Estimation of Behavioral Threshold Using Click Evoked ALR in Normal and Hearing Impaired individuals.

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A Dissertation Submitted in Part Fulfillment of
Final year M.Sc (Audiology),
University of Mysore, Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING
NAIMISHAM CAMPUS, MANASAGANGOTHRI
MYSORE-570006

Dedicated to my
Dearest….

Achan, Amma

Sujeshettan,

&
Animesh Sir

CERTIFICATE

This is to certify that this dissertation entitled ***"Estimation of behavioural threshold using click evoked ALR in normal and hearing impaired population"*** is the bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student (Registration No.06AUD003). 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

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DECLARATION

This is to certify that this dissertation entitled ***"Estimation of behavioural threshold using click evoked ALR in normal and hearing impaired population"*** is the result of my own study under the guidance of Mr. Animesh Barman, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore,and has not been submitted in any other university for the award of any diploma or degree.

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INTRODUCTION

An Audiologist works with patients as part of a multidisciplinary team of professionals as to identify and assess hearing and balance disorders, recommending and providing appropriate rehabilitation and management. One of the main objectives of the audiologist in hearing assessment is to establish frequency specific threshold. It helps the audiologist to arrive at an appropriate diagnosis. This intern helps the audiologist to find out the site of lesion. Appropriate recommendation and individualized rehabilitation plan can be made based upon the diagnosis. Establishing frequency specific threshold has significant importance in the selection of amplification, especially when the prescriptive formulas are used for hearing aid fitting.

There are several methods to obtain frequency specific threshold in clinical audiology. Pure tone audiometry is the most common and easy method to obtain frequency specific threshold. It is most popular because of its reliability. However, often audiologists fail to obtain behavioral threshold may be due to the inability of the clients to give voluntary responses or they may not be willing to give voluntary responses. In such conditions, auditory evoked potentials are often used to predict the behavioral threshold.

Auditory long latency response is one such auditory evoked potential came in to the field since 1960s. However, it has failed to gain much popularity due to the explosion of interest in the auditory brainstem response (ABR). This could be because of its accuracy and reliability to predict the behavioral threshold. ALR has not gain the popularity as it is affected by several factors such as subject factors, acquisition factors and stimulus factors. Most encountered problem is the subject factors such as age, it has been reported that latency decreases and amplitude increases as a function of age (Tanguchi, Picton, Orpin & Goodman, 1969; Callaway, 1975). Gender effect on ALR has been rarely investigated. Investigators reported that no consistent gender effect for ALR N1, P2, and N2 components (Hall, 2007). Attention and state of arousal is one of the most important factors which affect ALR (Picton & Hillyard, 1974). The influence of sleep was recognized by some of the earlier investigators (Rapin, Schimmels & Cohen, 1972). The drugs and alcohol intake can also affect ALR recording (Wolpaw & Penry, 1978).

Apart from this other acquisition factors such as electrode placement, filter setting and analysis time can also affect ALR recording. Electrode placement may affect the ALR because of its site of generation (Cody, Jacobson, Walker & Bickford, 1964). It has been reported that prestimulus time of 100 ms has to be included while recording ALR so that the EEG rhythmic activity can be monitored as it affect the ALR recording adversely (Hall, 2007). Sayers, Beagley and Henshall (1974) reported that frequency composition or spectrum for ALR response is in the frequency region less than 30 Hz and typically filter setting of 1-30 Hz is employed in ALR recording (Hall, 2007).

The stimulus factors can also affect the ALR recording such as type of stimulus, frequency, intensity and duration of the stimulus, the rate and inter stimulus interval etc.

Ceponiene et al. (2001) reported that amplitude of ALR components vary as a function of nature of stimulus and they also reported that amplitude of N1-P2 is higher for speech stimuli compared to tonal stimuli. Sugg and Polich (1995) reported that the amplitude for the N1 and P2 components larger and latency is longer for low frequency signal compared to high frequency signal. Many of the investigators suggested that click is not a good stimulus for ALR recording (McCandles, 1967; Hall, 2007). ALR amplitude increases and latency decreases as the intensity increase, it saturate for moderate to high intensity level (Beagley & Knight, 1967). Longer duration stimulus is preferred for ALR recording (Onishi & Davis, 1968). It has been reported that the ALRs are highly dependant on inter stimulus interval (Davis, 1966; Budd, Barry, Gordon, Rennie, & Michie, 1998).

ALR can be used as an assessment tool and also a rehabilitation measure. ALR can be used in assessment of children with Autism (Heinrich, 1987), Down syndrome (Dustman & Callner, 1979), Reading Disorder (Kutes, Ken & Besson, 1988), Central auditory processing disorders (Jirsa & Clentz, 1990) and adults with Schizophrenia (Hink & Hillyard, 1978). ALR can also be used a method of threshold estimation in hearing impaired population. It can also serve as an indicator of rehabilitation benefit in hearing aid selection (Korzack, Krutzberg & Stapelles, 2005) and cochlear implant (Oviatt & Kileny, 1991).

Even though ABR is considered as better choice of auditory evoked potential, there are some short comings for ABR which makes it a lesser efficient tool in spite of the clinical popularity. ABR is such an evoked potential which require better synchronization of the nerves for recording. There are some of the patients for whom the neural synchrony may not be adequate for recording ABR especially during early developmental stage and individuals with auditory dys-synchrony (AD). It has been reported that ALR require lesser neural synchrony for recording (Kraus et. Al., 2000). So ALR may be present in some of the cases, where ABR might be abnormal or absent. In such group, ALR could be an objective tool to estimate the threshold.

Need for the study:

Hyde, Alberti, Matsumoto and Liyl (1992) reported that tone burst evoked ALR audiometry can be used specifically at approximating the pure tone audiogram for the population such as at-risk infants, difficult-to-test children, and adults with certain mental or physical handicaps. They found that ALR can be used to estimate behavioral threshold within 10 dB in at least 90% of cases and for those subjects, who are both awake and passively cooperative.

However, there are lesser number of studies which used click as stimulus for threshold estimation due to its lack of frequency specificity and short duration. However, use of long duration click could predict behavioral threshold within short period of time. Hence, click stimulus has been used as the stimulus in the present study.

The effect of hearing loss on ALR has been studied extensively by several authors. Polen (1984) studied the effect of hearing loss on ALR components and compared the findings with normal hearing group. He found that moderate to severe SN hearing loss resulted in prolongation of latencies of P2, N2 components of ALR. Decreased N2 amplitude in the sensorineural hearing loss group in comparison to normal hearing group was also reported. However, there are inconsistencies among studies of ALR in hearing impaired subjects reported (Oates, Kurtzberg & Stapells, 2002). Hence, present study considered the sensorineural hearing loss population also as target group to find out the relation between ALR threshold and behavioral threshold.

Cortical potential like ALR requires different neural synchrony compared to the synchrony required for relatively shorter latency response (Kraus et al., 2000). It is possible that ABR or MLR which requires high synchronization may be disrupted in some subjects, where as low neural synchrony required for ALR may be intact. This may result in the presence of ALR in subject with absent MLR and ABR.

Auditory dys-synchrony is one such disorder characterized by abnormal or absent ABR and presence of OAE and / CM indicating normal functioning of OHC (Starr et al., 1991; Berline, Morlet & Hood, 2003). Even though ABRs are absent or severely abnormal in auditory neuropathy, cortical potential (eg: N100) are often present and frequently delayed in latency (Kraus et al., 2000, Govil, 2001; Rance et al., 2002, and Starr et al., 2003). Thus, ALR recorded from auditory dys-synchrony clients could be an important tool to predict behavioral threshold.

Niraj (2007) found that ALR is an efficient tool to differentiate auditory dys-synchrony and auditory maturation delay and to identify permanent hearing loss. He also suggested that ALR can also be used in the estimation of behavioral threshold in such population. However, attempt was not made to correlate the behavioral threshold and the ALR threshold. Hence, ALR can be used to estimate behavioral threshold in infants, subjects with auditory dys-synchrony and those with inconsistent responses.

Speech intelligibility is another problem consistent with sensorineural hearing loss and auditory dys-synchrony. Most of the affected adults with auditory dys-synchrony report perceptual difficulties for greater than, would be expected from their behavioral audiogram (Zeng et al., 2001 & Starr et al., 2003). Speech perception ability cannot be reliably estimated from behavioral audiogram, ALR components may offer a means of predicting perceptual skills (Rance et al., 2002) in individuals with auditory dys-synchrony. Hence, present study also aimed at finding out the relationship between ALR threshold and Speech identification score in individuals with hearing loss.

***Aim of the study*:**

Therefore this study aimed at finding out:

- Relationship between ALR threshold and pure tone average in individuals with normal hearing, sensorineural hearing loss and auditory dys-synchrony.
- Relationship between ALR threshold and speech identification score (SIS) in individuals with sensorineural hearing loss and auditory dys-synchrony.

- Relationship between click evoked ALR threshold and frequency specific pure tone threshold (250 Hz to 4000 Hz) in individuals with sensorineural hearing loss and auditory dys-synchrony.

REVIEW OF LITERATURE

Although standard pure tone audiometry provide subjective assessment of the degree and configuration of hearing impairment, any exaggeration either intentionally or subconsciously, may preclude the accurate identification of true extent of the deficit. There are several objective measures available for threshold estimation; one of such test is auditory evoked potentials.

