# SPEECH EVOKED AIDED CORTICAL POTENTIALS IN ADULTS USING HEARING AIDS

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**16AUD018**

**A Masters Dissertation Submitted as a part of fulfillment For Final Year**

**Master of Science**

**(Audiology)**

**University of Mysore, Mysuru**

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**May 2018**

## CERTIFICATE

This is to certify that this dissertation entitled **“Speech Evoked Aided Cortical Potentials in Adults Using Hearing Aids”** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No: **16AUD018**. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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# CERTIFICATE

This is to certify that this dissertation entitled **"Speech Evoked Aided Cortical Potentials in Adults Using Hearing Aids"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other University for the award of any other Diploma or Degree.


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## DECLARATION

This is to certify that this Master's dissertation entitled **"Speech Evoked Aided Cortical Potentials in Adults Using Hearing Aids"** is the result of my own study under the guidance of Dr. Prawin Kumar, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier in other University for the award of any Diploma or Degree.

Mysuru,
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*गुरुर्ब्रह्मा गुरुर्विष्णु गुरुर्देवो महेश्वरः ।*

*गुरु साक्षात परब्रह्मा तस्मै श्री गुरवे नमः ॥*

Dedicated to My
Mom, My Dad,
My Sister and
My Guide

Acknowledgments

I thank God Almighty for being with me all the time and showering his blessings. “Without the inspiration, drive, and support that you have given me, I might not be the person I am today.” Heartful thanks to my beloved Mummy and Papa. Thank you for your love, trust &constant motivation. It’s my fortune that I am blessed with the best parents in the world ........Love you lots.

I express my deepest gratitude and heartfelt thanks to my guide Dr. Prawin Kumar for believing in me with a provision of such a nice platform for research. Thank you so much, sir for all your inspiration, encouragement, guidance, comments, patient listening and untiring efforts in steering me through every phase of learning.

I would like to thank my mentor Deepa Valame, even though I lagged too much in obliging your efforts, I am dedicating this study to you... you were the first person to introduce word "research" in my life but I never got time to discuss my topic with you.:(.

I would like to thank director Dr.S.R. Savithri for giving me an opportunity to take up this project. I would also like to thank Dr.Sandeep M & Dr.Sujeet Kumar Sinha HODs of Audiology for allowing me to use resources of the department.

I thank full to all teachers who came in my life: Asha madam, Geetha madam, Chandni madam, Ajith Sir, Ganapathy Sir, Niraj Sir and Apeksha ma’am.

To go in higher place in life there will be some base for anything and everything happened in career life today all because of my NAIR Family. I would thank my HOD of NAIR Ms. Gayathri Ma’am thank you for all your help and support what you gave me until today. Still, I remember the first day of my BSc I would take this opportunity to thank all my staff members of “NAIR” Chandrahas

Sir, Mohite Ma'am, Pagare ma'am, Gayatri ma'am, Keer Ma'am, Sharma Ma'am, Parab Sir, Nana Mama, Bhalerao mama, Darole sir.
My persona is your gift. I am blessed enough to have you. Thanks to almighty for giving me life and wonderful parents and friends.

RAGHAV (Lalo), ADITI & NAINA thanks for being great pillars of my strength and my reason to look back towards AIISH. I learned a lot from you guys.

I would like to remember my cool pals – Mangal (Pandey & Co.), Ehte, Chandan K, Anup, Viswaraj, Udhay, Shiyam, Harish, Nepoleansir, Sujan, Rajesh, Kabali(vinayagar), Rajasuman, Chandan(Anntamma), Nikhil ba, Sam, Adithya, Shruthi, Shezin, Akriti (Chai partner),Varsha A, Rucha, who were always there for me whenever I had wanted the most. Thanks, you all.

I would also like to take this opportunity to thank my support system (friends) who aren't here but will be always there for me – Dr.Suraj (Godya), Dr. Dinesh, Dr. Prasad, Dr. Madhukar (Maddy), Dr.Anand(Radkamanus),Aditya(Aacho),Chaitanya(Chintu), Dr.Sandesh(PMS),Dr.Paritosh,Dr.Nikita,Dr.Preeti,Dr.Neha(Singham), Dr. Madhumita, Dr.Shalini, Dr. Sanket, Dr.Abhinav.

I am thankful to Sustainers, Decibels, Firebolt for making my journey memorable.
Special Thanks to Vikas sir, Rama Devi ma'am, Sanket,kriti, Manasa, for helping me in data collection.
At last, I want to thank all the participants those who had participated in my study. Without you, I would have never completed my dissertation. I am thankful to each and every one that I may have forgotten, unknowingly I apologize. Thank you from the bottom of my heart.

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# INTRODUCTION

Hearing is one of the five senses which helps an individual to understand his surroundings. Though hearing is an overlaid function over maintaining equilibrium and balance, its impairment poses certain difficulties in an individual's life. It hampers an individual's ability to communicate and results in challenges in various social situations thereby affecting his quality of life. An Identifying one's hearing problem at the very outset can help in remediating them much before the psychosocial symptoms set in. There have been various methods in order to identify an individual's hearing impairment. The most widely used pure tone audiometry (PTA) evaluation tells us about an individual's hearing ability at the peripheral level. PTA is a subjective test and requires patient cooperation and gives information about the functioning of the peripheral auditory system only. Obtaining hearing thresholds through objective measures such as auditory brainstem responses (ABR) allow Audiologists to decide on the candidacy of hearing aids in children and adults in many of the difficult situations (Byrne, Dillon, Ching, Katsch, & Keidser, 2001; Seewald & Scollie, 2003) and also elucidate the functioning of the central auditory system up to the level of the brainstem. Unfortunately, a reliable estimation of aided thresholds and thereby the appropriate adjustments of the hearing aid gain still poses a challenge while estimating the benefits from hearing aid in children and difficult to test population. There is a necessity of reliable measures, to evaluate the efficacy of hearing aid fitting for its maximum benefit.

