Comparison of tone-ABR and ASSR in prediction of behavoiral thresholds

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

MAY- 2004

Dedecated

To

My Grandpa

CERTIFICATE

This is to certify that the dissertation entitled *"Comparison of tone-ABR* ***and ASSR in prediction of behavioral thresholds"*** is a bonafide work in part of fulfillment for the degree of Master of Science (Speech and Hearing) of the student **(Reg. No.02SH0024).**

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CERTIFICATE

This is to certify that the dissertation entitled *"Comparison of tone-ABR and ASSR in prediction of behavioral thresholds'"* has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any diploma or degree courses.

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DECLARATION

This dissertation entitled *"Comparison of one-ABR and ASSR in prediction of behavioral thresholds"* is the result of my own study under the guidance of Dr. C.S. Vanaja, Lecturer, Department of Audiology, All India Institute of Speech and Hearing, Mysore and not been submitted in any other University for the award of any degree or diploma courses.

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Introduction

Auditory evoked potentials (AEPs) are the electrical responses of the nervous system to auditory stimuli (Stapells, Picton, Preze-Abalo, Read & Smith, 1985). Late latency and middle latency AEPs have failed to be objective techniques for prediction of pure tone threshold due to the dependency on age and state of the subjects. Early latency AEPs have gained wide spread acceptance in clinical audiology as it enables objective estimation of thresholds even in sleeping and sedated subjects. 'However obtaining frequency specific information from AEPs has been a challenging task for an audiologist.

Due to neuropsychological regions, the early latency AEPs are best recorded with very brief stimuli having an almost instantaneous onset (Hall, 1992). Therefore brief duration (0.1msec) clicks, which have an abrupt onset, are by for the most commonly used stimuli for recording auditory brain stem response (ABR), which is an early AEP. It has been reported in the literature that click evoked ABR evaluates the auditory function in the frequency range of 1000 to 4000Hz (Gorga, 1999), due to the spectral characteristic of the stimuli, frequency response of the transducer, ear canal resonance and cochlear physiology. Data from cochlear hearing impaired subjects demonstrate that a click-ABR threshold may represent a wide range (20-80dB) of pure tone thresholds. This is probably due to significant contribution from the more sensitive low frequency regions which leads to underestimation or overestimation heaiing loss (Stapells, Picton & Duriex- Smith, 1994). Hence click evoked ABR has limited usefulness in obtaining frequency specific information.

There are three general methods proposed to obtain frequency specific information from ABR (Stapells et al., 1994). They are masking method, derived response method and tonal method. Tonal method is the most straightforward method. The stimuli used are short duration tone burst, which would maximize frequency specificity and neural synchrony (Hood, 1998). Research has indicated that ABR thresholds for tone burst in quiet can predict pure-tone thresholds (Purdy & Abbas, 2002).

The field of clinical objective audiometry has recently gained a new technique promising to be a valuable addition to the AEPs test-battery. The auditory steady state response (ASSR), evoked by continuous amplitude modulated or mixed modulated tones, demonstrates unique characteristics developed primarily to address many of the limitations presented by the most widely used AEP, the auditory brainstem response (ABR). Unlike ABRs obtained with brief transient stimuli, ASSRs are evoked using sustained modulated tones. These modulated tones are frequency-specific because spectral energy is contained only at the frequency of the carrier tone plus and minus the frequency of modulation. While the 40 Hz responses initially kindled interest, its application has been limited by its susceptibility to state of consciousness (Hall, 1992; Hood, 1998). A faster modulation rate of between *15* - 110 Hz is not significantly affected by sleep or sedation representing essentially the same generators as the auditory brainstem response (ABR) (Lins, Picton & Picton, 1995). These higher rates are suitable for audiometric purposes across populations (Lins , Picton, Boucher et aJ., 1996; Rickards et al., 1994).

ASSR have been investigated in adults and children with varying degrees of hearing loss ASSR threshold in these subjects have generally been highly correlated with behavioural threshold particularly in case of sensory neural hearing loss (Ranee, Rickards, Cohen, Vidi & Clark, 1995). Evoked potential audiogram based on the ASSR threshold obtained in these subjects consistently mirrored both degree and configuration of hearing loss. Cone-Wessson, Dowell, Tomlin, Ranee & Ming (2002) reported a study by Kosmider (1997) who compared ASSR and tone burst ABR at 500Hz and 4000Hz in 10 normal hearing adults. Results showed that there was a good correlation between ASSR and tone-ABR thresholds when objective techniques were applied in detection of response to tone-ABR (Fsp). But tone-ABR was better in detection of thresholds compared to ASSR when subjective methods were used to determine threshold in tone-ABR. However, Aoyagi et al. (1999) compared tone-ABR and ASSR at lOOOHz in subjects with different configuration of hearing loss. Results revealed that in young sleeping children hearing prediction using 80Hz ASSR is more accurate than ABR elicited by tone. Thus studies have shown equivocal results.