An auditory evoked response (AEP) is an activity within the auditory system that is generated or elicited by acoustic stimuli. The most dramatic growth in clinical use of AEP has occurred since 1970. As equipment has become more available, different health care professionals have incorporated AEP into the scope of their practice – clinical use of AEP has correspondingly expanded. Auditory long latency response is one of the auditory evoked potentials which emerged as a popular tool to identify the functional deficit of the auditory system. Auditory long latency potentials (ALR) are low voltage (microvolt) discrete electrical potentials occurring in the electro encephalogram (EEG) to a time-locked sensory stimulus. These potentials are characterized by components comprising the time domain of 50 to 500 ms (McPherson & Starr, 1993). The components of ALR are labeled according to their latency and polarity at vertex (Picton, Woods, Stuss, & Compbell, 1978). The first component in ALR is characterized by an initial positive peak which occurs between the latency 60-80 ms. It is labeled as P1or P60. It has amplitude of 7 microvolt and width of about 15 ms. The second peak is a negative peak which occurs between the latency 90-100 ms and it is labeled as N1or

N100. It has amplitude 10 microvolt and width of 40-50 ms. The third peak is a positive peak occurring at about 100-160 ms and it is labeled as P1 or P160. It has amplitude of about 6 microvolt and width of 40-50 ms. The fourth peak is a negative peak occurring at 180-200 ms. It is labeled as N2 or N200. It has amplitude of 6 microvolt and width of 70 ms (McPherson & Starr, 1993). The P1, N1 and P2 are predominantly exogenous potentials. N2 is not truly an exogenous, an exogenous potential is affected by intrinsic factors of the subject such as attention and sleep (Ritter, Simmon, & Vaughan, 1983).

Generators of ALR

The location of ALR sources have been studied since 1970s. New insights to the source location have occurred only after 1985 because of the advances in two areas such as dipole source analysis (Scherg & Von cramon, 1985) and cortical auditory evoked magnetic fields (Hari, 1990). Knight, Scabini, Woods and Clay worth (1988) studied patients with lesion of superior temporal gyrus and inferior parietal lobe. They found that P1 (P60) and N1 (N100) are generated by radially oriented neuronal dipole located in the superior temporal gyrus. Makela, Alku, May, Makinen & Titinen (2004) provided evidence that the source for N1 activity elicited by vowel activity is limited to the left auditory cortex. This is consistent with the specialization of left hemisphere for speech processing. Cerebral region outside of the temporal lobe probably play a major role in the generation of early and later components with in the N1 wave complex such as N1b and N1c. There might also have influenced from the subcortical structures, including the thalamus, hippocampus, and reticular activating system (Naatanen & Picton, 1987). Magneto encephalographic studies have shown that the P2 wave receives contribution from multiple anatomical sources (Perrault & Picton, 1964; Godey et al., 2001). The majority of researches suggest that P2 (P160) is generated in the primary auditory cortex, within the sylvian fissure contra lateral to the side of stimulation (Baumann, Roger, Colaou & Saydjari, 1990; Makela & Hari, 1990). Simson, Vaughan and Ritter (1977a) argued that the response at 200 ms (N2/N200) originates from both primary auditory cortex and secondary auditory cortex. However, Makela and Hari (1990) suggested that N2 has its origins in the supratemporal cortex. Most of the studies conclude that there are multiple generators for ALR.

Factors Affecting ALR Recording

There are several factors which can affect ALR recording. Stimulus factors, acquisition factors, subject factors etc can severely affect ALR.

Stimulus factors

Acoustic stimulus used to elicit can affect ALR depending on its characteristics. Type of stimulus, frequency, duration etc has impact on ALR recording.

Type of stimuli: ALR can be evoked by a wide variety of transient sounds such as Click, Tone burst, noise burst, and syllable and also by sudden changes in continuous sounds such as in amplitude or frequency spectrum (Jerger & Jerger, 1970; Mc Envoy, Picton, Champagne, Kellett & Kelly, 1990). ALR can also be evoked by “nonstimuli”such as by gaps in a tone or noise, or omitted stimuli in a train (Simson, Vaughan & Ritter, 1976). But since 1960s tonal stimuli have traditionally been used to elicit ALR. Amplitude of ALR components vary as a function of nature of stimulus (Ceponiene et al., 2001; Ceponiene et al., 2005). Ceponiene et al. (2001) reported that the amplitude of N1 to P2 complex is larger for speech sounds than for single frequency tonal stimuli, but latency values for N1 and P2 are usually earlier for tonal versus speech stimuli. It has been reported by several authors that the ALR response vary according to the kind of stimulus used for recording.

Frequency of the stimulus: Stimulus frequency can alter the amplitude of N1-P2 even when the loudness of the stimulus is controlled. In contrast to the amplitude, latencies increase as the frequencies increases, particularly when high intensity stimulus is used. Sugg and Polich (1995) reported that the amplitude for the N1 and P2 components is larger, and the latency is longer for low frequency tonal signal in comparison to high frequency signals. However, Rothman (1970) reported that inter subject mean of N1-P2 amplitude is negatively correlated with frequency in the range of 500 Hz to 2 KHz. But he also reported that this function vary considerably between subjects. Grimes and Fieldman (1971) reported that no effect of frequency change from 500 Hz to 4000Hz on the difference between the behavioral threshold and ALR threshold. Mc Candles (1967) found that pure tones are better than clicks to elicit ALR. Hall (2007) reported that highly transient click signals are inappropriate for ALR. Longer duration tonal signals are preferred.

Intensity: This is the one of the most important parameter encountered mostly with the clinical protocol. One of the first observation made about ALR was that the amplitude of ALR is increased in an essentially linear fashion as stimulus intensity increased, where as latency decreased over the same intensity range (Rapin, Schimme, Tourk, Krasneggor & Pollack, 1966; Rothman, 1970). Changes in the amplitude as a function of stimulus intensity tended to level off, or saturates for moderate to high intensities approximately above 70 dBnHL (Beagley & Knight, 1967). Adler and Adler (1984) reported that the P2 amplitude may saturate at higher stimulus intensity than N1, but at lower intensity P2 latency increases more than N1 latency. Rapin, Schinnel, Tourk, Krasneger and Pollak (1966) reported that ALR latency changes with intensity vary for clicks versus tonal stimuli. For an ALR evoked by a click stimulus, Latency for the N1 or P2 components changes relatively little as stimulus intensity increases, except at the intensity closer to auditory threshold. They also found that the largest amplitude changes with intensity for 1000 Hz, less for 250 Hz, and least for 6000 Hz. It has been concluded that there is considerable inter and intra subject variability in the amplitude – intensity relation ship of ALR.

Duration: The effect of stimulus duration on ALR was studied extensively since 1960. Onishi and Davis (1968) reported that amplitude of ALR increases as the stimulus duration increases to approximately 30-50 ms. Most of the studies concentrated on explaining the effect of stimulus duration on ALR based on the temporal integration time. Alain, Woods and Covarrubias (1997) discovered that changes in signal duration produced different scalp distribution for the ALR N1 wave and P2 wave i.e. the fronto - central region for ALR N1 wave and the posterior electrode site for the P2 wave. These findings were based on the temporal integration properties of ALR.

Onishi and Davis (1968) used 1000Hz tone burst with linear on and off ramps, and pleatue of various duration were used to evoke ALR in five normal hearing individuals. In the first experiment duration of the signal is varied from 3, 10, 30,100 or 300 ms with rise time of 3 or 30 ms. In the second experiment rise time varied from 3 to 300 ms combined pleatue time of 2.5 ms. They found that with the rise time of 30 ms, the amplitude of N1-P2, latency of either N1or P2 were independent of duration of pleatue. They also found that with rise time of 3ms, amplitude were progressively reduced when pleatue was shortened from 30 ms to 0 ms. They also reported that with longer pleatue amplitudes were nearly constant.

Rate and Interstimulus interval (ISI): There are lots of studies which deal with the effect of Interstimulus interval on ALR recording. It has been reported that the ALRs are highly dependant on inter stimulus interval (Budd et al., 1995; Davis et al., 1966). Rothman, Davis and Hay (1970) reported that longer inter stimulus interval and concomitantly, slower stimulus rates produced substantially larger amplitudes for N1 and P2 components of ALR. However the latency of these ALR components had little effect. Conversely, Davis and Zerlin (1966) reported that with increase in ISI there are predictable increases also in ALR amplitude. The increased ISI is required for increased amplitude of ALR is due to the refractory period of the auditory nerve.

Roth, Ford, Lewis & Kopell (1976) reported that differential effect of interstimulus interval for the amplitude of N1 versus P2. The amplitude of P2 did increase rather systematically with stimulus rate, where as N1 amplitude remained relatively stable for ISI within the range of 0.75 to 1.5 ms. Bruneau, Roux, Guerin, Barthelemy and Lelord (1997) reported that ISI of longer than 1second is required to consistently record an N1 component from children. Picton, Woods, Baribear, Branu, and Healey (1977) also reported that reduction in the ISI from 4 sec to 1 sec may lead to reduction in the amplitude in the order of 50 percentages or more. It has been found that refractory period of N1 component decreases as a function of age. But on the other hand, the N2 appears to be relatively unaffected by increase in the stimulus rate.

Contra lateral signals: The ALR may be altered by sounds presented to the non stimulus ear .The contra lateral sound may be tones, some type of noise or speech. Competing sounds presented to one ear appear to interfere with subject attention (Hall, 2007). Many studies have shown that the effect of contra lateral sound was different for N1 and P2 waves. In addition, the effect of contra lateral signal on ALR varies as a function of the interaction of the various factors, including characteristics of the target stimulus, difficulty of the listening task, and subject factors such as age (Fisher, Morlet, & Giard, 2000; Hymel, Canford & Stuart, 1998).

Canford et al. (2004) further investigated the effect of competing noise on N1 and P2 components of ALR on 10 normal hearing female adults. The task involved was to discriminate between two frequencies. The amplitude of N1 and P2 were compared between two conditions i.e. with the competing noise and without the competing noise. They found that there is no change in the amplitude of N1, but there is a reduction in the amplitude of P2 when compared between two conditions. Based on this study they pointed out towards the independence of the N1 and P2 waves and argued against the simple analysis of N1-P2 complex within the ALR waveform.

Acquisition Factors

Several acquisition parameters also affect ALR. They have been extensive studies by several researchers; factors which affect the ALR have been reviewed and given below.

Electrode: Electrode placement may affect the ALR because of its site of generation. Cody, Jacobson, Waller, and Bickford (1964) reported that response amplitude was largest when recorded at vertex. Many investigators presented evidence confirming that the vertex, or a location within two or three centimeters lateral or anterior to vertex, is an optimal electrode site (Picton & Hillyard 1974; Ruhm, 1971; Teas, 1965; Vaughan & Ritter, 1970). Vaughan and Ritter (1970) studied ALR wave form recorded from different coronal electrode arrays and found that there is diminishing response amplitude at greater distance from midline and then clear change of the waveform polarity in the region or plane of temporal lobe.