To establish the efficacy of hearing aid fitting is a challenging process for an Audiologist, particularly while evaluating the behavioral measures with hearing aids in difficult to test population (Snik, Neijenhuis, & Hoekstra, 2001). The most common approaches for evaluating the efficacy of the hearing aids are through the behavioral evaluation, which is highly dependent on the response of the client (Hodgson, 1994) and electrophysiological measures. Recently, there is much interest in the measurement and quantification of hearing aid outcomes (Humes, Halling, & Coughlin, 1996; Snik, Neijenhuis, & Hoekstra, 2001; Golding et al 2007; Apeksha 2010). In general, 'outcome' refers to the measurable effect, either real or perceived, of the hearing on the individuals hearing disability or hearing handicap (Weinstein, 1997).

The cortical auditory evoked potentials (CAEPs) have been regarded as the most suitable measure to assess the audibility of hearing aid-amplified speech objectively. 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, Peggy; Kurtzberg, Diane; Stapells, 2005). Recording the aided cortical potentials shows the evidence of detection of speech at the level of the cortical structures in the auditory system in an aided condition. Subjective measures of performance, on the other hand, rely entirely on the adult's judgment or opinion and have no external reference for evaluation.

The recordings of the auditory brainstem responses and auditory steady-state responses using the frequency modulation can provide valuable information for the prescription of the hearing aids (Stapells & Kurtzberg, 1991). The cortical auditory evoked potentials which have generators at a higher level in the auditory pathway than ABR 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

(Van Maanen & Stapells, 2009). This has been shown to be related to speech perception scores and functional measures of hearing ability (Korczak, Kurtzberg, & Stapells, 2005; Golding et al., 2007).

Hearing aid fitting in the children and the adults requires reliable measures to reflect the benefit obtained by the hearing aid. These measures typically should provide information about the extent of benefit with the hearing aids. There are two ways in which hearing aid validation techniques can evaluate the outcomes of 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 performance (Cox, 2003).

It is essential that the Audiologist demonstrates the outcome to the client, either subjective or objective measures. Humes, Wilson, Lauren, Barlow, and Amos in the year 2002 have evaluated the longitudinal changes in the hearing aid satisfaction and the usage in the elderly over a period of one or two years after the 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, 2016). Therefore, in the current study, it is intended to study the relationship between behavioral measure and cortical auditory evoked potentials in adults using hearing aids, which are generally the two ways in which hearing aid validation techniques evaluate the outcomes from the hearing aid fitting process. The literature relevant to the present study has been provided under the following headings.

## Behavioral measures

There are also studies that reveal the utility of subjective and objective tool for the evaluation of the hearing aids, a sensitivity of the speech recognition tasks and whether it can serve as a more valuable tool for demonstrating the benefit. Speech perception in noise (SPIN), hearing in noise test (HINT), and quick speech in noise (Quick SIN) and subjectively the hearing aid performance inventory was used for the evaluation and concluded that these subjective tests are more sensitive in evaluating the speech perception abilities and better the subjective questionnaire performance would results in the better subjective scores in the individuals using hearing aids. Objective documentation of subjective impressions is essential for determining the efficacy of hearing aid fitting. The behavioral audiological tests include measures such as unaided and aided sound field warble tone evaluation, speech audiometry, subjective questionnaires or functional outcomes. The study by Flynn, Dowell and, Clark in the year 1998 reported the aided speech recognition abilities in the individuals with a severe-to-profound hearing loss. The findings revealed that there is a significant decrease in the performance in the presence of the background noise.

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. Some common questionnaires that assess hearing handicap include the Hearing Handicap Inventory (HHI) for Adults (Newman, Jacobson, Hug, & Malinoff, 1991), the Self-Assessment of Communication (SAC) for adults (Symons, Swanson, McGuigan, Orrange, & Elie, 2009), the Hearing Handicap Inventory for the Elderly (HHIE) for adults, the Hearing Performance Inventory (Giolas, Owens, & Lamb, 1979), Abbreviated Profile of Hearing Aid Benefit (APHAB, Cox et al., 1995), and the Client Oriented Scale of Improvement (COSI) by (Dillon, James, & Ginis, 1997).

The use of hearing handicap scale as a measure of hearing aid benefit was investigated by Tannahill (1979) in new hearing aid users with bilateral sensorineural hearing losses up to 55 dB HL. Changes in speech reception threshold, word identification, and hearing handicap scale were derived by comparing data obtained prior to hearing aid use with that obtained following four weeks of hearing aid use. Results showed a significant improvement for all three measurements and indicated that improvement in word identification presented at conversational level was more related to self-reported hearing aid benefit than was an improvement in speech reception threshold. Also, word identification ratings obtained with the stimuli presented at conversation speech level produced a significant correlation with hearing handicap scale. Another similar study by 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 years 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) and concluded that there was a significant improvement and satisfaction changes noted as the duration of the hearing aid use increased.

## Electrophysiological measures

The objective evaluation does not require the individual to actively participate in the testing and includes measures such as auditory evoked potentials. 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 aid fitting. The electrophysiological tests can be used as the hearing aid verification tools in the population where the behavioral test is not very reliable or feasible.

**Auditory brainstem responses (ABR)**

The ABR can be considered as the tool for estimating the thresholds in aided as well as unaided conditions. A Study done 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 Brown et al (1995) that electrical energy from the hearing aid as well as the transducer creates the interference with the recordings which would lead to the contamination of the waveform. Since ABR gives information more on the thresholds rather than the speech perception abilities, there are limitations on ABR to be used as the tool for the hearing aids evaluation.

**Auditory steady-state response (ASSR)**

A Study was done by Picton, Hunt, Mowrey, Rodriguez, and Maru in the year 1988 evaluated the utility of ASSR in assessing the benefit with hearing aids and they reported that the ASSR response was 13 dB to 17 dB higher than the behavioral 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. In a similar line, Damarla and Manjula in year 2005 compared the relationship between the real-ear insertion gain (REIG) and ASSR gain (unaided ASSR threshold versus aided ASSR threshold) on 30 subjects with mild to moderately severe sensorineural hearing loss in the age range of 15 years to 50 years (mean age 32 years). Based on the degree, configuration, and type of hearing loss, two digital BTE hearing aids were preselected. For each subject insertion gain and ASSR, gain was measured at 500 Hz, 1 kHz, 2 kHz and 4 kHz. The hearing aid that best matched with the target curve during insertion gain measurement was selected for the ASSR measurement. They reported ASSR gain and REIG were highly correlated among these individuals. Hence, they concluded that ASSR technique shows great promise in hearing aid fitting for those who cannot reliably respond to behavioral testing.

