Questionnaire overall	0.032	-0.033	0.014	>0.005	>0.005	>0.005
N1	AI	0.098	0.156	0.089	>0.005	>0.005	>0.005
	SIS	0.153	0.131	-0.543**	>0.005	>0.005	<0.005
	Questionnaire in quiet	-0.068	-0.082	-0.068	>0.005	>0.005	>0.005
	Questionnaire in noise	0.141	0.237	0.142	>0.005	>0.005	>0.005
	Questionnaire overall	0.035	0.101	0.136	>0.005	>0.005	>0.005

Table 4.4

Correlation between behavioural measures and CAEP (Aided LLR) children (B)

Aided LLR components	Behavioural measures	r (correlation coefficient)			*p* (Significance)		
		/m/	/g/	/t/	/m/	/g/	/t/
P1-N1 Amplitude	AI	-0.74	0.317	0.236	>0.005	>0.005	>0.005
	SIS	-2.74	-0/43	0.1	>0.005	>0.005	>0.005
	Questionnaire in quiet	0.044	-0.082	0.044	>0.005	>0.005	>0.005
	Questionnaire in noise	-0.068	-0.129	-0.068	>0.005	>0.005	>0.005
	Questionnaire overall	0.013	-0.062	0.013	>0.005	>0.005	>0.005
P1-N1slope	AI	0.135	-0.138	-2.87	>0.005	>0.005	>0.005
	SIS	0.135	-0.80	-0.106	>0.005	>0.005	>0.005
	Questionnaire in quiet	0.128	-0.58	-0.195	>0.005	>0.005	>0.005
	Questionnaire in noise	0.499	0.255	0.152	>0.005	>0.005	>0.005
	Questionnaire overall	0.289	0.149	-0.0254	>0.005	>0.005	>0.005

The Table 4.4 (A & B) depicts the correlation of the behavioural measures and electrophysiological measures. There is no significant correlation for most of the parameters. However, a significant negative correlation was observed for P1 latency for /g/, and N1 latency for /t/ stimulus. This indicates that an increase in the AI values and the SIS is reflected by a decrease in the P1 and N1 latencies for /g/ and /t/.

There was no significant correlation between the questionnaire measure and the LLR measures in the current study. This finding from the present study is contradicting that reported by Golding et al. (2007). They reported a significant relationship between the CAEP and functional outcome measures (i.e., PEACH), as the presence of CAEP can predict the auditory performance in the real life situation.

In order to validate the hearing aid, Hassan (2011) reported that the CAEP can be used as a tool for objectively assessing the hearing aid. In his study, behavioural measures such as aided pure tone thresholds, speech recognition in quiet and noise were utilized. His study revealed no correlation between the speech recognition in quiet and CAEP. However, his study found a positive relationship between the speech recognition abilities in noise and CAEP. This could possibly be because in the condition of speech and noise presented together, more areas are involved which reflected the number of generated wave this gave the possible information of the benefit of the hearing aids and the physiological activities of the cortex. In some cases there were no correlation between CAEP and SIS in quiet and noise. This could probably be because of the amount or the degree of the hearing loss in individuals. Their report is in consensus with the current finding where there was no significant correlation between the speech identification scores in quiet and the CAEPs. Possibly, severe hearing loss could have been one of the factors which would have prevented from significant correlation between the behavioural and electrophysiological measures.

The present findings also contradicts that reported by Rance et al. (2002) as it is reported in their investigation that the CAEP can predict the perceptual skills in the individuals with the age appropriate latency and amplitude; and this was also correlated with open set speech perception abilities and amplification benefit. In the present study, even though the participant selection was such that only an SIS of > 60% in quiet was included; there was no significant correlation found in children.

Further, there was no significant correlation between behavioural and objective measure in adults. It is therefore refuting with studies reported by Wong et al. (2008) reported the correlation between the behavioural findings like aided thresholds , speech thresholds were measured using Cantonese hearing in noise test. This was studied in the different conditions also i.e., quiet, noise from front, left. They concluded that the speech scores and CEAP are highly correlated with the behavioural audiometric thresholds. In the present study, there is no possible relationship with the different behavioural tests such as AI, SIS, questionnaire and SNR-50 with the CAEP, in adults.