Analysis time: It has been reported in the literature that ALR should be analyzed with a prestimulus average of 100ms and post stimulus analysis of 1000 to 1500 ms (Hall, 2007). ALR analysis time should be extended at least for 500 ms after stimulus (Hall, 2007). Pre stimulus analysis gives an idea about the variation of EEG such as the alpha rhythmic activity of the patient.

Filter: It has been reported that the filter setting for evoked potential is selected according to the frequency content of the response. Frequency composition or spectrum for ALR response is in the frequency region below 30 Hz (Sayers, Beagley, & Henshall, 1974; Yamamoto, Sakabe & Kaliho, 1979). Band pass filter setting of less than 1 Hz to 30 or 100 Hz is typically employed in ALR (Hall, 2007).

Goodin, Aminoff, Chernoff, and Holander, (1990) studied the effect of different high-pass filters on long-latency auditory evoked potentials was investigated in 25 subjects, 15 of whom were asymptomatic individuals seropositive for the human immunodeficiency virus (HIV) and 10 of whom were normal control subjects without known risk factors for HIV infection. High-pass filtering was done simultaneously at 0.25 Hz and 1.0 Hz. They recorded the responses for 2,000 Hz and 1,000 Hz tones from Fpz, Cz, and Pz electrode placements and averaged separately. Using either filter, well-formed and reproducible responses were obtained for N1, P2 and N2. Although the latencies of the N1, P2, N2 components of the response were slightly shorter when a 1.0 Hz filter was used. Although it could be argued that this makes the use of a 1.0- 30 Hz filter setting preferable in the clinical setting, the variability and reproducibility of the ERP were comparable when either 0.25 Hz or 1.0 Hz high-pass filter was used, and both resulted in similar findings in the HIV-infected individuals compared to individuals with normal hearing.

Subject characteristics

Not only the stimulus factors or acquisition factors can affect ALR, lots of other factors have an effect on ALR. Lots of other factors related to subjects can also affect ALR. Age, gender, subject status can influence auditory long latency response.

Age: The Prominent changes in ALR waves occur within the five years of life, and to a lesser extent with in 2-5 years age range (Suzuki & Taguchi, 1968). The N1 is not present in infants and young children, and for children age 3 to 10 years it is recorded only with extended inter stimulus interval of 1 second or longer (Ponton et al., 2000; Sharma, Kraus, Gee, & Nicol., 1997). Latency decreases and amplitude increases as a function of age during childhood (Tanguchi, Picton, Orpin & Goodman, 1969). ALR can be recorded from premature, full term, newborn and older children (Hall, 2007). Barnet, Ohlrich, Weiss, and Shanks, (1975) reported that the latency of P2 shortens from 230 to 150 ms; N2 from 535 to 320 ms during the age range of 15 days to 3 years. McPherson (1989) reported that ALR or at least one component of ALR could be recorded from normal hearing infants at birth. Some investigators have shown a general increase in the latency and decrease in the amplitude with advancing age (Callaway, 1975). However, Spink, Johannsen and Pirsig (1979) reported that shorter P2 latency for older subjects of 65 years of age compared to younger age group. Amenedo and Diaz (1998) reported that P2 latency does not change with aging.

Gender: Gender effect has been suspected by many of the investigated .But it has been rarely investigated. The gender effect in the brain structure and function are well documented (Witelson, 1991). The result of many studies emphasized on the complexity of interactions among ALR, stimulus conditions, age and gender. There are other investigators reported that no consistent gender effect for ALR N1, P2, and N2 components (Hall, 2007). Onishi and Davis (1968) reported that ALR amplitude in general tended to be larger for females and also reported that the amplitude versus intensity function steeper for females than males. Shucard and Colleagues (1981) found in both verbal and nonverbal conditions that females had higher amplitude responses from left hemisphere than male subjects, where as males showed higher amplitude responses than females from the right hemisphere.

Attention and state of arousal: Most of the reports showed that apparent increase in the amplitude of ALR response with increased stimulus oriented attention. Picton, Hillyard, Kravsz, and Galambos (1974) reported that the amplitude changes are most marked at the stimulus level near threshold. This effect may differ between the peaks. They also found an increase in the amplitude with increased stimulus oriented attention, progressively diminished amplitude of N1 from the awake state to sleep stage 4. During transition to deep sleep, P2 amplitude may actually increase although agreement on this trend is lacking (Campbell, Bell & Bastein, 1992). The influence of sleep was recognized by some of the earliest investigators of ALR. But the complexities of sleep effects appreciated only later. Amplitude of ALR generally becomes more variable in sleep (Rapin, Schimmels & cohen, 1972). Colaria, Diparsia and Gora (2000) reported that probably some of the sleep related changes in ALR waveforms are related to the underlying fluctuations in the EEG activity.

Drugs: This is one of the most influencing factors while recording ALR and the influence of this factor has to be monitored carefully while analyzing the findings. Drugs such as anesthetic agents, tranquilizers and psychotherapeutic agents may influence the ALR recording. Apart from this other like alcohol also influences ALR recording. Mendel et al. (1975) reported that sub cortical induced sleep was associated with increased variability in ALR and it is less accurate. The N1, P2, N2 components amplitude was reduced by benzodiazepine but the latency of these components is been less affected (Lader, 1977). There are some other sedative such as meperidine like morphine has no apparent effect on ALR. Properidol produced a latency prolongation of about 10 ms for P1 and N1 of the ALR components and amplitude reduction. Anesthetic agents also produce diverse effect on different components of ALR. Skinner and Shinota (1975) reported that during sedation with chloral hydrate, ALR variability is increased. Where as Halliday and Manson (1964) found no significant decrease in ALR amplitude. Different tranquilizers produce mixed effects on ALR components such as chlorpromazine increases latency of waves P2 and N2 with out affecting the latency of N1 component, nor the amplitude of any components (Lader, 1977). Another tranquilizer such as lithium increases ALR latency with out affecting the amplitude.

Alcohol: There are several authors investigated the influence of alcohol on the ALR components. The amplitude of ALR is decreased by acute alcohol intoxication (Porjesz & Begleiter, 1981; Wolpaw & Penry, 1978). Murata et al. (1992) investigated the effect of acute alcohol ingestion on the ALR N1 and P2 waves on 13 healthy males. ALR components were also recorded in a control condition. It was found that latency of the N1 component was significantly prolonged when the recording was done after 2 hours of alcohol ingestion, where as the P2 latency was found to be unchanged after the alcohol intake.

Handedness: Handedness along with the different electrode placement influences the ALR recording. Alexander and Polich (1997) investigated the possible influence of handedness on the N1, P2 and N2 components of auditory late response. Twenty left handed and twenty right handed males were served as the subjects for the study. They found that there was no handedness effect for N1 amplitude, latency of N1 component was shorter for left handed versus right hander. P2 amplitude were smaller for left handed subjects, where as latency was not related to handedness. They also reported that handedness was not a factor in N2 amplitude, but the anterior electrode placement resulted in shorter latency for left versus right handed subjects.

Clinical application of ALR

Clinical application of ALR has been limited. ALR can be used in the detection and localization of lesions affecting cerebral cortex (Godey et al., 2001). ALR can be used in assessment of children with Autism (Satter Field, Schell& Blacks 1967) Down syndrome (Dustman & Callner 1979) Reading Disorder (Kutes, Ken Petten, & Besson, 1988) Cochlear Implant (Oviatt & Kileny 1999) Central auditory processing disorders (Jirsa & Clontz, 1990) and adults with Schizophrenia (Hink & Hillyard 1978). ALR may help in differentiating between infants with auditory neuropathy or auditory dys-synchrony and those with maturation delay (Niraj, 2007)

ALR have been used very limitedly in Aural Rehabilitation. These potentials have been used to provide functional measure of the benefit provided by personal hearing aids (Korzack, Krutzberg & Stapelles, 2005). These potentials can be used to monitor changes after auditory training or after receiving cochlear implants (Kraus, Gee, Carrell, & Sharma, 1995; Tremblay & Kraus, 2002).

ALR in CAPD

Purdy, Kelly, and Davis (2002) reported ALR findings in central auditory processing disorders. The P2 component of ALR was not consistently recorded and typically smaller in amplitude. There were significant group difference for the ALR P1 (shorter latency in APD group) and the N1 component (smaller amplitude in the APD group). Warrier and colleagues (2004) found smaller amplitude for the P2 and N2 wave complex recorded from children with auditory learning problem when speech signal /ga/ was presented in the presence of background noise.

ALR in Down syndrome

Diaz and Zurron (1995) studied ALR components in 12 subjects with Down syndrome and compared that with 12 normal subjects. They recorded ALR using the passive oddball paradigm. They have observed that there was significantly large latency for the N1, P2, and N2 components of ALR. They also found that there is no significant difference in the N1 to P2 amplitude between the groups. But Barnet and Lodge (1967) reported that there is larger amplitude for ALR waves in Down syndrome cases.

ALR in schizophrenia

There are several investigators who reported the ALR abnormalities in patients diagnosed with schizophrenia (Shelley, Silipo & Javitt, 1999). Ford et al. (1998) reported the amplitude of the N100 wave evoked by external stimuli is reduced in schizophrenia patients. Adler et al. (1982) reported ALR abnormalities for patients diagnosed with schizophrenia. Rosburg et al. (2004) investigated the N100m component of the auditory evoked magnetic field in 20 male patients with the diagnosis of schizophrenia. They found that the mean global field power of N100m decreased with repeated presentation of 1000Hz. They also found that there was a modest increase in the latency. In addition to this authors also reported a habituation related change in dipole location.

ALR in cochlear implant

ALR can be recorded from individuals with cochlear implant. Latencies and amplitudes of N1 and P2 in good implant users are similar to those seen in normally hearing adults but are abnormal in poor implant users (Frisen & Trambley, 1998). They also reported that the latency and amplitude parameters are abnormal in “poor” implant users. They also found that the latency of P2 in particular may be a prognostic indicator in terms of separating “good” from “poor” users.