The question that arises is whether the AEP technique is able to provide all the necessary information to infer a hearing acuity profile in a clinically viable way. Picton (cited in Swanepoel, Schmulian & Hugo, 2004) specifies five criteria for the 'perfect' AEP in estimating behavioural auditory thresholds. The response must provide a reasonably accurate assessment of hearing threshold. The response should be easily recorded during different states, and changes of arousal. The response must be easily recognisable at all ages. The response should be present at all frequencies of the conventional audiogram. The aim of objective procedures should remain identical to traditional testing i.e. to obtain an audiogram, if not at all frequencies, then at least between 0.5 and 4 kHz. The stimulus used must evoke responses that measure thresholds specific to different frequencies. Arnold (2002) added an additional criterion, the time required to obtain this information. Objective test procedures must be performed as quickly as possible especially in the paediatric population.

Need for the study:

Frequency specificity can be achieved in short latency AEPs using tone ABR or ASSR. Tone-ABR is said to have good frequency specificity (Gorga, 1999). However, spectral splatter cannot be completely eliminated in tone-ABR. ABR to tonal stimuli obtained only at 20 to 30dBSL especially when low frequency tones are used. Stimulus artifacts interfere with the response when high intensity tone is used. So maximum intensity that can be used reliably for tone ABR is less (60 to 70 dBnHL) as compared to click stimuli (Pant & Vanaja, 2002). On the other hand, ASSR is expected to have good frequency specificity as it uses continuous signals and stimulus intensity can be increased till 120 dBHL. In other words ASSR can be recorded from subjects with profound hearing-impaired. However, ASSR gives an objective estimation of threshold ASSR have a limited database and there is a need for more peer reviewed research in adults and infants with hearing loss of varying degrees, configurations and etiologies (Stapells, 2004)

Picton (1995) specified the criteria for a perfect AEP technique in estimation of auditory thresholds. These criteria supply a framework from which one can view emerging AEP techniques providing comparisons with existing techniques, such as the

ABR, in order to determine the advantages and limitations of each. The emergence of the ASSR has necessitated that it be validated along with existing techniques such as the ABR. There is dearth of studies comparing ASSR and ABR and limited research shows equivocal results. Hence the present steady was undertaken.

This investigation was designed to study the following aims:

1) Comparison of tone-ABR and behavioral thresholds in normal and hearing impaired subjects.
2) Comparison of ASSR and behavioral thresholds in normal and hearing impaired subjects.
3) Comparison of ASSR and ABR thresholds in normal and hearing impaired subjects.

Review of Literature

/The threshold estimation is very important in diagnostic as well as rehabilitative audiology. Clinically threshold is obtained by psychophysical methods (behavioral methods) or electrophysiological methods (Objective methods). Behavioral methods pose difficulty in obtaining threshold in difficult to test population due to subjective involvement. Objective technique can be used to predict the thresholds in such population. Recording of auditory evoked potentials is one such electrophysiological method.

Auditory evoked potentials (AEPs) are the electrical responses of the nervous system to auditory stimuli (Stapells et al., 1985). From the very moment that auditory evoked potentials were first recorded from the human brain, audiologists have sought to exploit these responses to evaluate persons who are difficult to test. But early efforts were frustrating and disappointing, neither middle latency response nor late latency response provide entirely satisfactory results. Reproducibility and dependency on the age, state of central nervous system were presenting problems. In 1970's, the advent of auditory brainstem response (ABR) raised the hopes of audiologists substantially. Here was a response that can be reproduced with amazing accuracy yet seemed utterly impervious to fluctuations in the nervous system. Tone-ABR evolved as one of the procedures for obtaining frequency specific thresholds.

Another auditory evoked potential particularly suited to frequency-specific measurement is the auditory steady-state response. Auditory steady state response are recorded from the scalp in response to sinusoidal modulated tones (Amplitude or/and

Frequency). Response follows the modulation frequency, which is a discrete frequency component, and remains constant in amplitude and phase over an infinitely long time period (Regan, 1989 as cited in Picton, John, Dimitrijevic & PurcelL, 2003). This potential is also known as the envelope following response or EFR (Doliphin & Mountain, 1992 cited in Picton et aL, 2003) auditory steady state response or ASSR (Picton, Skinner, Champagne, Kellett & Maiste, 1987), and auditory steady state evoked potential or ASSEP (Rickards et al, 1994)

In this section, tone-ABR and ASSR are compared with respect to picton's criteria for perfect AEP (cited in Swanepoel, Schmulian & Hugo, 2004). The criteria given by picton can be grouped under three categories, stimulus related criteria, subject related criteria and criteria related to threshold estimation.

STIMULUS RELATED CRITERIA.

Picton (cited in Swanepoel, Schmulian & Hugo, 2004) specified that "the perfect AEP technique" should be able to elicit responses at all the frequencies of the conventional audiogram and stimuli used must evoke responses that measure thresholds specific to different frequencies. The stimuli used for recording tone-ABR and ASSR are discussed briefly here.