Table 4.5 (A)

Correlation between behavioural measures and CAEP (Aided LLR) adults (A)

Aided LLR components	Behavioural measures	r (correlation coefficient)			*p* (Significance)		
		/m/	/g/	/t/	/m/	/g/	/t/
	AI	0.426	0.221	0.426	>0.005	>0.005	>0.005
P1	SIS	-0.045	-0.052	-0.045	>0.005	>0.005	>0.005
	Questionnaire in quiet	0.212	0.442	0.212	>0.005	>0.005	>0.005
	Questionnaire in noise	-0.167	-0.020	-0.167	>0.005	>0.005	>0.005
	Questionnaire overall	0.050	0.278	0.050	>0.005	>0.005	>0.005
	SNR-50	0.512	0.413	0.091	>0.005	>0.005	>0.005
	AI	0.485	0.415	0.485	>0.005	>0.005	>0.005
N1	SIS	-0.394	0.026	-0.394	>0.005	>0.005	>0.005
	Questionnaire in quiet	0.094	0.405	0.094	>0.005	>0.005	>0.005
	Questionnaire in noise	0.451	-0.211	-0.451	>0.005	>0.005	>0.005
	Questionnaire overall	0.007	0.193	0.007	>0.005	>0.005	>0.005
	SNR-50	0.416	0.019	0.197	>0.005	>0.005	>0.005

Table 4.5*(B)* *Correlation between behavioural measures and CAEP (Aided LLR) adults*

Aided LLR components	Behavioural measures	r (correlation coefficient)			*p* (Significance)		
		/m/	/g/	/t/	/m/	/g/	/t/
	AI	-0.096	-0.031	-0.096	>0.005	>0.005	>0.005
P1-N1 Amplitude	SIS	-0.462	0.319	-0.462	>0.005	>0.005	>0.005
	Questionnaire in quiet	*-0.195*	*0.574*	*-0.195*	>0.005	>0.005	>0.005
	Questionnaire in noise	-0.258	0.191	-0.258	>0.005	>0.005	>0.005
	Questionnaire overall	-0.200	0.328	-0.200	>0.005	>0.005	>0.005
	SNR-50	0.098	-0.407	-0.028	>0.005	>0.005	>0.005
P1-N1slope	AI	0.067	0.298	0.298	>0.005	>0.005	>0.005
	SIS	0.233	0.277	0.691	>0.005	>0.005	>0.005
	Questionnaire in quiet	-0.015	0.011	-0.004	>0.005	>0.005	>0.005
	Questionnaire in noise	0.094	-0.035	0.115	>0.005	>0.005	>0.005
	Questionnaire overall	-0.267	-0.038	-0.004	>0.005	>0.005	>0.005
	SNR-50	-0.051	0.076	0.012	>0.005	>0.005	>0.005

In a study by Korezak et al. (2005), it was reported that the substantial use of hearing aids in the individuals can improve the detectabilty of the cortical potentials. They gave possible explanation on presence or absence of CAEP findings showed the more accurate and effective information regarding behavioural speech measures and CAEP in experienced hearing aid users. The study also reported on the degree of hearing loss this will also plays a major factor the authors have reported that the degree of hearing loss was taken from moderate level to profound, in this findings relationship between the behavioural measures and CAEP could be due to the effect of hearing aids, level of the intensity and the degree of hearing loss is important. In the present study, the participants selected were minimum one year of experienced hearing aid users and had severe degree of hearing loss, In present study finding is possibly in support with the above discussed information even though the participants were experienced hearing aid users as the degree of hearing of hearing loss is higher the between behavioural and CAEP is not always possible.