ALR and hearing aids

Earlier investigators cortical evoked potentials in aided vs unaided condition in children with varying degree of hearing loss (Hall, 2007). These studies have shown that there is good agreement with neural detection and audibility of sound. Even most of the subjects with hearing loss showed increased amplitude, decreased latency and improved morphology in aided condition, the amount of response change was quite variable. The variability may be due to the hearing aid which alters the acoustics of the signal. Which inurn affect the response pattern (Hall, 2007). Korzack, Kutzberg, and Stapells (1999) demonstrated that hearing aid improve the delectability of ALR, particularly for individuals with severe to profound hearing loss.

ALR and threshold estimation

ALR can be used to estimate hearing sensitivity that is to provide a non-behavioral analog of pure tone audiogram (Hyde, Matsumoto, Alberti & Liyl 1992). It can be used for threshold estimation in difficult to test population (Korzack, Krutzberg & Stapells, 2005). Recent studies indicate that ALR may be useful in evaluation of auditory neuropathy or auditory dys-synchrony (Kraus et al., 2000). Target population for ALR recording includes any subjects who are unable to or unwilling to provide an acceptable behavioral pure-tone audiogram. This can also include at risk infants, difficult to test children, adults with certain mental or physical handicaps, and those with suspected functional hearing loss. It also included persons for whom an "objective" measure of hearing is required, such as in medico-legal claims or compensation evaluation for occupational hearing loss (Hyde, Matsumoto, Alberti & Liyl, 1992)**.** Most of the early studies found that ALR thresholds were within 10 dB of co-operative adults with normal hearing (McCandles & Best, 1966; Price, Rosenblut, Goldstein, & Shepherd, 1966; Beagley & Kellogg, 1969). Alberti (1970) found that thresholds were within 10 dB in 90% or more of ears in both normal hearing and hearing impaired adults, for frequencies from 500 Hz to 4000 Hz.

ALR recording with click as stimulus: There is less number of studies of ALR using click as stimulus. This is because of less frequency specificity of stimulus and short duration nature. Price, Roseblut, Gold Stein and Shepherd (1966) recorded ALR in 160 hearing impaired subjects with click stimuli. The amplitude, latency, frequency of occurrence of the response of the ALR components was studied. The negative peaks such as N1and N2 were occurred at 85 and 250 ms and positive peak at 160 ms occurred. The frequency of the occurrence of the ALR components and latency did not relate to the race, sex and age of the subjects. He found that amplitude of the response are related to the these variables. He reported that white gave larger response than colored. Females had higher response amplitude than males. Younger and older gave larger response than in between age population. He also found that no significant relation ship between the frequency of ongoing EEG activity and the averaged evoked response. There was no relationship was found between the latency of P2 and frequency of the EEG. However the latency of N1, N2 showed higher negative correlation with the EEG frequency.

Davis et al. (1967) carried out the study with 162 pupil who had severe hearing impairment but whose thresholds lay with in the limits of audiometric equipment at 500 Hz, 1000Hz and 2000 Hz. Comparisons were made between “thresholds” estimated from ALR using tone pips (125, 250, 1000, 2000, 4000 Hz) and behavioral thresholds using the same audiometric equipment (laboratory behavioral threshold). Average estimation of thresholds was in excellent agreement with the laboratory threshold. But the individual data estimated scatter in the response considerably. The average deviation, case by case is 5.4 dB. The average of individual deviations taken frequency by frequency (500, 1000, and 2000 Hz) was 8.0 dB. The average deviation between ALR threshold and behavioral threshold for 500, 1000, and 2000 Hz taken separately is 11.4 dB. And at the other frequencies (125, 250, and 4000Hz) it is nearly the same.

Mc Candles (1967) studied Auditory long latency potential in 128 subjects using tone bursts of 250, 500, 1000 Hz 2000, 4000 Hz with rise and decay time of 20 msec.102 subjects among the 128 were below 10 years of age and 26 adults are also included as subjects. Definable responses were recorded on 90 of 102 children aged below 10 years. ALR Audiometry in older children such as above 6 years were easily measured and appeared to give an accurate measure of auditory sensitivity. In this study 12 children were mature to respond to play audiometry. Comparison of the voluntary threshold and ALR thresholds indicated that voluntary thresholds were 5 -10 times better than ALR threshold. However, in patients whose voluntary responses were to found to be unreliable, the evoked thresholds were observed to be lower. They also reported that the appearance of an evoked potential indicates a sound has alerted the patient’s cortex, it doesn’t imply that the patient can use auditory information meaningfully. Therefore interpretation of the ALR findings has to be made with caution. However, author reported that the procedure is time consuming and it is not sufficiently well developed as a general clinical tool.

Alberti (1970) carried out evoked cortical response audiometry using tone burst in normal hearing and patients with abnormal hearing. All were neurologically normal. He found that nine of the ten normal hearing subject’s threshold was within 10 dB at the best conventional threshold tested between 500 Hz and 4000 Hz. The Patients with hearing loss showed a little greater spread from 250 Hz to 2000 Hz and the thresholds were within 15 dB. There was some doubt at 4000 Hz. It was around 20 dB. He reported that cortical audiometry is valuable in detecting functional hearing loss. It saves time and helps to establish threshold in uncooperative patients and immigrant population with language difficulty.

Hyde, Matsumoto, Alberti and Liyl (1986) carried out auditory long latency potential in adult compensation claimants and Medico legal patients to verify the pure tone audiometry. ALR testing was carried out using tone bursts with 10 ms rise and fall times and 40 ms plateaus at frequencies of 0.5, 1, 2 and 3 KHz in large population of noise induced hearing loss patients. Large sample of comparison of ALR threshold and pure tone threshold showed that the ALR can estimate true hearing level within 10 dB in almost all patients. The recording of ALR was found to be difficult in about 5% of the cases because of high levels of alpha rhythmic activity in the EEG. They also reported that click stimuli, which is broad band in nature is inappropriate for ALR audiometry as it excites the entire cochlea leading to poor frequency specificity. For ALR, longer tones with fairly slow rise and fall times are perfectly adequate stimuli, and even high slope or notched audiometric configuration can be reproduced well. The validity of the ALR recording depends on the level of auditory evoked potential generation in the auditory neuron. A lesion more rostral than the generator site may result in normal ALR threshold even in the presence of significant hearing loss.

ALR in sensorineural hearing loss

Polen (1984) studied the effect of hearing loss on ALR components and compared the findings with normal control group. He found that moderate to severe SN hearing loss resulted in prolongation of latencies of P2, N2 components of ALR. It was also found that decreased N2 amplitude in the sensorineural hearing loss group in comparison to normal hearing group. However, Wall, Davidson and Dalebout (1991) studied ALR in five mild to moderate hearing impaired subjects. He found that there is no significant difference in the latency of N1 and P2 between normal hearing group and hearing impaired group. But still there was significant difference in the amplitude of these peaks with the exception of N1.

Tremblay, Piskosz, and Souza (2003) studied the effect of hearing loss on ALR components (P1, N1, P2) in sensorineural with sloping configuration. Average hearing threshold of 15 dB HL at 250 and 500Hz and decreasing rather systematically to 60 dB HL at 8000Hz. They found that there was change in the latencies of ALR component by different voice onset duration occurred as a function of aging. In general, ALR findings were similar for Normals and hearing impaired. However, there are inconsistencies of among studies of ALR in hearing impaired subjects (Oates, Kurtzberg & Stapells, 2002).

Mannen and Stapells (2005) evaluated the use of ALR and ASSR in estimating the behavioral audiogram in adults for compensation cases. They evaluated the threshold at 500 Hz, 1000Hz and 2000Hz using ALR in groups of 23 subjects. ASSR threshold also estimated using 40 Hz and 80 Hz modulation rate at carrier frequencies of 500 Hz, 1000Hz and 2000Hz and 4000Hz. The difference between the behavioral and auditory evoked threshold estimated was between 5 to 17 dB for 80 Hz ASSR, 1-14 dB for 40 Hz ASSR, and 20-22 dB for ALR measurement. The threshold for 40Hz ASSR was significantly closer to the behavioral threshold than ALR and 80 Hz response. The ALR threshold showed good correlation at all frequencies. This study confirmed that ALR is an accurate method for threshold estimation in passively or actively alert population. They also reported that the accuracy of this measure dependent up on the skill and experience of the tester. ALR has to be recorded one stimulus frequency at a time and one ear at a time.

ALR and auditory Dys-synchrony

Govil, (2001) Evaluated 7 auditory neuropathy patients with MLR, ALR, and MMN evoked potentials. He found that MLR present only in 2 subjects and ALR present in 6 subjects and MMN in 5 subjects. Latency of P1 varied from 51-84 ms, N1 from 96 to 145 ms and P2 from 167 to 167 ms. The presence of ALR in subject with absent MLR attributed to stimulus duration used for the two potentials and difference in neural synchrony. He found that auditory neuropathy has impaired processing for short duration stimuli compared to long duration stimuli and this might have lead to the absence of MLR, where short duration stimuli was used. The other possible reason for presence of ALR in the absence of MLR is that ALR require different neural synchrony compared to the synchrony required for shorter latency response (Kraus et al. 2000). Hece their group of auditory neuropathy patients, the evoked potential such as ABR, MLR which require high synchronization was disrupted where as slow neural synchrony required for ALR was intact. They also attributed the impaired stimuli related timing neural synchrony at the cortical level might have resulted in this result. They also reported that the variability in the auditory neuropathy could be due to central processing ability. Central auditory processing in this group could be either intact or disrupted, which can be reflected by the presence of auditory evoked potentials. They concluded that ALR, MLR and MMN in combination supplement clinical information in identifying central auditory processing dysfunction.