Tone burst Auditory Brainstem Response

Type of stimuli

Stimuli used for tone-ABR can be tone burst in quiet or tone burst in noise. The tone bursts are operationally defined as gated sinusoids having duration of less than one second (Gorga, Kaminski, Beauchaine & Jesteadt 1988). Acoustics of these stimuli have concentration of energy at the nominal frequency of the tone and side bands of higher or lower frequency (Gorga & Thornton, 1989). This spread of energy to frequency other than nominal frequency of the tone is termed as "spectral splatter" (Durant, 1983). The spectrum of these stimuli is defined by two parameters, duration of the stimuli and rise time. In the spectra, first few milliseconds of the stimulus which is defined as critical duration is important in eliciting onset response. This critical duration is approximately 2msec for 2000Hz and 4msec for 500Hz tones (Kodera, Marsh, Suzuki & Suzuki, 1983). Davis and his collogue recommended the use of2-1-2 cycles, which approximates critical duration, be used for recording tone-ABR.

Generally windowing functions, either linear or nonlinear are used to reduce the spectral splatter of the signal. Linear windowing function results in a 27dB difference between the main lobe and the first side lobe and a further decrease of 12/octive in the side lobe amplitude as one move away from the first side lobe. Blackman window, a non-linear windowing of higher order trigonometric function reduces the energy splatter in the stimulus (Harris, 1978 cited in Stapells et al., 1994). There is a tendency that center lobe widens as side lobe decrease for some gating functions. For a Blackman gated tonal stimuli the first side lobe is -58 dB relative to the energy in the main lobe with slightly wider main lobe than that achieved in linear windows. Side lobe amplitude continues to decrease at a rate of 18 dB/octave after this first side lobe.

For tonal stimuli presented at high intensities there will be likely contribution from frequencies away from tone's nominal frequency due the spectral splatter seen the tonal stimuli (Stapells et al., 1994). Noise masking paradigms may be used to restrict the regions of the basilar membrane contributing to the ABR, and thus improve the frequency specificity of the ABR to high intensity stimuli. The noise used can be high pass noise, notched noise or white noise.

Tonal stimuli presented simultaneously with high pass masking noise prevents auditory nerve fiber with characteristic frequency higher than the high pass cutoff frequency, from contributing to the response with little or no effect on contribution from fibers with characteristic frequency below the high pass cut off frequency. High pass masking technique has been shown to give reliable estimate of hearing sensitivity at 500 Hz in both normal and hearing-impaired subjects (Kileny, 1981). The disadvantage is that it is inappropriate for middle and high frequency tones, which can lead to underestimation of hearing loss.

Notched noise technique can be used is to prevent low, mid, and/or high frequency regions of the cochlea not in tone's nominal frequency from contributing to the response. Stapells et al., (1994) reported that tonal stimuli in notched noise show best correlation with the behavioral thresholds. Thresholds range from 10-20 dB of behavioral thresholds in hearing impaired subjects. Disadvantage of notched noise technique is the spread of masking in to the notch, especially from the low frequency edge (Stapells et al., 1994).

A third masking noise technique that has been suggested to improve the frequency specificity of ABR to tones is white noise masking. The advantage of this type of noise is that it requires less complex instrumentation and calibration than high pass noise and/or notched noise and provides same frequency specificity as notched noise (Stapells et al., 1994). The disadvantage of white noise is that it results in response amplitude which is 33% lower than recorded in notched noise. This is due to partial masking of energy at the tone's nominal frequency (Stapells et al., 1994), making waveform identification more difficult, especially close to threshold.

Frequency of the Stimulus

The ABR to tonal stimuli is generally recorded in the frequency range of 500Hz to 4000Hz. This can also be recorded to higher frequency stimuli above 8000Hz (Gorga, Kaminski, Beauchanie & Bergman, 1993). The latency of wave V decreases with increase in frequency. The wave morphology of wave V recorded to the 500Hz tones is broader in comparison to the response recorded to the 2000 *Hz* and 4000Hz tonal stimuli. Though it has been reported that there is no change in amplitude of the response across frequency (Gorga et al., 1988; Stapells & Oates, 1997), the thresholds estimated at low frequency is slightly higher than that observed at high frequency (Stapells, 2000).

Intensity of the Stimuli

As the stimulus intensity decreases, wave latency increase and amplitude decreases. Theses latency and amplitude changes occur for all stimulus frequencies (Gorga et al., 1988). When presented in quiet, the latency and amplitude changes are greater for response to low frequency tones (Suzuki, Hirai & Horiuchi, 1977). When masked by notched noise, these latency and amplitude changes are same across stimulus frequency (Stapells & Oates. 1997). Many studies carried out on infants, children and adults have shown that tone-ABR can be recorded at 10- 30 dBnHL for tone bursts of 500 to 4000Hz presented in quiet or in noise (Stapells et al., 1994). The

ABR to brief tones does not appear to distinguish between severe and profound hearing loss. The limitation of tone-ABR for evaluation of profound hearing loss is due to the 25 to35dB peak to peak SPL calibration level for OdBnHL, and the output limitations of ear phones.