In order to find out the significant difference across groups and across variables, Mixed ANOVA (for three different conditions of the questionnaire, latency and amplitude measures) and MANOVA (for AI and SIS) was performed to know the main effect and the interaction. The results of the overall analysis show that there is no main effect and interaction between the different parameters.

The two-way repeated measures ANOVA (MANOVA) with between subject factor as group was performed. The findings revealed that there is a significant difference between the groups [$F(1,23)=5.344$, $p<0.005$] for the AI but not for SIS [$F(1,23)=1.612, p>0.005$]. There was no significant difference in SIS between the groups, the main effect and interaction effects were also not present. That is, the pattern followed in the groups is similar between the AI and SIS.

In order to evaluate the questionnaires, latencies and amplitude, Mixed ANOVA was done. This was done for questionnaire included three different conditions (quiet, noise & overall), three different stimuli (stimulus /m/, /g/ &/t/) considering the latency, amplitude and slope information the results evaluated the main effect and interaction effect between the groups.

The results found that [$F(2,46)=0.267, p>0.05$]for the questionnaire that there is no main effect of group and interaction effects were found in conclude to say that the pattern and the trend found in both the groups are similar. The significant difference was found between different conditions in the questionnaire (quiet, noise & overall) for within a groups [$F(2,46)=128.5, p<0.001$] but when comparing between the group [$F(1,23)=133.3, p>0.05$]it is noted that there is no significant difference.

To evaluate t the significant difference between the CAEP, in both the group of participants. The latency and amplitude information were taken (P1, N1, & P1-N1 amplitude) from the current findings of the study it is noted that there is no main effect of group and interaction effect was noted. It was found that there is no significant difference [$F (1, 23)= 1.66, p>0.05$] for the within group latencies comparison , but, the between groups the results found to be [$F(1,23)= 913.9, p<0.001$] highly significant between both the groups for the P1 latency.

N1 latency [$F (2, 46) =2.58, p>0.01$] results also revealed the similar results as similar to the P1 latency the main effect and the interaction effect was noted .The within group comparison showed [$F (1, 23) =1.28, p>0.05$] there was no significance difference. But in the between group comparison [$F (1, 23) =60.05, p<0.001$] this is possibly indicating the difference between the children and adult groups. [$F (2, 46) =2.58, p>0.01$] result of P1-N1 amplitude a similar pattern were noted as mentioned in the previous information on the latencies there was no main effect and interaction effects noticed, this possibly reveals the trend and patterns followed in both the group are similar, [F (1,23) =2.45, $p>0.05$] in the present study findings there is no main effect and interaction effect were noted, [F (2,46) 1.64=, $p>0.05$] and the significant difference in the amplitude was not found in within group comparison [F (1,23) = 2.45, $p>0.01$ but it was noted for the between groups the result findings shows that [F (1,23) =6.53, $p<0.001$] it is noticed that significant difference was found. Hence, the findings of the present study reveal that there was no main effect groups and interaction effect for the entire variable. But it is clearly indicating that the within group comparison for the questionnaires in all the conditions were significant apart from that all other measures did not show the significance, in order to consider the between group comparison the significant difference were found for (AI, aided LLR)

Wunderlich et al. (2003), In their study, age was reported to be one of the important factors as it could support for the present findings of the study is the age, the developmental changes have not been attained completely by the child. The children group taken for the study are having the mean age of 6.6 years so it ensures that the response present between groups is significant. The findings of the present study conform to the maturation effects, degree of hearing loss (congenital), duration of the hearing aid use.

To summarize the findings of the present study is given. It was found that all the mean of behavioural measures was found to be higher in the adult group than in the children group. It was also found that for the all the parameters the children group had higher mean for all the parameters compared to adults. The parameters included latency of P1 & N1, amplitude P1-N1 and slope of P1-N1 for three different stimuli (/m/, /g/ & /t/).