**Middle Latency response (MLR)**

There are few studies which have investigated the evaluation of hearing aids through the middle latency response (Jerger, Henry & Chmiel, 1993; Korczak, Kurtzberg, Stapells, & David, 2005). Firszt, Chambers, and Kraus in year 2002 evaluated the speech perception abilities and the middle latency responses (MLR) in quiet and noise conditions, for words and sentences. It was found that those with better amplitude and lower thresholds on MLR had better speech perception in both quiet and noise situation. However, there is a high possibility of the occurrence of the postauricular muscle artifact while recording MLR.

**Mismatch negativity (MMN)**

The cortical evoked potentials such as mismatch negativity or P300 are evoked by a change from a frequent "standard" stimulus to an infrequent "deviant" stimulus. Oates, Peggy, Kurtzberg, Diane and Stapells in year 2002 investigated MMN and P300 discriminative evoked potentials in response to /ba/ and/da/ speech stimuli in adults with mild to severe or profound hearing loss, who were using hearing aids, sensorineural hearing loss led to amplitude and latency changes for the earlier (N1, MMN) cortical responses. However, the MMN is smaller in amplitude, generally < 2 microvolts, 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 with normal hearing sensitivity or those with varying degrees of sensorineural hearing loss. It is less reliably elicited in children compared to adults (Jenstad, Marynewich, & Stapells, 2012).

**Cortical auditory evoked potentials (CAEP)**

The auditory 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 is having three major components which 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 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, lesser number of stimulus presentations are needed for a response to be generated (Purdy, Katsch, Storey, Dillon, & Agung, 2006) . 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 behavioral 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, McMahon, & Newall, 2006).

The cortical potentials are used as one of the important tools in the evaluation of the 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 CAEP as the biomarker of the development of the auditory system, which assesses the response components such as P1 and Nl which 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 behavioral 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 et al., 2007).

The cortical auditory evoked potentials are used as the tool for the validation of the hearing aids was reported by (Hassaan, 2011). A Study was done by Kolkaila, Emara and Gabr in the year 2012 reported the use of aided LLR in children 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

LLR 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 Jenstad 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 is 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 behavioral measures of the speech sound processing (Korczak et al., 2005). They investigated the effect of the severe to profound sensorineural hearing loss and prescribed hearing aids using discrimination tasks. Thus, the use of personal hearing aids can improve the detectability 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, McGee, Littman, Nicol, & King, 1994). The subject who had good discrimination behaviorally for /ta/ and /da/ showed the presence of MMN and P300, but the subject with poorer discrimination revealed an absence of MMN and P300. From this, it can be inferred that there is a positive relationship between the behavioral and the cortical responses.

The cortical potentials such as LLR has advantages (Agung et al., 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. A Study done by Apeksha and Devi (2010) studied ALLR differed for different speech stimuli sounds (/ba/, /da/, & /ga/) in 12 normal hearing individuals (20-50 years) and 25 hearing impaired individuals with moderate to severe degree of hearing loss. There was a significant difference for ALLR between normal and hearing-impaired groups, high significance difference for /ba/ and /da/ than for /ga/. They concluded that in spite of individuals wearing hearing aid according to the degree of hearing loss, the responses obtained were different from that of normal hearing, the hearing aid helps to compensate for hearing loss by amplifying sound but effectiveness depends on the central auditory system ability to integrate the spectral and temporal information by hearing aid.

**Need for the study**

There are many behavioral measures which are used for the evaluation of the hearing aids but the effectiveness of all the tests is not similar. The behavioral tests used for evaluating the performance of the hearing aids are similar to those used for evaluating the hearing sensitivity. They are aided thresholds, speech identification scores and, subjective questionnaires.

Assessment of aided speech skills could be a difficult task in certain adults. Accordingly, there is a dearth of objective tests such as the aided auditory evoked potentials to effectively establish the efficacy and performance of the hearing aids. There are many objective tests currently available but all tests have 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 of behavioral and cortical auditory evoked potentials, more evidence is required to generalize the findings (Rance, Cone-Wesson, Wunderlich, & Dowell, 2002; Korczak, Kurtzberg, & Stapells, 2005; Shruthi, 2007; Wong et al. 2008; Apeksha, 2010; Hassaan, 2011; Deepika, 2014). There are studies correlating outcomes of hearing aid using behavioral measures and cortical auditory evoked potentials in children. However, there is an uncertainty in the literature on the relationship between the behavioral measures, subjective outcomes and the CAEPs in adults. In literature, it's found that there is no relationship between behavioral and CAEPs finding. Hence, the present study intends to use different behavioral measures (SIS, SAHH Questionnaire) and their relationship with cortical auditory evoked potentials in adults who use hearing aids. This can also serve as an evidence to show benefit from hearing aid and used to validate patient's subjective response.

**Aim and objectives of the study**

The aim of the present study is to evaluate hearing aid fitting in adults using speech evoked cortical auditory evoked potentials and to examine the relationship between unaided and aided cortical auditory evoked potentials. The specific objectives of the study are -

1. To study the behavioral measures i.e. speech identification scores (SIS), Subjective questionnaires **(**Self-assessment of Hearing Handicap (SAHH)) for evaluating the outcome of hearing aid, in adults.

2. To study the objective measure (Aided cortical potentials latency and amplitude) for evaluating the outcome of hearing aid, in adults.
3. To compare the behavioral and objective outcomes of the hearing aids, in adults.

**Null Hypotheses**

1. No effect of subjective measures (SIS, SAHH questionnaires) in adults with hearing aid users.
2. No effect of objective measures (aided CAEP) in adults with hearing aid users.
3. There is no significant relationship between the behavioral outcome and cortical auditory evoked potentials in the individuals using hearing aids.

# METHOD

The present study was aimed to investigate the relationship between behavioral measure and cortical auditory evoked potential (CAEP) in an individual with hearing impairment using hearing aids. To achieve the above aim, the below mentioned method was adapted.

## Participants

There were 15 individuals with moderate-to-moderately severe sensorineural hearing impairment in the age range of 50 to 70 years (mean age 58.92 years) considered for the study. All the participants were a native speaker of Kannada. All the participants were naive hearing aid users. Written/Oral Consent was obtained from all the participants prior to data collection after explaining the procedure.