Rance et al., (2002) Studied aided and unaided speech perception abilities of children with auditory neuropathy. They compared the performance with the sensorineural hearing loss group. They investigated the speech perception ability using PB-K word list in both aided and unaided condition and ALR measurement was also carried out. They found that speech perception ability cannot be reliability estimated from behavioral audiogram in these children. ALR testing may offer a means of predicting perceptual skills in these children. The presence of ALR with age appropriate latency and morphology was correlated with significant open set speech perception abilities, amplifications benefit. The absence of ALR in contrast, indication of profound hearing disability evidenced by profound hearing loss and /or extremely poor speech perception. In sensorineural hearing loss group there was absent ALR response for three subjects, whose PB-K scores ranged from 51 to 58%. These scores were slightly lower than the other sensorineural hearing loss subjects. Indicating that ALR measurement better correlated with speech perception abilities in auditory neuropathy group.

Zeng, Oba, Garde, Sininger, and Starr (2005) studied temporal processing in 12 normal hearing adults and 14 auditory dys-synchrony patients using auditory evoked potentials such as ALR and psychoacoustic method. ALR was measured to brief silent intervals (gaps) of 50, 20, 10, 5, and 2 ms duration embedded in a continuous broad band noise. Latencies and amplitude of N100 and P200 were measured and analyzed in two conditions: active and passive. The ALR components could be recorded only for longer gaps of 10 to 50 ms duration. There was a close agreement between psychoacoustically measured gap detection threshold and electrophysiological measurement in normals and auditory neuropathy groups. This result indicated that ALR can provide information about the auditory temporal processing in auditory neuropathy subjects. In auditory neuropathy patients, there was altered neural input due to the decrease in the number of functioning fibers. The prolongation of the latency of the ALR components in auditory neuropathy could be due to the elevation of the threshold in this group and also could be the central resulted from sensory deafferentation. From the study they concluded that combination of electrophysiological and psycho physiological methods provide useful measure of temporal processes.

From the above review, it is clear that ALR can be used for threshold estimation especially in cases with individuals with normal hearing and sensorineural hearing loss. Many researchers have reported that good correlation between the behavioral pure tone threshold and tone burst ALR. However there are a few studies which tried to correlate the pure tone threshold and click evoked ALR due to lack of frequency specificity. However, to elicit ALR using tone burst is a tedious work and it is time consuming.

Whereas click evoked ALR would limit the time for recording. Hence the current study has used click to elicit ALR components. Several investigators have used ALR in auditory dys-synchrony to understand the processing deficit. However there are no studies about estimating the threshold using ALR in this population. Hence, this study focused on estimating the threshold using ALR in individuals with auditory neuropathy.

METHOD

This study aimed at finding out relationship between ALR threshold and Behavioral threshold in individuals with normal hearing and sensorineural hearing loss. Attempt was also made to know whether ALR can be used to predict behavioral threshold as it require lesser neural synchrony in individuals with auditory dy-synchrony, where ABR is usually absent. This information would help to predict behavioral threshold in infants or in children with auditory neuropathy or auditory dys-synchrony. To accomplish the goal, three groups of subjects were taken.

Subjects

A total of 37 subjects were participated in the study. Participants were grouped in to three groups. Group I: Included individuals with normal hearing (control group), group II included individuals with cochlear hearing loss and group III included individuals with auditory neuropathy or auditory dys-synchrony. Group II and III were further divided in to three subgroups each depending upon their severity of hearing loss as mild, moderate and moderately severe for comparison.

Group I: consists of 20 ears with normal hearing from 14 individuals. The age range was between 18 to 50 years with a mean age of 33.9 years.

Selection Criteria

Subjects who fulfilled the following criteria were included in this group.

- Pure tone threshold within 15 dB HL at each octave frequencies between 250 Hz and 8000 Hz for air conduction and between 250 Hz and 4000 Hz for bone conduction.
- All the subjects had Good speech identification score (>90%).
- All the subjects had "A" type tympanogram with normal acoustic reflex thresholds, indicative of normal middle ear function.
- No abnormality observed in click evoked ABR at 90 dBnHL.
- No history of acute or any chronic ear infection, ear ache, tinnitus, vertigo or any other otological problems.
- No history of any observable medical or neurological impairment.

Group II: This group included 16 ears with cochlear hearing loss from 12 individuals. The age range was between 18 to 60 years with a mean age of 36.4 years.

Selection Criteria

The subjects who fulfilled the following criteria were included in this group.

- Pure tone threshold varied from mild to moderately severe degree (26 dB HL to 70 dB HL) at octave frequencies between 250 Hz and 8000 Hz for air conduction.
- Air bone gap was within10 dB HL.
- Speech identification scores were proportional to their averaged pure tone threshold obtained at 500 Hz, 1000 Hz and 2000 Hz.
- All of them had 'A' type tympanogram with normal, elevated or absent acoustic reflex, indicating normal middle ear function.

- No indication of retrocochlear pathology or components, which was ruled out based on ABR and OAE test findings.
- No history of acute or any chronic ear infection or any other otological problems.

Group III: This group consisted of individuals with auditory neuropathy or auditory dys-synchrony. Data were obtained from 20 ears of 11 individuals. The age range was 18 - 50 years with a mean age of 30.1years.

Selection criteria:

The following criterion was adopted to select the subjects in this group.

- Pure tone threshold varied from mild to moderately severe degree (26 dB HL to 70 dB HL) at octave frequencies between 250 Hz and 8000 Hz for air conduction.
- Air bone gap was within10 dB HL.
- All the subjects had poor speech identification scores or poor speech in noise score (SPIN) at 0 dB signal to noise ratio.
- All the subjects had ‘A’ type tympanogram with absent acoustic reflexes, indicative of normal middle ear function.
- All the subjects had absent or abnormal click evoked ABR at 90 dBnHL.
- TEOAEs were present for all the ears participated in this group.
- No history of acute or any chronic ear infection or any other otological problems.

Instrumentation

- A calibrated double channel diagnostic Madsen Orbiter 922 (version.2) audiometer with TDH 39 ear phone was used to estimate air conduction threshold and establish speech identification scores. B-71 bone conduction vibrator was used for bone conduction testing.

- A calibrated immittance meter (Granson Stadler Inc. Tymp Star) was used to assess middle ear status.
- ILO 292 DP Echo port (Otodynamics, version.5) system was used for recording TEOAEs.
- Auditory brainstem responses and auditory long latency responses to click stimuli was recorded using Intelligent Hearing System (IHS smart EP, NSB version 2.39) evoked potential system. The click stimuli was delivered using ER-3A insert receiver.

Test environment

All the tests were carried out in a well illuminated air conditioned room. The ambient noise level in the room was within the permissible limits as recommended by ANSI 1996.

Procedure

- Pure tone threshold for air conduction were obtained at octave frequencies between 250 Hz and 8000 Hz and from 250 Hz to 4000 Hz for bone conduction. Modified Hughson –West lake procedure (Carhart and Jerger, 1959) was used to obtain pure tone threshold.

- Speech identification score was obtained at 40 dB SL with reference to speech recognition threshold in each ear independently. Phonetically balanced list developed by Mayadevi (1978) was used for the same.
- Speech in noise test was carried out at 0 dB SNR condition (both signal and noise were presented at 40 dB SL). Phonetically balanced list developed by Mayadevi (1978) was used to establish the SPIN scores.
- Tympanometry was carried out using 226 Hz probe tone frequency. Acoustic Reflexes were checked at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz pure tones, for both ipsi and contra laterally to rule out middle ear pathology.
- TEOAEs were recorded using nonlinear broad band click. A total of 256 sweeps were presented to elicit TEOAEs. The eliciting stimulus was presented at around 75 dB peSPL. Prior to the TEOAE recording appropriate probe fit was obtained. TEOAEs were considered to be present when the amplitude was greater than +6 dB SPL with a reproducibility of 80%. TEOAEs were recorded to identify the presence or absence of cochlear pathology depending on its absence or presence.
- AEP recording: For AEP recording, i.e. for both ABR and ALR recording, subjects were asked to sit comfortably and relax on a reclining chair facing away from the instrument. They were also instructed to avoid extraneous movements of head, neck and limbs during testing, as it might interfere with the EEG recording.

Electrode placement

Each electrode site was first cleaned by scrubbing with cotton dipped in skin preparing paste. The electrodes were then dipped in to skin conduction paste and fixed on the scalp sites using a surgical tape. It was ensured that independent electrode impedance was less than 5 kΩ and inter electrode impedance was within 3 kΩ. Three silver chloride disc type electrodes were used for AEP recordings. After the appropriate placement of the electrodes ABR recording was done. The parameters used to record ABR can be seen in the Table 3.1.

Table 3.1: Depicts the parameters used to record ABR

Stimulus parameters	
Stimuli	Click
Duration	100 µs
Rate	11.1/sec / 90.1/sec
Polarity	rarefaction
Sweeps	1500
Intensity	90 dBnHL
Transducer	ER-3A insert receiver
Acquisition parameters	
Filter	100- 3000 Hz
Notch filter	On
Artifact rejection	40%
Gain	1,00,000
Time window	10 ms
Electrode montage	Inverting –left mastoid(M1)/ right mastoid (M2) Ground-M2/M1 Non inverting -high forehead (FpZ)

ABR was recorded twice for replicability. It was then compared with the behavioral threshold to identify the presence or absence of retrocochlear pathology. Absent ABR with the presence of TEOAEs, indicated the presence of auditory neuropathy or auditory dys-synchrony.

Pure tone, immittance, TEOAEs and ABR testing were carried out for the selection of subjects. The subjects were put in to different groups based on the tests results. After ABR testing the subjects have undergone ALR recording. The parameters used to record ALR are given in the Table 3.2

Table 3.2: Depicts the parameters used to record ALR

Stimulus parameters	
Stimuli	Click
Rate	1.1/s
Duration	500μs
Polarity	Alternating
Sweeps	500
Intensity	Variable
Transducer	ER-3A insert ear phone
Acquisition parameters	
Filter	1- 30 Hz
Notch filter	Off
Artifact rejection	40%
Gain	50,000
Prestimulus time	100 ms
Time window	500 ms
Electrode montage	Inverting - M1/M2, Ground-M2/M1, Non inverting- high forehead (FpZ)

ALR Testing was initiated at 80 dBnHL for normal hearing and sensorineural hearing loss group, where as for auditory dys-synchrony group ALR was initiated at 90 dBnHL. Intensity was then gradually reduced if the observable ALR was noticed. Initially intensity was reduced by 20 dBnHL for normal hearing group and 10 dBnHL for sensorineural hearing loss and auditory neuropathy group till no response was obtained. Then the intensity was increased by 5 dB till the response (N1-P2) was observed. ALR was recorded twice at each presentation level to check for replicability. The responses were stored for further analysis. Later wave forms were recalled and analyzed. Waveforms were shown to three experienced audiologists to identify the N1-P2 complex. When there was agreement among the audiologist regarding the presence of N1-P2 complex at the lowest intensities, were considered as threshold. The lowest intensity at which N1-P2 occurred was noted.