Auditory Steady State Response

Type of stimuli

ASSR has been recorded with various kinds of stimuli. Initial studies mainly recorded ASSR to clicks and tone burst stimuli. These stimuli have energy at multiple frequencies in the spectrum. Later studies used modulated tones to reduce the spectral energy.

Amplitude modulation (AM) is defined as the change in amplitude of the carrier signal according to the strength of modulating signal. The depth of amplitude modulation is defined as the ratio of difference between the maximum and minimum amplitudes of the signal to the sum of the maximum and minimum amplitudes. The stimuli contain spectral energy at the carrier frequency and at two sidebands on either side of the carrier, at a frequency separation equal to the modulation frequency. Amplitude of the side bands increases as the depth of modulation increases (Picton, et al., 2003). The modulation depth has an effect on amplitude and phase of ASSR. Maximum amplitude reaches at 100% of modulation depth. There is no effect of modulation depth on phase of the response after the 25% modulation depth (John, Dimitrijevic, Van-Roon & Picton, 2001).

Frequency modulation (FM) is defined as a change in the carrier frequency which is determined by the modulating frequency. The amount or the depth of modulation is the difference between maximum and minimum frequency divided by carrier frequency (Picton et al., 2003). Like amplitude modulation, the response to frequency modulation is also affected by depth of modulation. While recording ASSR for 40Hz and 80Hz modulated tone, the response amplitude increases as the depth of modulation increases (Picton et al., 1987; John et al., 2001). FM is not usually preferred due to more spectral width which *is* more than a critical band.

(A stimulus that is modulated for both amplitude and frequency is called as mixed modulation (MM). The spectrum of mixed modulation varies with the relative phase between two modulations, which is termed as modulation index. When the maximum amplitude and frequency occurs at same time then they are in phase. It has been reported in the literature that response to mixed modulation has higher amplitude than AM or FM alone when both AM and FM are in phase and leads to better detection of threshold (Cohen, Rickards & Clark, 1991; John et al., 2002). Cohen, Rickards & Clark, (1991) recommended the use of 90Hz modulation frequency with 100% of AM and 20% of FM.

Frequency of the Stimulus

(The effects of carrier frequency are quite different for stimuli modulated at rates near 40Hz and near 80Hz. The 40Hz response significantly decreases in amplitude with increasing carrier frequency (Galambos, 1981 cited in Picton et al., 2003). For the 80Hz-100Hz responses, the amplitude is larger for the mid frequency than for higher frequencies or lower frequencies. The noise levels also decrease as the frequency is increased which helps in better detection of response in high frequency (Cohen, Rickards & Clark, 1991. The effect of modulation rate on amplitude of the steady state responses may vary with carrier frequency and with the age of the subject. Cohen, Rickards & Clark, (1991) reported that modulation frequency at which the ASSR was most efficiently recorded varied with the carrier frequency. However, these effects are not large in adults. Rickards et al, (1994) found that the response amplitude in neonates was larger at lower modulation frequencies for low carrier frequencies, with optimal value of 72, 85 and 97Hz for 500, 1500, and 4000Hz, respectively. The thresholds estimated at low frequency is little higher than at high frequency (Picton et al., 2003).

Intensity of the stimuli

As the intensity of the signal increases, the amplitude of the response increases and latency decreases. The amplitude of the response increases by 3-9 nV/dB at lower intensities and at higher intensities more rapid increase in amplitude (7.8nV/dB) is seen. The latency increases is quite linear (Lins, Picton & Picton, 1995). The effects of intensity are mediated by multiple physiological factors. So at lower intensities the number of samples required is more to get the response (Hardman & Stapells, 2003). Ranee, Rickards, Cohen, Vidi & Clark (1995) reported that ASSR estimates thresholds with in 8 to 16 dB and as ASSR employs continuous stimuli, the maximum intensity that can be used is 120 dBHL and thus helps in differentiation of severe and profound hearing loss.

Comparison of characteristics of stimuli used for tone-ABR and ASSR

It can be observed from Figer-1 and 2, that spectrum of the modulated signal is less than that seen in tone burst stimulus (Lins, Picton & Picton, 1995). This shows that modulated tone is more frequency specific than tone burst. However, tone burst gated stimuli gives frequency specific information at octave frequencies (Gorga, 1999). For this it can be said that tone burst gated stimuli is as frequency specific as modulated signal for threshold estimation. Purdy and Abbas (2002) reported that tone-ABR using linear window and Blackman window has same frequency specificity and underestimates hearing loss only in steep sloping hearing loss. Similarly, Stapells et al. (1994) reported that tonal stimuli in quiet give as much frequency specificity as in noise except in steep sloping hearing loss. In ASSR, Aoyagi et al. (1999) estimated the audiograms for different configuration of hearing loss and almost 90% present of time ASSR threshold followed the pure tone audiometric configuration. Indicating that ASSR also has good frequency specificity. Thus one can infer from these studies that both tone-ABR and ASSR fulfills one of the Picton's criteria for perfect AEP in similar way. However the maximum intensity of the signal available for testing is higher in ASSR compared to tone-ABR.