## Inclusion and exclusion criteria

The participants in this study were diagnosed to have moderate-to-moderately severe sensorineural hearing loss based on pure tone audiometry with 'A'/'As' type Tympanogram in the test ear. Their aided open set speech identification scores (SIS) was not less than 50% in quiet. They had a post-lingual acquired hearing impairment with adequate speech and language ability. Individuals having middle ear infections, neurological disorders and cognitive deficit were excluded from the study based on structured case history.

## Test environment

The entire audiological tests were conducted in an air-conditioned sound treated single/double room, with noise levels within the permissible limits (ANSI S3.1-1991).

## Equipment & tools

A dual channel calibrated audiometer (GSI 61) with sound field facility was used for the study with the loudspeaker positioned at 45°Azimuth and at a distance of one meter from the participant. This arrangement facilitated to establish the speech identification score in unaided and aided condition. A calibrated immittance meter (GSI Tympstar version 2) was used to assess the middle ear function. HEAR Lab aided cortical assessment (ACA) was used to record the CAEP, the loudspeaker was calibrated and a participant is made to sit at one meter away from the loudspeaker. Self-assessment of hearing handicap (SAHH) developed by Vanaja in 2000 was used to identify the performance of hearing aids in different situations (Quiet & noise) among hearing aid users. OAEs and ABR are not done on this individuals.

## Procedure

The preliminary procedure was initiated with a detailed audiological evaluation. The pure tone audiometric thresholds were obtained using modified Hughson-Westlake procedure (Carhart & Jerger, 1959). Air-conduction (AC) thresholds at octaves between 250 Hz to 8000 Hz and bone-conduction (BC) thresholds for octaves between 250 Hz to 4000 Hz were established for each ear. This was done using a calibrated clinical audiometer, TDH-39 headphone encased in MX-41AR ear cushion for air conduction thresholds and Radio Ear B-71 bone vibrator for bone conduction threshold. Speech audiometry was done to obtain the speech recognition threshold (SRT), speech identification scores and uncomfortable level (UCL) for speech.

Tympanometry was carried out, by making the participants sit comfortably on a chair and not to move until the test was completed. Immittance testing was administered with a probe tone frequency of 226 Hz. Ipsilateral and contralateral acoustic reflex thresholds were obtained at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz to ensure normal middle ear functioning in each ear.

Self-assessment of hearing handicap, a questionnaire based scale which consists of 15 questions were used to identify the performance of hearing aid users. There were 8 questions which focused 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, and watching televisions. The remaining 7 questions were targeted to assess listening to the radio, conversing in the shop, co-passenger, and talking to a family member without visual cues. The scoring was done separately for quiet and noise conditions.

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 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 SAHH questionnaire. Phase III involved objective assessment by recording cortical auditory evoked potentials in hearing aid users.

**Phase I**: Hearing aid programming and optimization.

Optimization of the hearing aid was performed by using Ling's six sounds. The participants were made to sit at one meter away from the loudspeaker, with the loudspeaker positioned at 45° Azimuth. Their aided thresholds were within speech spectrum up to 4 kHz. This phase was proceeded by Phase II of the study.

**Phase II**: Behavioral measures

Phase II involved administration of questionnaire i.e. self-assessment of hearing handicap to measure the hearing aid benefit for hearing aid users, the aided and unaided speech identification scores in quiet were obtained. The participant was seated at one meter away from the calibrated loudspeaker at 45° Azimuth. For unaided and aided SIS in quiet, participants were presented with the PB-word list developed by Manjula, Geetha, Antony and Kumar in the year 2013. These words were presented through monitored live voice mode and the presentation level was 40 dBHL. The VU meter monitoring was done to ensure that it did not exceed the average deflection.

**Phase III:** Objective measure

The participants were recorded with both unaided and aided cortical auditory evoked potential. 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 active electrode at vertex position, a ground electrode at forehead and reference electrode at the mastoid position. It was ensured that the impedance was within 5 kΩ. The ongoing EEG activity was monitored to prevent the contamination of the response or high rejection. The protocol for measuring unaided and aided CAEP is given in the Table. 1

Table 1: The protocol used for recording unaided and aided CAEPs

| **Parameters** | **Settings** |
|---|---|
| Test type | Cortical auditory evoked potentials |
| Conditions | Unaided and Aided |
| Transducer | Loudspeaker |
| Position of the loudspeaker | 1-meter distance with the Azimuth of 0° |
| Electrode sites | Ground electrode: Forehead<br>Reference electrode: Left/Right mastoid (test ear).<br>Active electrode: Vertex position |
| No. of epochs | 200 |
| Intensity level | 60 dB SPL |
| Speech Stimuli used | /m/ (30ms), /g/ (20ms), and /t/ (30ms). |
| Filter settings | 0.16 Hz -30 Hz |
| Polarity | Alternating |

**Statistical analysis**

The data from different phases were tabulated and analyzed using Statistical Package for Social Science (SPSS version 20.0). Shapiro Wilks test was done to check for the normal distribution of the data, which shows data were not normally distributed ($p>0.05$). Hence, a non-parametric test was administered to fulfill the objective of the study. Descriptive statistics were done to obtain mean, and standard deviations (SD) for the different parameters of behavioral and CAEP measures. Wilcoxon Signed-rank test were used to find out the significant differences between the unaided and aided performance of the hearing aid users for both behavioral and objective measures. Further, to check the correlation between behavioral and CAEP parameters, Spearman's correlation analysis was done.

# RESULTS AND DISCUSSION

To meet the objective of the study, results are tabulated and analyzed under the heading behavioral and electrophysiological measures in both unaided and aided conditions. They were further statistically analyzed for the relationship between behavioral and electrophysiological measures in naïve hearing aid users.

**Behavioral measures**

Descriptive statistics of unaided and aided behavioral measures which includes mean, standard deviations (SD) and range of speech identification scores (SIS) in quiet mentioned below in Table 2. From the table 2, results show the mean of aided SIS scores is four times higher (better) than unaided conditions, which reflect the benefit with the first fit programme using pre-selected digital hearing aids among naïve hearing aid users. Further, Wilcoxon signed rank test revealed statistically significant differences ($Z = -3.41$, $p<0.05$) between unaided and aided conditions among naïve hearing aid users in quiet.