Wave form analysis

- The latency of P1, N1, P2 and N2 components of ALR were noted. The amplitude of N1-P2 complex of ALR was recorded as it is recommended by McPherson (1996). The data obtained from the subjects were analyzed as follows:
- Morphology of the ALR wave forms were discussed across individuals with normal hearing, Sensorineural hearing loss and auditory neuropathy or auditory dys-synchrony.
- The mean, Standard deviation and range were computed for different components of ALR for all the three groups obtained at different intensities.

- Amplitude and latency change in ALR components with respect to change in intensity were analyzed in individuals with normal hearing, Sensorineural hearing loss and individuals with auditory dys-synchrony separately.
- ALR threshold (lowest intensity at which N1-P2 complex is visually detected) and the pure tone average (average of behavioral threshold at 500 Hz, 1 KHz, 2 KHz) were compared in individuals with normal hearing, sensori neural hearing loss and auditory dys-synchrony.
- Relationship between ALR threshold and the speech identification scores were obtained in individuals with sensorineural hearing loss and individuals with auditory dys-synchrony.
- Relationship between click evoked ALR threshold and the pure tone threshold at each frequency (250 Hz, 500 Hz, 1000 Hz, and 2000 Hz, 4000 Hz) were computed for all the three groups.
- Amplitude of (N1-P2) and latency of all the ALR components at 80 dBnHL were compared in individuals with sensorineural hearing loss and auditory dys-synchrony.

RESULTS AND DISCUSSION

The main aim of the study was to find out find out whether click evoked ALR can be used as a tool to estimate behavioral threshold in individuals with normal hearing, sensorineural hearing loss and auditory dys-synchrony. To establish this goal, latency of the P1, N1, P2, N2 waves and amplitude of N1-P2 complex were noted. The mean, standard deviation (SD) and range were calculated for each parameter for both the groups separately. This can be seen in the Table 4.1.

Table 4.1- *Mean, SD, range of the latency for each component of ALR (P1, N1, P2, and N2) and the amplitude of N1-P2 complex at different intensity levels*

		Normal			SNHL	
	Intensity	80 dBnHL	60 dBnHL	40 dBnHL	80 dBnHL	60 dBnHL
P1 Latency	Mean	58.55	78.95	94.34	50.5	76.5
	SD	9.27	9.4	11.9	6.78	18.3
	Range	40 - 76	69 - 96	79 - 126	44 - 65	55 - 99
N1 Latency	Mean	96.75	116.9	136.8	84.8	114.6
	SD	11.84	14.45	19.69	12.27	7.53
	Range	78 -121	92 - 159	99 - 180	79 - 95	98 - 131
P2 Latency	Mean	148.94	168.47	187.63	146.6	175.4
	SD	15.67	14.48	22.16	14.69	21.21
	Range	103 - 169	132 - 200	139 - 239	121 - 165	131 - 163
N2 Latency	Mean	204.4	225.5	246.5	209	235
	SD	13.85	16.95	19.12	21.21	16.14
	Range	176 - 222	195 - 255	213 - 285	182 - 255	219 - 270
N1-P2 Amplitude	Mean	4.23	2.77	1.58	5.5	3.44
	SD	0.97	0.83	0.63	0.99	0.99
	Range	2.58 - 5.87	1.29 - 4.37	.60 - 3.15	3.23 - 6.72	1.63 - 5.38

It can be seen from the Table 4.1 that as the intensity of the stimulus was reduced from 80 to 40 dBnHL, there was an increase in the latency of all the ALR components and decrease in the N1-P2 amplitude in both the normal hearing group and sensori neural hearing loss group. The SD and range of latency for different ALR component were more than that of amplitude of N1-P2 complex for both normal hearing and sensorineural hearing loss group. This indicates that the latency of ALR has limited clinical utility.

The Kruskal wallis test was carried out for the comparison of latency of the P1, N1, P2 and amplitude of N1-P2 complex across the normal hearing, sensorineural hearing loss and auditory dys-synchrony groups. The latency value of N2 is not considered for this analysis as it was absent in majority of the auditory neuropathy cases. The result indicated that P1, N1and P2 latency and N1-P2 amplitude were significantly different across the groups; Whereas P2 latency did not show any significant difference.

Table 4.2 - *chi- square value, degrees of freedom and significance level of different ALR components across the groups at 80 dBnHL*

	Chi-Square	df	Sig.
P1Latency	6.665	2	.036
N1Latency	10.496	2	.005
P2Latency	1.060	2	.589
N1P2 Amplitude	6.067	2	.048

In order to know the significant difference between the two groups, Man Whitney test was carried out. The result can be seen in the Table 4.3.

Table 4.3 - *Depicts the Z-value and the significance level for all the parameters of ALR between the groups at 80 dBnHL*

	P1 Latency		N1Latency		P2 Latency		N1-P2 Amplitude	
	Z- value	Sig level	Z-value	Sig level	Z- value	Sig level	Z- value	Sig level
Normal Vs SNHL	2.14	0.032	3.02	0.002	1.08	0.279	2.42	0.016
Normal Vs AD	1.811	0.07	1.02	0.919	0.205	0.838	0.951	0.342
AD Vs SNHL	1.24	0.213	2.15	0.031	0.207	0.836	0.826	0.409

From the Table 4.3 it can be seen that, between normal hearing and sensorineural hearing loss group, latency of P1, N1 and amplitude of N1-P2 differed significantly. Whereas, the latency of P2 did not differ significantly. Between auditory dys-synchrony and sensorineural hearing loss group only the latency of N1 component showed significant difference. Apart from this other latency parameters and N1-P2 amplitude parameter did not show statistical significant difference. Between normal hearing and auditory dys-synchrony group, no significant difference was obtained for all the ALR parameters.

To see the relation ship between the ALR threshold and pure tone average (PTA), sensorineural hearing loss and auditory dys-synchrony group have been further divided in to mild, moderate and moderately severe hearing loss. The mean, SD and range for ALR threshold and PTA value obtained for normal hearing and subgroups of sensorineural hearing loss and auditory dys-synchrony were calculated. The values obtained for different groups are given in the Table 4.4.

Table 4.4 – *Depicts the mean, SD, range for ALRT and PTA for sensorineural (SNHL), auditory dys-synchrony (AD) and Normal hearing groups*

	ALRT			PTA		
	MEAN	SD	RANGE	MEAN	SD	RANGE
SNHL Mild	49 (n=5)	5.48	40-55	32.96	3.21	30-38
SNHL Mod	62.5 (n=4)	5.00	55-65	50.38	6.01	60-70
SNHL Ms	65 (n=7)	5.00	60-70	62.34	4.29	58-68
AD Mild	85 (n=6)	8.37	70-90	34.63	4.39	26-40
AD Mod	83.33 (n=3)	11.54	70-90	46.07	7.74	41-60
AD Ms	75 (n=2)	21.21	60-90	58.3	0.00	58 -58
Normal	35.25 (n=20)	6.78	20-40	7.34	2.43	3.3-12

It can be seen from the Table 4.4 that the ALR threshold increased gradually as the degree of sensorineural hearing loss increased. This trend was not observed in the auditory dys-synchrony group. It can be seen that for moderately severe (Ms) sensorineural hearing loss, difference between the ALR threshold and PTA was less compared to mild and moderate (Mod) hearing loss. It can also be seen that the difference between the ALR threshold and PTA reduced as the hearing loss is increased. The difference was maximum for normal hearing group. The range of ALR threshold was less in auditory dys-synchrony group even though the degree of hearing loss in this group varied from mild to moderately severe. The behavioral pure tone threshold obtained was lesser than the ALR threshold in all the groups and this was relatively better in auditory dys-synchrony group.

The ALR threshold obtained from different groups were then compared with the behavioral threshold. Pearson product moment correlation was done to identify the relationship between the ALR threshold and pure tone average.

Table 4.5 - *Depicts the r- value and the significant level obtained between the ALR threshold and PTA for all the three groups*

GROUP		r value	Sig level
Normal	ALR vs PTA	0.11	0.644
SNHL	ALR vs PTA	0.833	0.000
AN	ALR vs PTA	-0.394	0.205

A highly significant positive correlation obtained between ALR threshold and PTA in sensorineural hearing loss group. A weak positive correlation, but not significant was observed in normal hearing group. Where as in auditory dys-synchrony group weak negative correlation is observed. This suggests that ALR can not predict behavioral threshold in auditory dys-synchrony individuals rather the presence or absence can give an idea about their processing ability. ALR can predict behavioral threshold very well in individuals with sensorineural hearing loss.

The similar findings have been reported by several authors (Rodriguez et al.1986; Lins, 1996). Mc.Candless (1967) found that there is a good agreement between ALR threshold and behavioral threshold in subjects with hearing loss. It has been observed that ALR threshold was with in 5 to 10 dB of the behavioral threshold.

Alberti (1970) reported that the threshold difference between ALR and behavioral threshold is lesser in normal hearing individuals compared to hearing impaired population. Current study result is in contradictory to this study. ALR in auditory neuropathy has been studied by several authors. Variability in ALR result has been reported in this population (Starr et al., 1996; Kraus et al., 2000).