In order to evaluate the third objective of the study, to compare the behavioural outcome and objective measures, the correlation statistics and comparison were done using i.e., Pearsons correlation, MANOVA and Mixed ANOVA were done to evaluate the relationship and significant difference between the groups. To infer from the present study, there was a significant correlation found for the children group for two parameters of P1 latency of /g/ with AI, and N1 latency of /t/ with SIS in quiet. It was found that as the behavioural outcome scores increased, the P1 and N1 latency reduced. But in the adult group, there was no significant correlation noted between the behavioural measures and aided LLR.

The main effect of the groups, interaction effect of the variables and significant difference was analysed using MANOVA and Mixed ANOVA. It was noted in all the parameters the pattern followed were similar. There was no main effect and interaction effect. But the significant difference was noticed on the MANOVA. It can be inferred that AI has a significant difference between groups but not for the SIS and Mixed ANOVA infers there was no main effect and the interaction effects noted.

The significant difference was noted between the quiet, noise and overall condition within the group. The latency, amplitude and slope information showed the significant difference for between groups in the current study.

Thus, the null hypothesis was accepted since there was no significant correlation between the behavioural and electrophysiological measures.

CHAPTER 5 - SUMMARY AND CONCLUSIONS

The aim of the present study was to evaluate the efficacy of the hearing aids using the behavioural measures and objective measures in hearing aid users; and to investigate the relationship between. The specific objectives of the study were -

1. To study the behavioural measures such as AI, SIS, SNR-50, subjective questionnaires, for evaluating the outcome of hearing aid, in adults and children.
2. To study the aided LLR for evaluating the outcome of hearing aid, in adults and children.
3. To compare the behavioural and objective outcomes of the hearing aids, in adults and children.

The data for the present study were collected from 15 ears of 10 children; and 10 ears of 7 adults. The criteria for inclusion were that the aided thresholds were within speech spectrum; SIS was not less than 60%; and the participants having a PTA of greater than 70 dB HL.

The data collection process was done in three phases. Phase I included the programming and optimization of the participant's own digital BTE hearing aid. In this phase, all the participants underwent optimization of hearing aid using the Ling's six sounds. Phase II comprised of administration of P.E.A.C.H questionnaire for Group I and SAHH questionnaire for Group II. It also involved establishment of SIS in quiet for both the groups; and SNR-50 for Group II. Phase III involved objective assessment by recording aided LLR for /m/, /g/ and /t/ stimuli. The aided LLR was recorded for participants from both the groups. Thus, the data on the behavioural measures and electrophysiological measures were collected, tabulated and analysed.

The data collected were subjected to stastical analysis using Statistical Package for Social Sciences (Version 17.0). The descriptive statistics was used to obtain the mean, SD and range of the present findings. To investigate the correlation between behavioural outcome and electrophysiological measures (CAEP- Aided LLR), Pearson's correlation was used. To evaluate the main effect, interaction effects and significant difference of the variables, mixed ANOVA and MANOVA were used. Bonferroni adjusted multiple comparison was done, when indicated, to evaluate the presence of significance between the pairs of conditions.

i) Aided behavioural measures in children and adults

The data on the behavioural measures such as AI, SIS, Questionnaire and SNR-50 (only adults) were analysed for the descriptive statistics. The results revealed that the adult group had a greater mean for AI, SIS and questionnaire measures than the children group.

ii) Aided LLR in children and adults

The data on the electrophysiological measure of aided LLR included three parameters such as latency, amplitude and slope. The HearLAB instrument was used for the recording aided LLR in children and adults. The speech stimulus /m/, /g/ and /t/ at 65 dBSPL were used for the recording.

The collected information on the latency, amplitude and slope was tabulated and the results of the statistical analysis will be discussed. Using the descriptive statistics the Mean, S.D and range were computed. A higher mean for the latencies P1 N1was noticed in children than adults. This possibly leads to a prolonged latency in the children.

For the measures of different stimuli /m/, /g/ and /t/, the mean latency and amplitude, of P1 and N1, of children group showed a higher value and low SD indicating the higher degree of consistency with the data of the latency and amplitude component.