Table 2: Mean, standard deviation (SD) and range of SIS (%) in Quiet among hearing aid users

| **Conditions** | **Mean** | **SD** | **Minimum** | **Maximum** |
|---|---|---|---|---|
| Unaided SIS (%) | 21.07 | 18.422 | 0 | 52 |
| Aided SIS (%) | 80.27 | 8.614 | 64 | 96 |

The performance of the hearing aid users in quiet and noise conditions were also analyzed using self-assessment hearing handicapped (SAHH) questionnaires. There were 15 questions in 3-point rating scale related to quiet and noise conditions. The maximum possible score is 45 including both quiet and noise condition. The actual scores divided by total scores and multiplied by 100 helps in obtaining a percentage of performance in each condition. They obtained overall mean (SD) scores of 47% (8.7%), out of which 41% (10.3%) in quiet and 53.2% (8.3%) in noise condition.

**Electrophysiological measures**

Descriptive statistics of the unaided and aided speech evoked CAEPs include mean and standard deviations of latency of the different speech sounds i.e. /m/, /g/, and /t/ sounds at 60 dB SPL is mentioned in table 3. Based on Table 3, it is noted that overall the mean latency of P1, N1 and, N2 for /g/ sounds is lesser (better) compared to /m/ and /t/ sounds for both unaided and aided conditions. Figure 1, 2 and 3 shows graphical representation of mean and 95% confidence interval (CI) of P1, N1, and P2 latency for /m/, /g/, and /t/ speech sounds respectively.

Table 3: Mean and Standard deviations (SD) of CAEPs latency of naïve hearing aid users

| | | **Unaided condition** | | **Aided condition** | |
|---|---|---|---|---|---|
| Stimulus | Latency | Mean | SD | Mean | SD |
| /m/ | P1 | 67.06 | 19.88 | 56.46 | 7.66 |
| | N1 | 124.00 | 22.94 | 108.93 | 11.81 |
| | P2 | 213.80 | 25.16 | 185.40 | 25.39 |
| /g/ | P1 | 52.28 | 25.96 | 42.86 | 7.57 |
| | N1 | 96.40 | 26.97 | 91.40 | 13.56 |
| | P2 | 193.60 | 32.61 | 164.60 | 26.41 |
| /t/ | P1 | 62.33 | 32.56 | 44.00 | 8.26 |
| | N1 | 112.73 | 34.46 | 92.73 | 8.66 |
| | P2 | 205.26 | 37.47 | 166.86 | 14.63 |

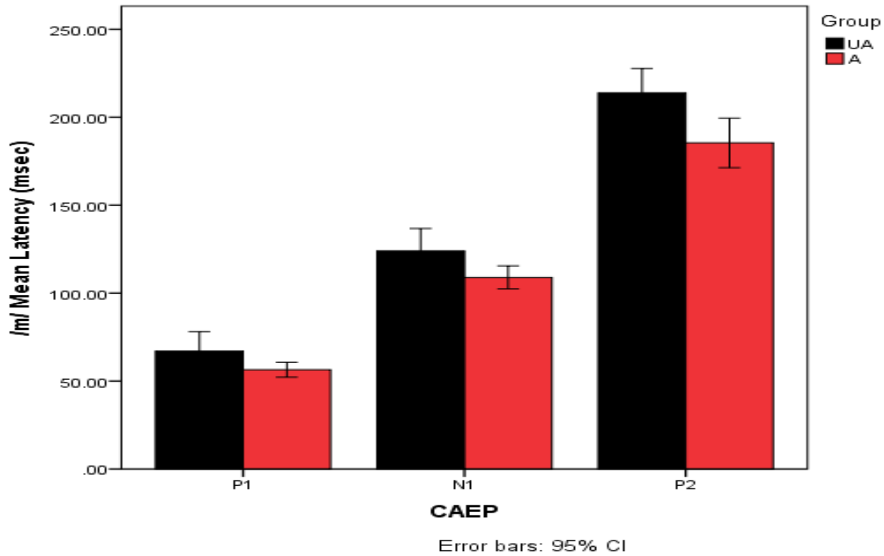


Figure 1: Mean and 95% Confidence interval (CI) of latency for P1, N1, and P2 for /m/ sounds *(UA: Unaided; A: Aided)*

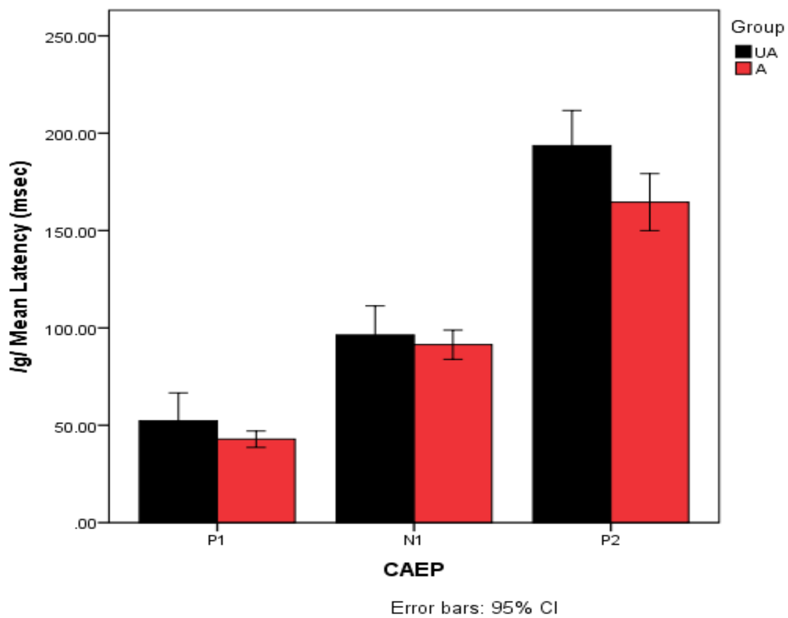


Figure 2: Mean and 95% Confidence interval (CI) of latency for P1, N1, and P2 for /g/ sounds *(UA: Unaided; A: Aided)*