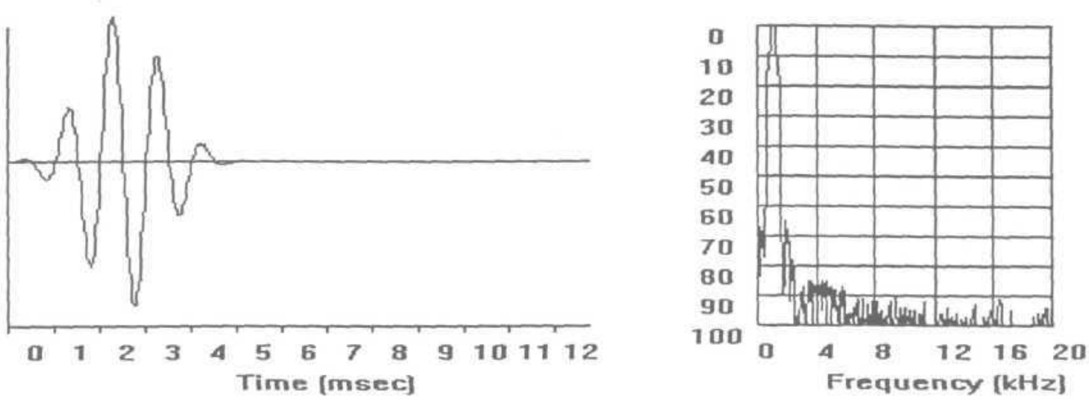


Fig-1: Stimulus wave form and frequency spectrum of 1000 Hz tone burst

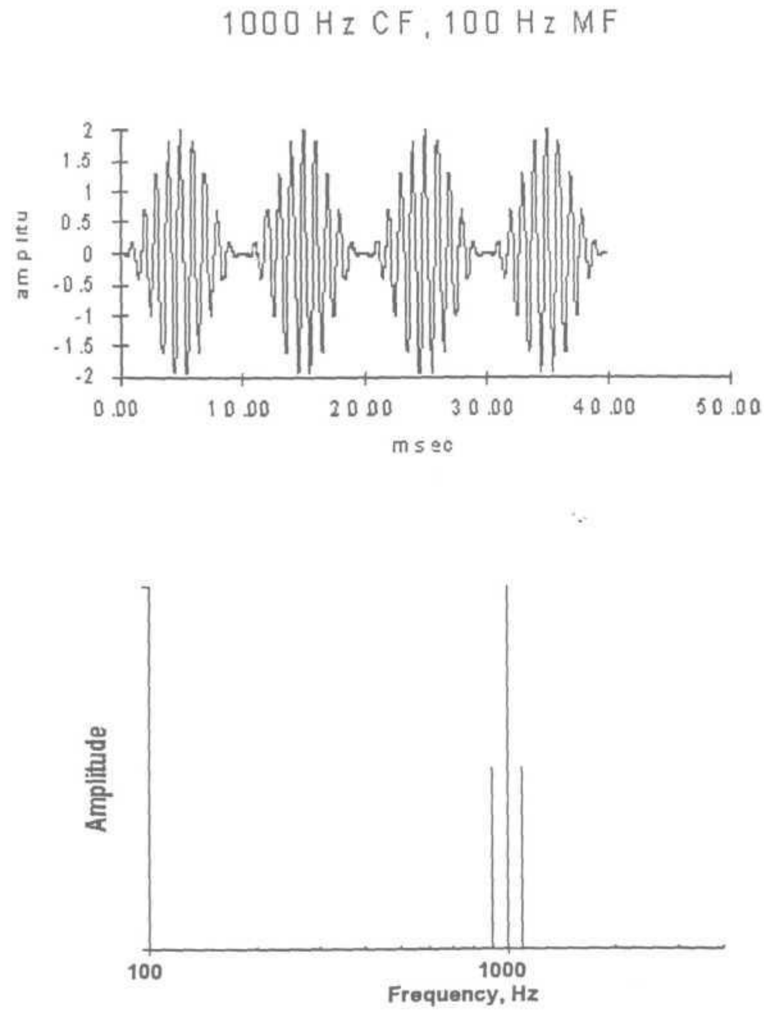


Fig-2: 1000Hz modulated at 100Hz stimuli and frequency spectrum.

SUBJECT RELATED CRITERIA

Picton (Swanepoel, Schmulian & Hugo, 2004) specified that the "prefect AEP technique" should be easily recordable form subjects of all ages, during different states and changes of arousal. The effect age and state of subject on tone-ABR and ASSR is briefly reviewed here.