There is a reduction in the latency of P1 and N1 components of the LLR in adults. This systematically shows the maturational aspects of the children group possibly accounts for the mean difference between the groups.

iii) Compare the behavioural and objective outcomes of the hearing aid in adults and children.

The present study was attempted for the comparison of behavioural and objective measures in adult and children group. The comparison was done using MANOVA and Mixed ANOVA. It was found that there was no main effect and interaction effect among the variables. This indicates that the pattern followed in both the groups is similar and there is no significant difference within the group. There was a significant difference between the groups. The variables that provide possible explanation include maturation aspects, degree of hearing loss, duration of the hearing aid use between the two groups.

Future directions for research

1. This study is one of the preliminary attempts made in the direction of finding out the relationship between the behavioural measures and cortical potentials in the hearing aid users. An attempt was made on correlating and comparing the behavioural and cortical potentials.

2. The study was done only on the individuals having greater than or equal to severe hearing loss. There is a need for the study to be done with the different degrees of hearing loss (mild, moderate, moderately severe hearing loss), in individuals who are naive hearing aid users.
3. This study can be done individuals with different configuration of the hearing loss.
4. The aided LLR is one of the tests for the detection, possibly the higher potentials like P300 and MMN can be used to evaluate the relationship between the behavioural measures and CAEP.
5. To evaluate the relationship between behavioural and electrophysiological (aided LLR) in experienced and naive hearing aid users.
6. The study can be extended to find out the relationship between the behavioural and electrophysiological measures in the individuals using cochlear implants.

References

Agung, K., Purdy, S. C., McMahon, C. M., & Newall, P. (2006). The Use of Cortical Auditory Evoked Potentials to Evaluate Neural Encoding of Speech Sounds in Adults. *Journal of American Academy of Audiology, 17*, 559-572.

Anderson, S., Chandrasekaran, B., Yi, H. G., & Kraus, N. (2010). Cortical-evoked potentials reflect speech-in-noise perception in children. *European Journal of Neuroscience, 32*, 1407-1413.

Arlinger, S.D. (2001). How to assess outcomes of hearing aid fitting in children. *Scandinavian Audiology*, 30, 68–72.

Billings, C.J., Tremblay, K.L., Souza, P.E., & Binns, M.A. (2006). Effects of hearing aid amplification and stimulus intensity on cortical auditory evoked potentials. *Audiology Neurootology, 12,* 234 – 246.

Bray, V., & Nilsson, M. (2002). Assessing hearing aid fittings: an outcome measures battery approach. In M. Valente (Ed.). *Strategies for Selecting and Verifying Hearing Aid Fittings*. New York: Thieme Press.

Brown, C. J., Abbas, P. J., Bertschy, M., Tyler, R. S., Lowder, M., Takahashi, G., Gantz, B. J. (1995). Longitudinal Assessment of Physiological and Psychophysical Measures in Cochlear Implant Users. *Ear and Hearing, 16*.

Ceponiene, R., Lepisto,T., Alku, P., Aro, H., Naatanen, R. (2003). Event related potential indices of auditory vowel processing in 3-year-old children. *Clinical Neurophysiology* 114, 652–661.

Chang, H.W., Dillon, H., Carter, L., Dun, B. V., & Young, S. T. (2012). The relationship between cortical auditory evoked potential (CAEP) detection and estimated audibility in infants with sensorineural hearing loss. *International Journal of Audiology, 51*, 663-670.

Ching, T. & Dillon, H. (2001). Prescribing amplification for children Adult-equivalent hearing loss, real-ear aided gain, and NAL-NL1. *Trends in amplification, 7*, 1-9.

Cox, R. (2003). Assessment of subjective outcome of hearing aid fitting: getting the client's point of view. *International Journal of Audiology, 42*, S90-S96.

Cox, R., & Alexander, G. (1995). The abbreviated profile of hearing aid benefit. *Ear and Hearing*, *16*(2), 176-186.