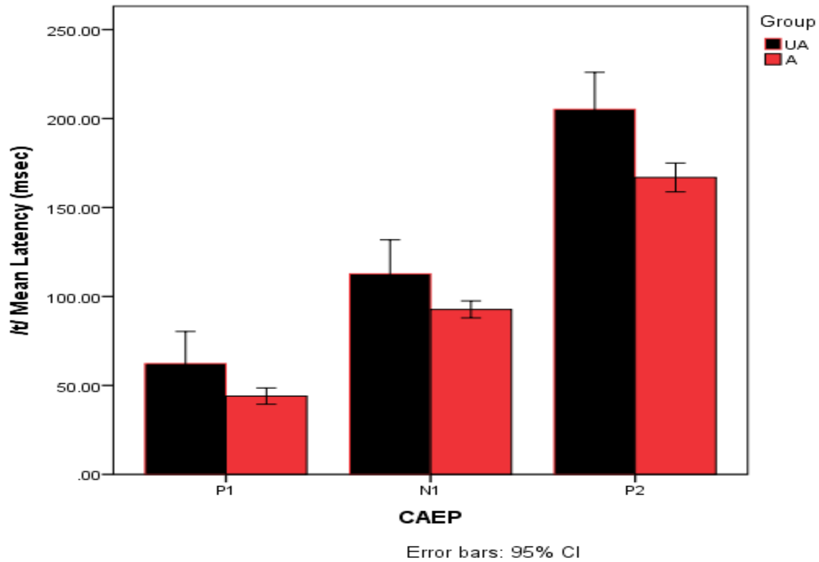


Figure 3: Mean and 95% Confidence interval (CI) of latency for P1, N1, and P2 for /t/ sounds *(UA: Unaided; A: Aided)*

Wilcoxon signed rank test revealed statistically significant difference between unaided and aided conditions for latency of P1 (Z = -2.74, $p<0.05$), N1 (Z = -2.64, $p<0.05$), and P2 (Z = -3.09, $p<0.05$) of /m/ speech sounds. Similarly, Wilcoxon signed rank test revealed statistically significant difference between unaided and aided conditions for latency of P1 (Z = -3.35, $p<0.05$), N1 (Z = -3.24, $p<0.05$), and P2 (Z = -3.23, $p<0.05$) of /t/ speech sounds. However, Wilcoxon signed rank test revealed statistically significant difference between unaided and aided conditions for latency of only P2 (Z = -2.74, $p<0.05$) of /g/ speech sounds. There were no statistically significant differences noticed between unaided and aided latency of P1 (Z = -1.76, $p>0.05$), and N1 (Z = -0.65, $p>0.05$) for /g/ sounds.

Descriptive statistics of the unaided and aided speech evoked CAEPs include mean and standard deviations of the peak-to-peak amplitude of the different speech sounds i.e. /m/,

/g/, and /t/ sounds at 60 dB SPL is mentioned in table 4. Based on Table 4, it is noted that overall the mean amplitude of P1-N1 for /m/ sounds is higher (better) compared to /g/ and /t/ sounds for both unaided and aided conditions. However, mean amplitude of N1-P2 for /g/ sounds is higher (better) compared to /m/ and /t/ sounds for both unaided and aided conditions. Figure 4, 5 and 6 shows a graphical representation of mean and 95% confidence interval (CI) of P1-N1 and N1-P2 amplitude for /m/, /g/, and /t/ speech sounds respective.

Table 4: Mean and Standard deviations (SD) of CAEPs amplitude of naïve hearing aid users

| | | **Unaided condition** | | **Aided condition** | |
|---|---|---|---|---|---|
| STIMULUS | Amplitude | Mean (µV) | SD | Mean (µV) | SD |
| /m/ | P1-N1 | -5.17 | 2.71 | -8.58 | 4.46 |
| | N1-P2 | 3.43 | 2.35 | 4.86 | 2.25 |
| /g/ | P1-N1 | -4.85 | 3.66 | -6.02 | 5.91 |
| | N1-P2 | 3.93 | 1.29 | 4.20 | 1.54 |
| /t/ | P1-N1 | -3.96 | 2.58 | -6.17 | 3.86 |
| | N1-P2 | 2.44 | 1.12 | 3.76 | 1.35 |

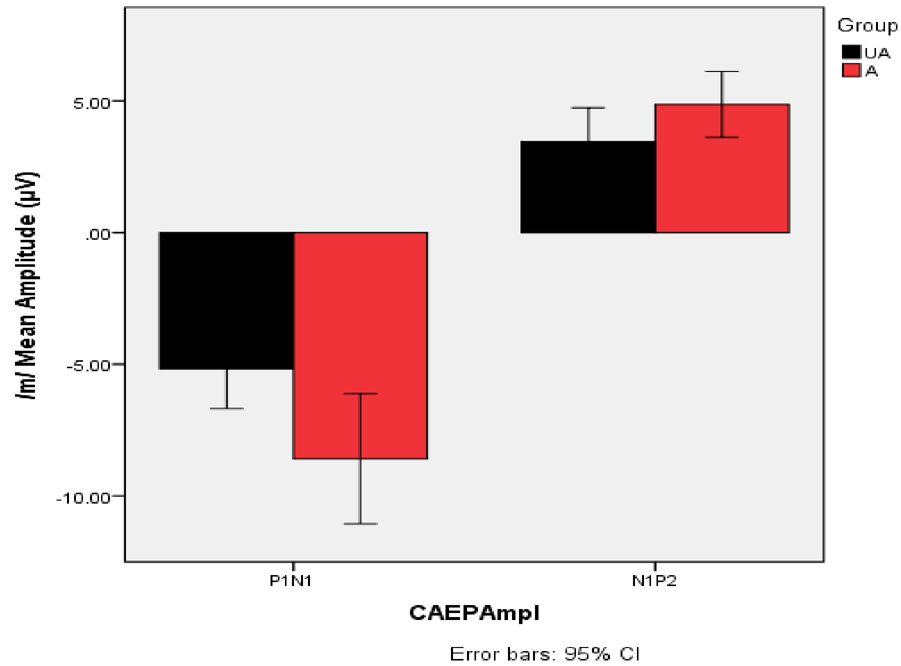


Figure 4: Mean and 95% Confidence interval (CI) of amplitude for P1-N1 and N1-P2 for /m/ sounds *(UA: Unaided; A: Aided)*