Subject state

Auditory brainstem response

A majority of the available clinical data indicate that there no difference in ABR waveform and response amplitude recorded in sleep or awake for moderate to high intensity stimuli or for low intensity stimuli close to auditory threshold (Hall, 1992). However, the muscular and movement artifact is a major source of artifact noise in recording ABR and seriously reduce the signal to noise ratio. Therefore it is custmary during clinical measurement of ABR to encourage the subject to sleep or to induce medically drowsy or sleep (Hall, 1992).

Auditory steady state response

ASSR can be obtained to a large range of modulation frequency (20Hz-200Hz). The modulation frequency below 60Hz is not widely recommended for threshold estimation due to dependency on state of subject. It has been reported that the response recorded is inconsistent and threshold is elevated by 10-15dB during sleep (Stapells et al., 1988). Lins, Picton and Picton, (1995) reported that response amplitude for low modulation frequency decreased during sleep. This subject state dependency of response for modulation frequency below 60Hz is attributed to generator sites similar to middle latency response (Cohen, Rickards & Clark, 1991.

Large number of clinical reports shows that the higher modulation frequencies are best recorded during sleep state (Rance et al., 1998; Rickards et al., 1994a). This may be due to the feet that modulation frequency higher than 60Hz are generated from brainstem structures similar to ABR (Cohen, Rickards & Clark, 1991; Aoyagi et al., 1994a; Lins, Picton & Picton, 1995). Lins, Picton and Picton, (1995) reported that the response amplitude is unchanged for higher modulation frequency during sleep. However, Cohen, Rickards and Clark, (1991) reported that background EEG was reduced during sleep and improved the S/N ratio which in turn improves the response detection.

Subject age

Auditory brainstem response

A majority of clinical data shows that tone-ABR can be recorded even in new born infants. Investigators have reported no effect of age on tone-ABR but studies mainly concentrated on threshold estimation rather than the latency and morphology of the wave form (Gorga, 1999; Stapells, 2000).

Studies investigating threshold estimation in infants and children using tone-ABR show good approximation to the behavioral thresholds estimated in later ages (after 6 months) (Stapells et al., 1995; Sininger, Abdala & Cone-Wesson, 1997). Stapells (2000) in his mata-analysis compared the threshold estimated in infants and children with adults. Results show that no difference in thresholds estimated in infants and adults. Similar results are reported by other investigators (Sininger, Abdala & Cone-Wesson, 1997; Stapells et al., 1995).

Auditory steady state response

A large amount of research on ASSR indicate that higher modulation frequencies (>70Hz) are best recorded in infants and children. But low modulation frequencies (<70Hz) are not recommended for infants and children. Aoyagi et al. (1994b) found a general increase in the delectability of 40Hz steady-state response from 6 months to 15 years of age. So the ASSR for lower modulation frequencies are not developed completely developed by birth and are affected by the age of the subject. Cohen, Rickards and Clark (1991) reported that ASSR to low modulation frequencies are generated from the cortical structures and sub cortical structures which matures in later age whereas ASSR to 80Hz and above are mainly generated from the low brainstem structures which matures earlier (Cohen, Rickards & Clark, 1991).

Thresholds estimated in infants and younger children are higher than those obtained in older children and adults. The thresholds are elevated by 10-20dB in infants than those of adults and children older than lyear and there is a decrease in thresholds over first year of life. The decrease is more at high frequencies than at low frequencies (Picton et al., 2003; Savio, Ca'rdenas, Perez-Abalo, Gonzalez & Valden, 2001). However, Ranee et al. (1995) reported that thresholds estimated in children and adults were comparable to the tone-ABR thresholds estimated in infants by Stapells et al. (1995). These differences may be due to the methodological differences across the studies. Ranee et al. (1998) said that ASSR threshold can be recorded at approximately 8 to 16dB above the behavioral thresholds in infants. Thus behavioral thresholds can be well predicted in infants by ASSR.

Comparison of subject related factors affecting tone-ABR and ASSR

To summarize, sleep state does not affect threshold estimation by tone-ABR and ASSR to tones modulated at higher rates. However, probably the muscular and movement artifacts may increase the back ground EEG and reduce signal to noise ratio while recording both the potentials. Though there are equivocal reports on effect of age on ASSR, tone-ABR and ASSR to higher modulation can be used for estimation of threshold in infants and children. So both procedures fulfill Picton's subject criteria for perfect AEP in similar way.

THRESHOLD ESTIMATION

This section gives brief review of investigations carried out to check the efficiency of tone-ABR and ASSR in threshold estimation.