Cox, R., & Alexander, G. (1999). Measuring satisfaction with amplification in daily life: The SADL. *Ear and Hearing, 20*, 306-320

Cox, R., & Alexander, G. (2003). Maturation of hearing aid benefit: Objective and subjective measurements. *Ear and Hearing*, *13*, 131–141.

Cunningham, J., Nicol, T., Zecker, S., Kraus, N. (2000). Speech-evoked neurophysiologic responses in children with learning problems: development and behavioural correlates of perception. *Ear and Hearing* 21, 554– 568.

Davis, H., & Silverman. (1947). *Hearing and Deafness*. New York: Holt, Rinehart and Winston.

Dillon, H. (2005). So Baby, how does it sound? Cortical assessment of infants with hearing aids. *The Hearing Journal, 58*, 10 -17.

Dillon, H. 2001. *Hearing Aids.* Sydney: Boomerang Press.

Dillon, H., & Carter, L. (2012). The relationship between cortical auditory evoked potential (CAEP) detection and estimated audibility in infants with sensorineural hearing loss. *International Journal of Audiology, 51,663*-670.

Dillon, H., James, A., & Ginis, J. (1997). The Client Oriented Scale of Improvement (COSI) and its relationship to several other measures of benefit and satisfaction provided by hearing aids. *Journal of American Academy of Audiology, 8*(2), 27-43.

Eggermont, J.J., Ponton, C.W. (2003). Auditory-evoked potential studies of cortical maturation in normal hearing and implanted children: correlations with changes in structure and speech perception. *Acta Otolaryngology,* 123:249–252.

Ewing, I. & Ewing, A. (1944). The ascertainment of deafness in infancy and early childhood. *Journal of Laryngyngology,* 59:309–333

Firszt, J. B., Chambers, R. D., & Kraus, N. (2002). Neurophysiology of Cochlear Implant Users II: Comparison among Speech Perception, Dynamic Range, and Physiological Measures. *Ear and Hearing*, *23*(6), 516-531

Fitzpatrick, E.M., Olds, J., Gaboury, I., McCrae, R., Schramm, D., & Durieux-Smith, A. (2012). Comparison of Outcomes in children with Hearing aids and cochlear implants. *Cochlear Implants International*, *13*(1), 5-15.

Flynn, M. C., Dowell, C. R., & Clark, G. M. (1998). Aided speech recognition abilities of adults with a severe or severe-to-profound hearing loss. *Journal of Speech Language Hearing Research*, *41*(2), 285-299

Gary, R., Barbara, C.W., Julia, W., & Richard, D. (2002) Speech perception and cortical event related potentials in children with auditory neuropathy. *Ear and Hearing*, *23*, 239-253.

Gatehouse, S., & Noble, W. (2004). The Speech, Spatial and Qualities of Hearing Scale (SSQ). *International Journal of Audiology; 43*, 85 -99

Giolas, T., Owens, E., & Lamb, S. (1979). Hearing performance inventory. *Journal of Speech and Hearing Disorders, 44*, 169-195.

Golding, M., Dillon, H., Seymour, J., Purdy, S. C., & Katsch, R. (2007). Obligatory Cortical Auditory evoked potential (CAEPs) and functional measure in young infants. *Journal American Academy of Audiology, 18,* 117-125.

Golding, M., Pearce, W., Seymour, J., Cooper, A., & Ching, T. (2007). The relationship between obligatory cortical auditory evoked potentials (CAEPs) and functional measures in young infants. *Journal American Academy of Audiology, 18,* 117 – 125.

Gorga, M. P., Neely, S. T., Hoover, B. M., Dierking, D. M., Beauchaine, K. L., & Manning, C. (2004). Determining the Upper Limits of Stimulation for Auditory Steady-State Response Measurements. *Ear and Hearing*, *25*(3), 302-317.

Hassaan, M. R. (2011). Aided evoked cortical potential: An objective validation tool for hearing aid benefit. *Egyptian Journal of Ear, Nose, Throat and Allied Sciences*, *12*, 155-16.