The poor agreement between the ALR threshold and pure tone average obtained in the normal hearing group and good agreement in sensorineural hearing loss group could be due to the active and passive mechanism that takes place at the cochlea. In sensorineural hearing loss group the active mechanism of inner ear is affected, so passive mechanism take part in exciting more number of auditory nerves as it excites larger area of the basilar membrane. This might have resulted in increasing amplitude of the response and passed on to higher centers. This would have given rise to better agreement between behavioral threshold and ALR threshold in sensorineural hearing loss subjects.

Another factor which could have contributed to the better agreement in sensorineural hearing loss group, is that the stimulus which used in this study.

Where as in normal hearing group, active mechanism is intact. The presence of active mechanism results in sharp tuning leading to the excitation of a few auditory nerves. This would have resulted in lesser compound action potential. Thus, causing higher ALR threshold resulted in poor agreement between behavioral threshold and ALR threshold.

In individuals with auditory dys-synchrony poor agreement was obtained. This could be due to the reduced transmission of signal to higher centers. This could be due to the leakage of signal conduction or a conduction block due to demyelization. Thus, resulting in reduced but broadening of compound action potential (Starr, Picton & Kim, 2001). Hence, resulted in higher ALR threshold. In auditory dys-synchrony group there is altered temporal synchrony of auditory nerve and afferent discharges (Zeng, Oba, Garde & Starr, 1999). In neuropathy particularly, a demyelinating neuropathy, nerve impulses become slow when a demyelinated segment of the axon is encountered and then regain normal speed when that segment is passed (Mc Donald 1980). This type of conduction change results in a slowing of nerve conduction velocity. Demyelinated axons are impaired in their ability to transmit the information to the higher cortical centers. This might have lead to poor ALR threshold compared to behavioral threshold and thus poor correlation as ALR is a far field recording potential.

The lesser change in the latency of the ALR waves with intensity change has been reported by the three audiologists while analyzing. The stimulus duration and temporal property could be the reason for ambiguity in the latency and poor morphology of ALR. Rapin et al., (1966) observed that the ALR latency changes with intensity vary for clicks versus tonal stimuli and latency for the N1 or P2 components changes relatively little as stimulus intensity increases, except at it intensity closer to auditory threshold for click stimulus.

Morphology of ALR in normal hearing, Sensorineural and Auditory neuropathy groups

Three audiologists analyzed the morphology of ALR wave forms in all the three groups during analyzing the ALR wave form. They reported that:

In the normal hearing group, 50% of the subjects had good morphology. All the judges reported that well defined peaks at higher intensity and gradual reduction in the morphology with decrease in intensity. They also felt that at lower intensity i.e. near threshold all of them had difficulty in marking N1-P2 complex.

In the sensorineural hearing loss group, 80% of the subjects had good morphology. The judges reported that this group maintained the morphology very well even at or near the threshold level. They also felt that the overall morphology was comparatively better in this group compared to the other two groups. Even reduction in the intensity of the stimulus did not result much change in the morphology of the wave form compared to normal hearing group.

Out of twenty ears of auditory neuropathy ALR could be recorded only from eleven ears. Lots of variability in the morphology of the waveform was reported in individuals with auditory dys-synchrony. Morphology of the waveform reported as fairly good at very at high intensity such as 90 or 80 dBnHL. There was complete degradation of the wave form morphology even with the reduction of 10 dB stimulus level regardless of the behavioral threshold.

The variability in the morphology of the waveform could be due to the stimulus property, ie click has been used as the stimulus for the present study. There are many authors reported that click is not a convenient stimulus for ALR. McCandles (1967) found that pure tones are better than clicks. Hall (2007) reported that highly transient click signals are inappropriate for ALR. Longer duration tonal signals are preferred. It has been reported that temporal integration time is directly related to the latency of the response. The temporal integration time is longer for ALR i.e. greater than 30 ms (Onishi & Davis, 1968). With the click stimuli of short duration is used. Temporal integration may not be adequate. That might be the reason for poor morphology of ALR. Even Hyde, Matsumoto, Alberti and Liyl (1986) found that there is difficulty in recording ALR in about 5% of the cases because of high levels of alpha rhythmic activity in the EEG.

Relation ship between ALR threshold and speech identification score (SIS) in individuals with sensorineural hearing loss and auditory dys-synchrony

To establish the relationship between ALR threshold and speech identification scores, the ALR threshold and speech identification scores were considered only for sensorineural hearing loss and auditory dys-synchrony groups. Normal hearing individuals were not considered as all of them had 100% speech identification score. The mean, SD and range for these two aspects were calculated according to the degree of hearing loss. This information can be seen in the Table 4.6.

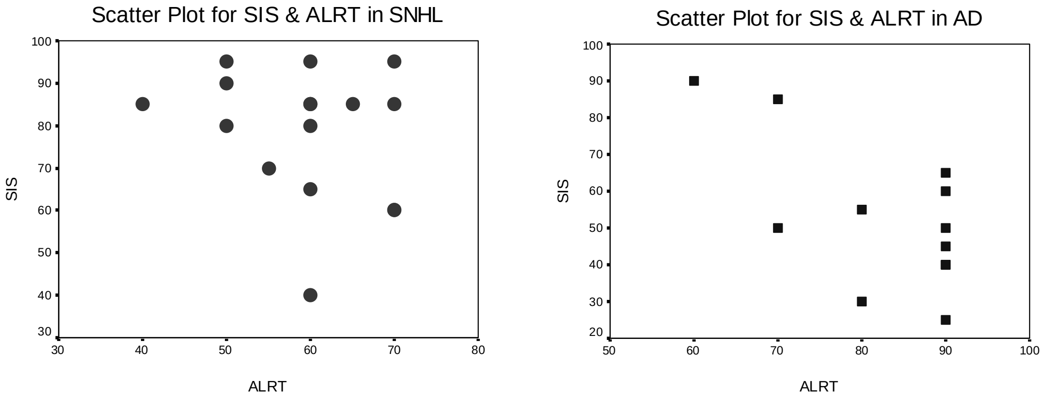
Table 4.6 – *Depicts the mean, SD and Range of ALR threshold and SIS obtained in sensorineural hearing loss and auditory dys-synchrony group*

	ALRT			SIS		
	Mean	SD	Range	SI Mean	SI-SD	Range
SNHLMild	49	5.47	40-55	84	9.61	70-95
SNHLMod	62.5	5	60-70	88.75	7.5	80-95
SNHL MS	65	5	60-70	68.57	17.25	40-85
AD Mild	85	8.36	70-90	47.5	12.14	25-60
AD Mod	83.33	11.54	70-90	55	25.98	40-85
AD MS	75	21.21	60-90	77.5	17.68	65-90

It can be seen in the table 4.6 and figure 4.1 that SD is more for speech identification scores in individuals with auditory dys-synchrony compared to individuals with sensorineural hearing loss. To understand the relation between ALR threshold and the speech identification scores in individuals with sensorineural hearing loss and auditory dys-synchrony, Pearson product moment correlation was calculated.

Table 4.7 - *Depicts the r- value and the significance level between ALR threshold and SIS for sensorineural hearing loss and auditory dys-synchrony group*

Group		r value	Sig level
SNHL	ALRT Vs SIS	-0.242	0.366
AN	ALRT Vs SIS	-0.646	0.023



Scatter Plot for SIS & ALRT in SNHL

Scatter Plot for SIS & ALRT in AD

Figure 4.1 – Depicts the SIS against the ALR threshold for auditory dys-synchrony and sensorineural hearing loss group

It can be seen in the Table 4.7 and Figure 4.1 that SIS and ALR had significantly negative correlation in auditory dys-synchrony group. SIS reduces as the ALR threshold increased. However, no significant correlation was obtained in individuals with sensorineural hearing loss.

Kraus et al. (2000) reported that speech evoked ALR is a good predictor of speech processing in individuals with auditory dys-synchrony. Rance et al. (2002) found that speech perception abilities of auditory dys-synchrony children can not be reliably estimated from behavioral audiogram as like sensorineural hearing impaired group. The P1, N1, P2 and N2 components may offer a means of predicting perceptual skills. The current study is in agreement with the Kraus et al's and Rance et al's findings. In auditory dys-synchrony group where the difficulty in perception of speech is related to impaired temporal processing. The temporal processing is important for speech perception and to elicit the auditory evoked potentials. Thus, degraded processing would have resulted in better correlation.

In sensorineural hearing loss group, speech perception ability is correlated with the pure tone threshold. The cochlear distortion effects, increases with the increase in the degree of hearing loss results in loss of cochlear amplifier leading to reduction in speech perception (Moore, Poston, Eggermont & Huang, 1996). In cases of sensorineural hearing loss, perceptual problem is related to loss of frequency resolution. The spectral processing that occurs in the normal ears is achieved through "active process" mediated by outer hair cells (Moore, Poston, Eggermont & Huang, 1996). In ears with cochlear hearing loss, outer hair cell damage disrupts the active cochlear mechanism (sellik and

Rubbel, 1982). And frequency resolution is impaired. This would have result in impaired listener's ability to spectrally separate the features within the speech signal (Moore, Poston, Eggermont & Huang, 1995). Broadening of the basilar membrane movement would resulted in the excitation of more number of neurons resulted in increased compound action potential leading to better ALRT. Thus, this would have resulted in poor agreement between the SIS and ALR threshold in sensorineural hearing loss group.

Relationship between click evoked ALR threshold and frequency specific pure tone threshold, in individuals with sensorineural hearing loss and auditory dys-synchrony

To establish the relationship between ALR threshold and the frequency specific pure tone behavioral threshold, ALR threshold and pure tone threshold was obtained at each frequency from 250 Hz to 4000 Hz. The mean, SD and range were then computed. This can be seen in the Table 4.8.