Tone burst Auditory Brainsterm Response

A number of investigators have studied the usefulness of tone-ABR in threshold estimation. Some investigators have used tone in noise whereas others have used tones quiet. Stapells, Picton, Durieux-Smith, Edwards and Moran (1990) studied the thresholds for ABR to tones in notched noise in *20* normal hearing and 20 hearing-impaired subjects. This technique estimated pure tone thresholds within 11.6, 6.1, 6.3 and 0.8 dBnHL at 500, 1000, 2000 and 4000 Hz respectively. These estimates were better in the hearing impaired patients. Similar results were observed by Mannerly, Greville, Purdy and Keith (1991), who obtained ABR thresholds to masked tone pip stimuli from the three groups of hearing impaired subjects. They used high pass masking for 500Hz tone pips and notched noise masking for 1000, 2000 & 4000 Hz tone pips. ABR thresholds in low frequency, high frequency or flat cochlear losses were compared to conventional pure tone audiogram thresholds. There was a positive relationship between ABR thresholds and behavioral thresholds. Absolute ABR threshold at 500Hz was significantly higher than those at higher frequencies.

An investigation by Staplles, Gravel, and Martin (1995) showed that tones in notched noise can be used for threshold estimation even in infants and children. The ABR thresholds for the infants with bilateral normal hearing were 23.6, 12.9 and 12.6 dBnHL for 500, 2000, and 4000 Hz, respectively. Most infants with normal hearing showed ABR to 30 dBnHL tones. Across all the subjects a high (>94%) correlation was found between ABR and behavioral thresholds.

Balfour, Pillion and Gaskin (1998), conducted a study to investigate the usefulness of clicks and non-masked tone burst ABR thresholds and DPOAEs in estimation of behavioral threshold in children with SN hearing loss characterized by islands of normal hearing sensitivity. Tone burst with center frequencies of 500, 1000, 2000, and 4000Hz, were gated through Blackman window with zero plateau. Results indicate that 70% of ABR thresholds in hearing impaired subjects were within 10 dB of respective behavioral threshold and 95% were within 20 dB.

ABR thresholds for tone-burst in quiet are slightly higher than those reported for tone-burst in noise. Saynyukta (1998) reported that the mean tone-ABR thresholds were 23 dBnHL at 500 Hz and 27 dBnHL at 2000Hz for the tone burst in quiet. These results are similar to those reported by Baitte and Torre (1997) who observed mean thresholds of 35dB and 35.6dB for 500Hz and 2000Hz. They also reported that pure tone thresholds predicted based on tone-ABR thresholds were within ±10 dBHL of actual thresholds in 85% of subjects. Research has shown that tone burst in quiet can predict reliable thresholds in subjects with sloping hearing loss (Pant & Vanaja, 2002; Purdy& Abbas, 2002).

Based on mata-analysis of 32 studies, Stapells (2000) reported that tone-ABR thresholds in individuals with normal hearing are around 10 to 20 dBnHL. Tone-ABR thresholds in participants with sensory neural hearing loss are typically 5 to 15 dBSL of behavioral thresholds in adults. There is no significant difference in threshold prediction between infants and adults. Importantly, threshold results are quite consistent across studies, and 95% confidence intervals are no longer than ±5 dB.

Auditory Steady State Response

Over the years, many studies have demonstrated that steady state response to modulation frequencies 75 -100 Hz can provide reliable estimate of hearing thresholds in children and adults. In general the 80Hz response can be recognized at 15 dB above hearing threshold. Aoyagi et al. (1999) have published audiograms which highlights the usefulness of evoked response to tones that are amplitude modulated at 80 Hz in predicting behavioral thresholds. For a group of hearing impaired children and adults, with hearing loss ranging from mild to profound, the correlation between the pure tone and ASSR thresholds ranged from 0.729 at 500 Hz to 0.915 at 4000 Hz. Similarly Lines and colleagues (1996) observed correlation coefficient of 0.82 with the difference between pure tone and ASSR threshold ranging from 9 to 14 dB.

Rickards et al. (1994) estimated the thresholds in 337 normal hearing infants at 500 Hz, 1500 Hz and 4000 Hz. They used the modulation frequency of 72 Hz at 500

Hz, 87 Hz at 1500 Hz and 97 Hz at 4000 Hz. The mean thresholds estimated were 41 dBHL at 500 Hz, 24 dBHL at 1500 Hz and 34.5 dBHL at 4000 Hz. Similar results were reported by Aoyagi et al. (1994).

(Ranee and collegues (1995) predicted hearing thresholds using ASSR in a sample that include children and adults. Participants had sensorfneural hearing losses that were of moderate degree to profound hearing loss. ASSR thresholds were estimated using tones with mixed modulation frequency of 90Hz for carrier frequencies 250 to 4000Hz. Correlation between pure tone and ASSR thresholds was 0.96 for 250 Hz and as high as 0.99 for 2000 and 4000 Hz. The difference between ASSR threshold and behavioral threshold decreased with increase in degree of hearing loss?)