Hodgson ,W.R. (1994). Evaluating infants and young children. In: Katz J, ed. *Handbook of Clinical Audiology.* 4th edition. Baltimore: Williams and Wilkins, 465–475.

Humes, L. E., Halling, D., & Coughlin, M. (1996). Reliability and stability of various hearing aid outcome measures in a group of elderly hearing aid wearers. *Journal of Speech and Hearing Research*, *39*, 923–935.

Humes, L. E., Wilson, D. L., Barlow, N. N., Garner, C. B., & Amos, N. (2001). Longitudinal Changes in Hearing Aid Satisfaction and Usage in the Elderly over a Period of One or Two Years after Hearing Aid Delivery. *Ear and Hearing*, *23*(5), 428-438

Kolkaila, E. A., Emara, A. A., & Gabr, T. A. (2012). Cortical auditory evoked potentials in children using hearing aids. *Audiological Medicine*, *10*, 132-142.

Korczak, P. A., Kurtzberg, D., & Stapells, D. R. (2005). Effects of sensorineural hearing loss and personal hearing AIDS on cortical event-related potential and behavioural measures of speech-sound processing. *Ear and Hearing*, *26*(2), 165-185.

Kraus, N., & Mc Gee, T. J. (1994). Mismatch negativity in assessment of central auditory function. *American Journal of Audiology, 3*, 39-51.

Kraus, N., & Mc Gee, T. J. (1994). Mismatch negativity in assessment of central auditory function. *American Journal of Audiology, 3*, 39-51.

Kumar , S., Rout , N., Kumar , N., Chatterjee , I., & Selvakumaran , H. (2013). Performance of Indian Children with Cochlear Implant on PEACH Scale. *ISRN Otolaryngology*, *2013*, 1-6.

Kurtzberg, D. (1989). Cortical event-related potential assessment of auditory system function. *Seminars in Hearing, 10*, 252 – 262.

Lee, W.L. & Humes, E.L. (1993) Evaluating a speech reception threshold model for hearing impaired. *Journal of the Acoustical Society of America,* 93(5), 2879-2885.

Manjula, P. (2008). *Hearing Aid Selection Using Speech Intelligibility Index*. An unpublished doctoral thesis submitted to the University of Mysore.

Manjula, P., Kumar, K. S., Geetha, C., & Anthony, J. (2013). *Development of Phonemically Balanced word list in Kannada for Adults.* ARF 2013, Department of Audiology, All India Institute of Speech and Hearing, Mysore.

Martin, B. A., & Boothroyd, A. (1999). Cortical, Auditory, Event-Related Potentials in Response to Periodic and A periodic Stimulus with the Same Spectral Envelope. *Ear and Hearing*, *20,* 33-44.

Marynewich, S., Jenstad, M. L., & Stapells, D. R. (2012). Slow Cortical Potentials and Amplification? Part I: N1-P2 Measures. *International Journal of Otolaryngology, 2012,* 1-11.

Mendel, L. L. (2007). Objective and Subjective Hearing Aid Assessment Outcomes. *American Journal of Audiology, 16*, 118-129.

Mueller, G. (1997). Outcome measures: The truth about your hearing and fitting. *Hearing Journal* , 50, 21-32.

Nash, A., Sharma, A., Martin, K. A. Clinical Application of the P1 Cortical Auditory Evoked Potential (CAEP) Biomarker- Chapter 3: A Sound Foundation through Early Amplification.

Newman, C., Weinstein, B., Jacobson, G., & Hug, G. (1991). Test-retest reliability of the Hearing Handicap Inventory for Adults. *Ear and Hearing, 12,* 355-357

Oates, P.A., Kurtzberg.D, & Stapells, D.R. (2002). Effects of sensorineural hearing loss on cortical event-related Potential and behavioural measures of speech-sound processing. *Ear and Hearing,* 23, 399–415.

Picton, T., Dimitrijevic, A., John, M.S. (2002). Multiple auditory steady-state responses. *Ann Otol Rhinol Laryngol Suppl* 189, 16–21.