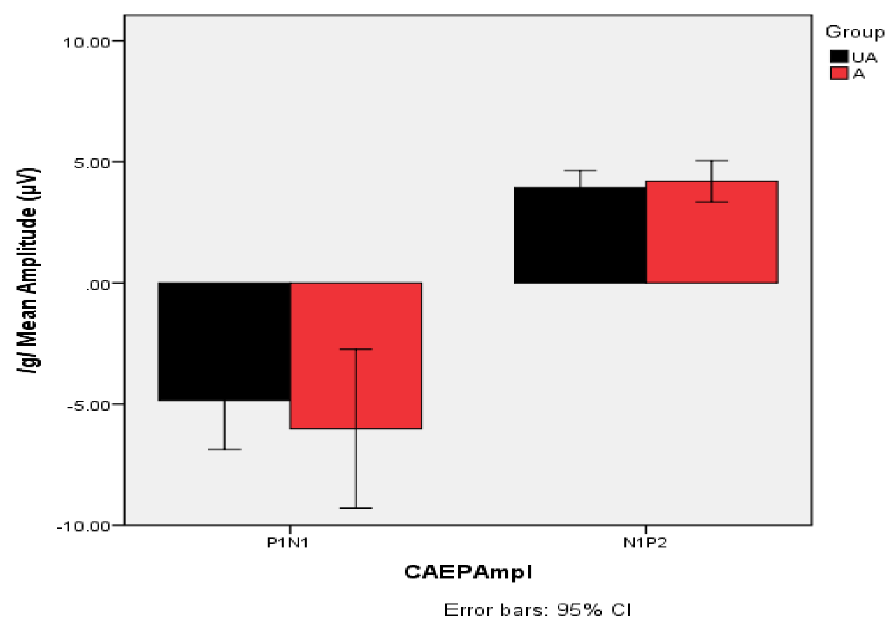


Figure 5: Mean and 95% Confidence interval (CI) of amplitude for P1-N1 and N1-P2 for /g/ sounds *(UA: Unaided; A: Aided)*

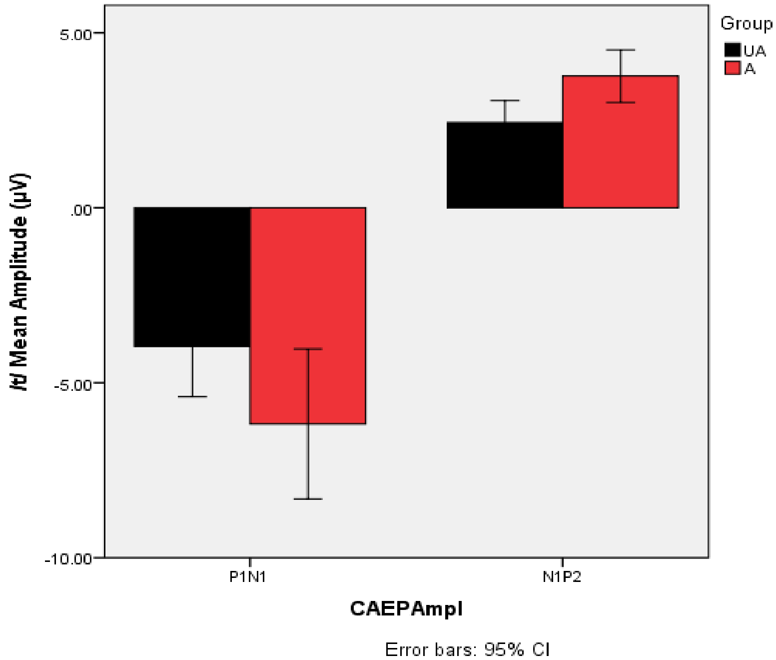


Figure 6: Mean and 95% Confidence interval (CI) of amplitude for P1-N1 and N1-P2 for /t/ sounds *(UA: Unaided; A: Aided)*

Wilcoxon signed rank test revealed statistically significant difference between unaided and aided conditions for peak-to-peak amplitude of P1-N1 for /m/ ($Z = -3.40$, $p<0.05$) and /t/ ($Z = -3.40$, $p<0.05$) sounds. Similarly, statistically significant differences noticed between unaided and aided conditions for peak-to-peak amplitude of N1-P2 for /m/ ($Z = -2.15$, $p<0.05$) and /t/ ($Z = -2.55$, $p<0.05$) sounds. However, Wilcoxon signed rank test did not show statistically significant differences between unaided and aided conditions for peak-to-peak amplitude of P1-N1 ($Z = -1.47$, $p>0.05$) and N1-P2 ($Z = -1.10$, $p>0.05$) of /g/ sounds.

**The Relationship between behavioral and electrophysiological measures**

The relationship between behavioral and electrophysiological measures was assessed using Spearman's correlation analysis. The results revealed that there was no correlation obtained in aided condition between behavioral measures (SIS, SAHH) with latency and amplitude of CAEPs. The above finding indicates probably both the measures are independent in assessing the functioning of hearing aid users.

This study depicts the correlation of the behavioral measures and electrophysiological measures. There is no correlation for most of the parameters. A Study done by Deepika (2012) is in consonance of the present study. They reported no main effect of group and its interaction between children and adults for the SAHH questionnaire. However, within-group comparison showed a significant difference between different conditions in the questionnaire (quiet, noise & overall). The latency (wave P1, & wave N1) and amplitude (P1-N1) of cortical evoked auditory potentials were significantly different between children and adults. However, no differences noticed within the group. Further, they did not report a correlation between behavioral and electrophysiological measures. However, study done by Wong et al. (2008) contradicting the above finding as they reported a correlation between the behavioral measures such as aided scores, speech recognition thresholds measured using Cantonese hearing in noise test and electrophysiological measures. This was studied in the different conditions i.e. quiet and noise. They concluded that the speech scores and CEAP are highly correlated with the behavioral audiometric thresholds.

Shruti and Vanaja (2007) studied cortical potentials using different speech stimuli (/i/, /m/, & /s/) in hearing aid users. Significant effect of speech stimuli was demonstrated, they observed shortest latency for /i/ sounds which is having more energy in mid-frequency and /s/ had the longest latency which is having more energy in high frequency and /m/ had the latency between /i/ and /s/ having more energy in low frequency. They reported the difference between unaided and aided condition. They observed differences in waveform morphology for different speech stimuli in terms of latency and amplitude measures in hearing aid users. However, the present study did not reflect significant difference across different speech sounds.