Table 4.8 – *depicts the mean, SD and range for ALR threshold and pure tone threshold at each frequencies for different subgroups of sensorineural hearing loss and auditory dys-synchrony group.*

		Mild SN	Mod SN	Ms SN	Mild AN	Mod AN	Ms AN
250Hz	Mean	19	37.5	52.86	40.83	40	55
	SD	7.42	10.41	4.88	8.01	8.66	7.07
	Range	30-40	25-50	50-60	30-50	35-50	50-60
500Hz	mean	24	43.75	55.71	43.33	45	55
	SD	6.51	9.46	6.07	8.16	13.23	0
	Range	20-35	30-50	50-65	30-55	35-60	55-55
1KHz	Mean	32	48.75	62.1	35.83	45	55
	SD	2.73	2.5	5.67	3.76	8.66	0.00
	Range	30-35	45-50	55-70	30-40	40-55	55-55
2KHz	Mean	44	56.25	70	25	43.33	65
	SD	2.25	4.79	10.4	7.07	5.77	0.00
	Range	40-45	50-60	55-80	15-35	40-50	65
4KHz	Mean	53	63.75	82.14	23.33	46.67	52.5
	SD	10.37	13.15	12.20	2.58	2.89	10.61
	Range	40-65	45-75	65-95	20-25	45-50	45-60
ALRT	Mean	49	62.5	65	85	83.3	75
	SD	5.48	5.00	5.00	8.37	11.55	21.21
	Range	40-55	55-65	60-70	70-90	70-90	60-90

It is evident from the Table 4.8 that the ALRT is in close approximity to mid frequency pure tone threshold in sensorineural hearing loss group. Whereas pure tone threshold observed at 4 KHz is seem to be higher than the click evoked ALR threshold. However, in auditory dys-synchrony group, ALR threshold was much higher than any frequency pure tone threshold except for the individuals with moderately severe (Ms) hearing loss. Pearson product moment correlation was done to find out the correlation between ALR threshold and each frequency pure tone threshold. The results of the Pearson product moment correlation coefficient can be seen in the Table 4.9.

Table 4.9 - *Depicts the r value and the significance level between the ALR threshold and pure tone threshold at different frequencies for sensorineural hearing loss group and auditory dys-synchrony group*

Group		r value	Sig level
SNHL	ALRT vs 250Hz	0.807	.000
	ALRT vs 500Hz	0.757	.000
	ALRT vs 1KHz	0.794	.001
	ALRT vs 2KHz	0.817	.000
	ALRT vs 4KHz	0.711	.002
AN	ALRT vs 250Hz	-0.251	0.431
	ALRT vs 500Hz	-0.457	0.135
	ALRT vs 1KHz	-0.326	0.302
	ALRT vs 2KHz	-0.384	0.218
	ALRT vs 4KHz	-0.411	0.184

It can be seen in the Table 4.9 that the ALRT and frequency specific pure tone threshold had shown significant positive correlation in sensorineural hearing loss group. In individuals with auditory dys-synchrony no significant correlation was obtained between ALRT and pure tone threshold at any frequency.

Alberti (1970) estimated thresholds using tone burst ALR in normal and hearing impaired adults for frequencies between 500 HZ to 4000 Hz and found that the thresholds were with in 10 dB in 90% of the subjects. Present study findings are in agreement with the result as obtained by Alberti(1970) in sensorineural hearing loss group. Hyde, Alberti, Matsumato and Liyl (1980) correlated ALR threshold with the behavioral threshold. They suggested that click is not a good stimulus in estimating threshold, as click stimuli excites entire cochlea leading to poor frequency specificity. In the present study even using click stimuli, better correlation obtained at all frequencies in the sensorineural hearing loss group. This suggests that ALR can be recorded from the contribution of all the frequencies. Hence, it is difficult to predict frequency specific threshold if click is used to elicit ALR.

ALR in auditory dys-synchrony group was obtained at high presentation level in spite of the varying degree of severity of hearing loss. In a few individuals with auditory dys-synchrony ALR could be recorded even at 60 dBnHL level and their PTA was 55 dB HL. This could be the reason why there is poor agreement between ALR threshold and pure tone threshold. Another reason could be the temporal processing deficit in individuals with auditory dys-synchrony (Starr et al., 1996). Thus, it can be concluded that click evoked ALR is not a good tool to estimate frequency specific behavioral pure tone threshold in auditory neuropathy individuals. However, click evoked ALR can closely predict the behavioral threshold in individuals with sensorineural hearing loss.

SUMMARY AND CONCLUSION

There are several investigators reported that tone burst evoked ALR can be used for approximating the pure tone audiogram in the population with at-risk infants, difficult-to-test children, adults with certain mental or physical handicaps. They found that ALR can be used to estimate behavioral threshold with greater accuracy. The use of click evoked ALR could reduce the time of testing and predict behavioral threshold. So click stimulus has been used as the stimulus for the present study. Auditory dys-synchrony is one another clinical population, where ABR may be absent most of time even with the presence of ALR. Hence, here an attempt has been made to evaluate the behavioral threshold in these population using click evoked ALR.

The present study was to investigate the relationship between the ALR threshold and the behavioral threshold in normal hearing individuals and hearing impaired population such sensorineural hearing loss and auditory dys-synchrony. This study also focused to know whether ALR threshold can reflect on the speech perception abilities on sensorineural hearing loss and auditory dys-synchrony. Furthermore, the click evoked ALR could show any correlation with any specific frequency behavioral threshold.

To accomplish the objectives, thirty seven subjects were participated in the study. These subjects were divided into three groups as 20 ears with normal hearing, 16 ears of cochlear hearing loss and 20 ears from auditory dys-synchrony. Eleven ears from auditory dys-synchrony group which had the presence of ALR were only considered for the analysis. ALR threshold was estimated using click stimuli in all the three groups. For ALR threshold estimation, recording was initiated at 80 dBnHL or 90 dBnHL and gradually reduced the intensity in 10 dB steps. The lowest intensity at which N1-P2 was noticed considered as the threshold. Apart from this pure tone threshold at each frequency, PTA and speech identification score were also calculated.

The mean, standard deviation and range were calculated for the latency of the P1, N1, P2 and N2 and amplitude of N1-P2 for both sensorineural hearing loss and auditory dys-synchrony group at different intensity level. The Kruskal wallis test was carried out for the comparison of latency of the P1, N1, P2 and amplitude of N1-P2 complex across all the three groups. In order to know the significant difference between the two groups, Man Whitney test was also carried out. The mean, SD, range for ALR threshold and PTA for individuals with sensorineural hearing loss, auditory dys-synchrony and normal hearing groups were calculated. Pearson product moment correlation was done to identify the correlation between the ALR threshold and pure tone average, ALR threshold and SIS, ALR threshold and pure tone threshold at each frequency.

The results obtained in the present study are follows:

- Poor morphology of the ALR wave was observed in normal hearing and auditory dys-synchrony group especially at lower intensity compared to sensorineural hearing loss group. Overall morphology was better with sensorineural hearing loss group.

- Latency shift was relatively less with change in intensity in sensorineural hearing loss group.
- A highly significant correlation between behavioral threshold and ALR threshold in sensorineual hearing loss was observed.
- No significant correlation between behavioral threshold and ALR threshold in normal hearing and auditory dis-synchrony was noticed.
- There was significant negative correlation obtained between ALR threshold and SIS in the auditory dis-synchrony groups.
- No significant correlation was observed between ALR threshold and SIS in sensorineural hearing loss group.
- ALR threshold and frequency specific pure tone threshold had shown significant positive correlation in sensorineural hearing loss group. No significant correlation was obtained in individuals with auditory dys-synchrony.

Even the evaluation of the morphology of the ALR waveform was carried out by three audiologists. They observed that the morphology was good in sensorineural hearing loss group compared to the other two groups. This could be due to the stimulus property, i.e. click has been used as the stimulus for the present study. The click is not a convenient stimulus for ALR. With the click stimuli of short duration; temporal integration may not be adequate. That may be the reason for poor morphology of ALR. And another reason for poor morphology could be because of the high levels of alpha rhythmic activity in the EEG of the subjects.

The poor agreement between the ALR threshold and pure tone average obtained in the normal hearing group and good agreement in sensorineural hearing loss group could be due to the active and passive mechanism that takes place at the cochlea. In sensorineural hearing loss, passive mechanism take part in exciting more number of auditory nerves as it excites larger area of the basilar membrane. This might have resulted in increasing amplitude of the response. Hence, the better agreement between behavioral threshold and ALR threshold in sensorineural hearing loss subjects. Where as in normal hearing, the presence of active mechanism results in sharp tuning leading to the excitation of a few auditory nerves. This would have resulted in lesser compound action potential. Thus, causing poor agreement between behavioral threshold and ALR threshold.

No significant correlation was obtained between ALR threshold and SIS in individuals with sensorineural hearing loss. This could be because of the outer hair cell damage which disrupts the active cochlear mechanism and frequency resolution. This would have resulted in impaired listener's ability to spectrally separate features with in the speech signal and broadening of the basilar membrane movement would resulted in the excitation of more number of neurons resulted in increased compound action potential. Thus, this would have resulted in poor agreement between the SIS and ALR threshold in sensorineural hearing loss group.

In individuals with auditory dys-synchrony group poor agreement was obtained. This could be due to reduced transmission of signal to higher centers. This could be due to the leakage of signal conduction or a conduction block due to demyelization. Thus, resulting in reduced but broadening of compound action potential. Hence, resulted in higher ALR threshold.

It was found that click evoked ALR had better correlation with the entire specific frequency behavioral threshold. This is because of the property of the click stimuli. As click stimuli excites entire cochlea leading to poor frequency specificity. Hence, it is difficult to predict frequency specific threshold if click is used to elicit ALR.

Conclusion

Thus, it can be concluded that click evoked ALR is not a good tool to estimate frequency specific behavioral threshold. But it can closely estimate the behavioral threshold in sensorineural hearing loss group. Even though ALR has lost its popularity clinically throughout these years, this attempt made a thought to use click evoked ALR as clinical tool with less time consumption and more effectively in some of the hearing impaired population. ALR can also provide an insight to the speech perception abilities in auditory dys-synchrony group.

Implications of the study

- ALR can be used as a quick tool to predict behavioral threshold especially in individuals with sensorineural hearing loss.
- ALR can be used to predict speech perception ability in individuals with auditory dys-synchrony.

- Presence of ALR in auditory dys-synchrony can be considered as an indication for candidacy for cochlear implant.
- It could be a tool to assess the usefulness of the hearing aid.

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