Potential indices of auditory vowel processing in 3-year-old children. Clinical Neurophysiology. 114, 652–661.

Purdy, S. C., & Kelly, A. S. (2001). Cortical auditory evoked potential testing in infants and young children. *The New Zealand Audiological Society*, *11*(3), 16-24.

Rance, G., Cone, B., Wunderlich, J. & Dowell, R. (2002). Speech perception and cortical event related potentials in children with auditory neuropathy. *Ear and Hearing, 23,* 239 – 253.

Rapin, I., & Graziani L, J. (1967). Auditory-evoked responses in normal, brain damaged, and deaf infants. *Neurology, 17*, 881 – 894.

Ross, B., Lutkenhoner B., Pantev, C., & Hoke, M. (1999). Frequency- specific threshold determination with the Ceragram method: basic principle and retrospective evaluation of data. *Audiology and Neuro-Otology*, *4*, 12–27

Seewald, R., & Scollie, S. (2003). An approach for ensuring accuracy in paediatric hearing instrument fitting. *Trends in amplification*, *7*, 29-40.

Sharma, A., Martin, K., Roland, P., Bauer, P., Sweeney, M. H., Gilley, P., & Dorman, M. (2005). P1 Latency as a Biomarker for Central Auditory Development in Children with Hearing Impairment. *Journal of American Academy of Audiology*, *16*, 564-573.

Sirimanna, K.S. (2001). Management of the hearing impaired infant. *Seminars in Neonatology*, 6, 511–519.

Snik, FM., AD., Neijenhuis. N & Hoekstra. (2001)Auditory performance of young children with hearing aids: Nijmegan Experience. *Scandinavian Audiology*, 30(53), 61-67

Stapells, D. (2009). Cortical event-related potentials to auditory stimuli. In: Katz, J. Handbook of clinical audiology. pp. 395- 430, Lippincott Williams.

Stapells, D.R. & Kurtzberg,D. (1991).Evoked potential assessment of auditory system integrity in infants. *Clinical Perinatology*, 18,497–518.

Stelmachowicz, P.G. (1999). Hearing aid outcome measures or children. *Journal of American Academy of Audiology* 10:14–25.

Tannahill, J.C. (1979). The hearing handicap scale as a measure of Hearing aid benefit. *Journal of Speech and Hearing Disorders*, *44*(1), 91-99

Thabet, M. T., & Said, N. M. (2012). Cortical auditory evoked potential (P1): A potential objective indicator for auditory rehabilitation outcome. *International Journal of Pediatric Otorhinolaryngology*, *76*, 1712-1718.

Vanaja, C.S, (2000). Self assessment of hearing handicap: A few audiological and non-audiological correlates. Thesis 31, AIISH, Mysore.

Vandana, D., & Yathiraj, A. (1998). Phonemically balanced wordlist in Kannada. Developed at the Department of Audiology, All India Institute of Speech and Hearing, Mysore.

Walden, B., Demorest. M., & Helper, E. L. (1984). Self-report approach to assessing benefit derived from amplification. *Journal of Speech and Hearing Research, 27*, 49-56.

Watson, L. & Tolan, T. (1949). *Hearing Tests and Hearing Instruments*. Baltimore: Williams & Wilkins.

Weinstein, B. (1997). Outcome measures in the hearing aid fitting selection process. *Trends in Amplification*, *2*, 117–137.

Wong, L. N., Cheung, C., & Wong, E. M. (2008). Comparison of hearing thresholds obtained using pure-tone behavioural audiometry, the Cantonese Hearing in Noise Test (CHINT) and cortical evoked response audiometry. *Acta Oto-Laryngologica*, *128*, 654-660.

Wunderlich, J. L. & Wesson, B. K. (2006). Maturation of CAEP in infants and children: A review. *Hearing Research*, *212*, 212-223.

Yathiraj, A. & Vijayalakshmi, C. S. (2005). Phonemically balanced wordlist in Kannada. Developed at the department of Audiology, All India Institute of Speech and Hearing, Mysore.