In order to support the present study, Hassan (2011) reported that the CAEP can be used as a tool for objectively assessing the hearing aid fitting. Behavioral measures such as aided pure tone thresholds, speech recognition in quiet and noise were estimated. They reported speech recognition in presence of noise lower (poorer) than in quiet. Difference between behavioral thresholds and electrophysiological ones were relatively small, especially at low-frequency tonal stimuli. When using tonal stimuli, the low-frequency tone had the more formed potential. The more enhanced response of /ga/ stimulus in comparison to /wa/ stimulus could be attributed also to the amount of sound energy. Despite the absence of correlation between the number of emerged waves and aided speech recognition scores in quiet, it was positively correlated with the speech recognition scores in noise. As speech recognition scores in noise reflected more challenge to the central auditory system, it would be correlated more with its efficiency. This added to the evidences of the positive relationship between the benefit from the hearing aids and the physiologic activity of the cortex. Their study revealed no correlation between the speech recognition in quiet and CAEP. However, their study found a positive relationship between the speech recognition abilities in noise and CAEP. The present findings also contradict that reported by Rance et al. (2002) because they estimated CAEP which 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 a study by Korezak et al. (2005), it was reported that the substantial use of hearing aids in the individuals can improve the detectability of the cortical potentials. They gave a possible explanation on presence or absence of CAEP findings showed the more accurate and effective information regarding behavioral speech measures and CAEP in experienced hearing aid users. Even though the majority of the hearing-impaired subjects showed increased amplitudes, decreased latencies, and better waveform morphology in the aided condition, the amount of response change (improvements) seen in these measures showed considerable variability across subjects. These results suggest that hearing-impaired individuals' brains process speech stimuli with greater accuracy and in a more effective manner when these individuals use their personal hearing aids. This is especially true at the lower stimulus intensity. The effects of sensorineural hearing loss and personal hearing aids on cortical ERPs and behavioral measures of discrimination are dependent on the degree of sensorineural loss, the intensity of the stimuli, and the level of cortical auditory processing that the response measure is assessing.

Apeksha (2010) studied ALLR differed for different speech stimuli sounds (/ba/, /da/, and /ga/) in moderate-to-severe hearing impaired individuals and compared with normal hearing individuals. They reported in aided condition, /ga/ stimuli showed shortest latency followed by /ba/ and /da/. There was a significant difference for ALLR between normal and hearing-impaired groups, high significance difference for /ba/ and /da/ than for /ga/. They concluded that in spite of individuals wearing hearing aid according to the degree of hearing loss, the responses obtained were different from that of normal hearing, the hearing aid helps to compensate for hearing loss by amplifying sound but effectiveness depends on the central auditory system ability to integrate the spectral and temporal information by hearing aid. These findings are in contrast with Dun et al, 2012 who found there was no significant difference in group average for latency and amplitude between different speech sounds (/m/, /g/, & /t/). However, Golding et al (2006) who reported that /t/ sound evoked CAEPs larger in amplitude and earlier in latency than the other two sounds.

# SUMMARY AND CONCLUSIONS

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

1. To study the behavioral measures such as SIS, subjective questionnaires, for measuring the outcome of hearing aid, in individuals with hearing impairment.
2. To study the aided CAEPs for evaluating the outcome of hearing aid, in individuals with hearing impairment.
3. To check the relationship between behavioral and CAEPs measures among individuals with hearing impairment with naïve hearing aids.

The data for the present study were collected from 15 individuals with hearing impairment. The criteria for inclusion were that the aided thresholds were within speech spectrum; SIS was not less than 50% in quiet, and the participants having a PTA of 55-70 dB HL. 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 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 SAHH questionnaire. Phase III involved objective assessment by recording cortical auditory evoked potentials in hearing aid users for /m/, /g/ and /t/ stimuli. Thus, the data on the behavioral measures and CAEPs measures were collected, tabulated and analyzed. The data from different phases were analyzed using Statistical Package for Social Science (SPSS version 20.0). Shapiro Wilks test was done to check for the normal distribution of the data, which shows data were not normally distributed (p>0.05). Hence, a non-paramteric test was administered to fulfill the objective of the study. Descriptive statistics were done to obtain mean, and standard deviations (SD) for the different parameters of behavioral and CAEP measures. Wilcoxon Signed-rank test was used to find out the significant differences between the unaided and aided the performance of the hearing aid users for both behavioral and objective measures. Further, to check the correlation between behavioral and CAEP parameters, Spearman's correlation analysis was done.

Behavioral measures which includes speech identification scores and SAHH questionnaire had greater (better) mean in aided condition compared to unaided condition. Electrophysiological measures includes unaided and aided CAEPs recording to obtain latency and amplitude using different speech stimuli. The HearLAB instrument was used for the recording unaided and aided CAEPs in adults. The speech stimulus /m/, /g/ and /t/ at 60 dB SPL were used for the recording. Descriptive statistics shows reduction (better) in the latency and increase in amplitude of /m/ & /t/ stimuli as compare to /g/ stimuli. Spearman’s correlation analyses revealed no relationship between behavioral and objective measures of the hearing aid in adults.

The present study was attempted for the comparison of behavioral and objective measures in an adult. The comparison was done using Wilcoxon Signed-rank test. It was found that there was no main effect and interaction effect among the variables. This indicates that the both behavioral and CAEPs measures two different areas.

## Implication of the Study

1. This study is one of the preliminary attempts made in the direction of finding out the relationship between the behavioral measures and cortical potentials in the hearing aid users. An attempt was made on correlating and comparing the behavioral and cortical potentials.
2. Present study helps in understanding the processing of speech stimuli at cortical levels based on CAEPs measures.
3. Add information to the literature.

## Future directions

1. The study was done only on the individuals having greater than or equal to moderate to moderately 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, severe, profound), in individuals who are naive hearing aid users.
2. To evaluate the relationship between behavioral and electrophysiological (CAEPs) in experienced and naive hearing aid users.
3. This study can be done individuals with a different configuration of the hearing loss.
4. The aided CAEPs 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 behavioral measures and CAEPs.

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