ASSR gained a wider acceptance as a clinical tool after Rance et al. (1998). demonstrated its advantage in determining residual hearing thresholds for those infants and children from whom ABR could not be evoked (at 100 dBnHL) using click stimuli/ ASSRs were obtained using mixed modulation for stimulus frequency at 250 to 4000 Hz with modulation frequency of 90 Hz. In a sample of 109 children, whose hearing loss ranged from moderate to profound, the average discrepancy between ASSR and behavioral thresholds was only 3 to 6 dB (with standard deviation of 6 to 8), with larger discrepancies and standard deviation found at 250 Hz and 500 Hz as in previous studies. ASSR thresholds were within 20 dB of pure tone thresholds for 99 % of comparisons and less than 10 dB for 82 % of subjects.

Comparison of tone-ABR and ASSR in threshold estimation

As tone ABR and ASSR are two approaches that help us to estimate the thresholds, having their own advantage and disadvantages, studies have compared the threshold estimation in both. Cone-Wess on et al. (2002) reviewed a study in which ASSR and tone ABR were compared at 500 Hz and 4000 Hz in normal adults. Results showed a good correlation between ASSR and tone-ABR threshold when objective techniques (Fsp) was applied in detection oftone-ABR. But tone burst ABR was better than ASSR in detection of thresholds when subjective methods were used to determine thresholds in tone ABR. However, Aoyagi et al. (1999) reported that ASSR is more accurate when compared to tone ABR, in determining thresholds in young children. This conclusion was based on an investigation comparing tone ABR and ASSR at l000 Hz in subjects with different configuration of hearing loss. Statistical analysis showed no significant difference between tone-ABR and ASSR threshold. However hearing prediction using 80Hz ASSR was more accurate than that by auditory brainstem response elicited by tone.

Thus, a review of literature shows that both tone-ABR and ASSR fulfills Picton's criteria for a perfect AEP. However, there is dearth of information on relative advantage of one over the other, in threshold estimation.

Method

Subjects:

Subjects were divided in to two groups control group and experimental group. Control group included a sample of 20 normal-hearing subjects (10 females & 10 males) between 18- 30 years of age. Behavioral pure tone thresholds were 15 dB HL or less at octave frequencies between 0.5 and 4 kHz (ANSI, 1996) Experimental group included 15 ears of subjects with cochlear hearing loss in the age range of 18 to 50 years. The behavioral threshold ranged from 25 dB HL to 85 dB HL.

Instrumentation:

Calibrated diagnostic audiometer was used for estimation of pure tone thresholds. Calibrated GSI-33 (Version-2) middle ear analyzer was used for Immittance measurements. Nicolet Bravo (Version-4.0) was used for recording tone-ABR and GSI Audera ASSR (Version 1.0.2.2) was used for recording ASSR.

Test environment:

All the experiments were conducted in acoustically treated room.

Procedure:

Puretone thresholds were obtained using modified Hughson and Westlate procedure (Carhart & Jarger, 1959), across octave frequencies from 250 to 8000Hz for air conduction and 250 to 4000Hz for bone conduction. Tympanometery and reflexometery was carried out to rule out any middle ear pathology.

Subjects were reclined on the bed and were instructed to relax, close their eyes and sleep if possible while recording tone-ABR and ASSR. Tone-ABR and ASSR were recorded from single channel. The site of electrode placement was prepared with skin preparing gel. Silver chloride (AgCl) electrodes were placed with conducting gel. The non inverting electrode was placed on the forehead inverting electrode on the test ear and common electrode on the non-test ear. It was ensured that the inter electrode impedance was <5 KΩ.

Tone ABR and ASSR were recorded using the test protocol given in the Table-1 and Table-2 respectively.

Table - 1: Test protocol tone ABR

Type of the stimuli	Tone burst
Transducer	Supraural Earphone (TDH-39)
Test frequency	500Hz, 2000Hz, 4000Hz
Polarity	Alternating
Envelope	Blackman
Duration of stimuli	2cycles rise time-1 cycle platue-2cycle fall time
Number of samples	2000
Repetition rate	30.1/sec
Intensity	varied to estimate threshold
Time window	24msec

Table- 2: Test protocol for ASSR

Type of the stimuli	Mixed modulated stimuli
Transducer	Supraural Earphone (TDH-39)
Test frequency	500Hz, 2000Hz, 4000Hz
Modulation frequency	78Hz-500Hz, 89Hz-2000Hz, 91Hz-4000Hz
Depth of Amplitude modulation	100%
Depth of Frequency modulation	10%
Noise level criteria	-122.5dBv (Cohen, 1991)
Intensity	Varied to estimate threshold

Thresholds were obtained by using a bracketing approach. At higher intensities 10-20 dB steps were used and at lower intensities 5dB steps were used to vary the intensity. The frequencies to be tested were chosen randomly. In hearing loss group, the testing was carried out in only in one ear due to time constraints. Eighth nerve, brainstem pathologies and auditory desynchrony were ruled out using click-ABR and other special tests.

The recording parameters like repetition rate, time window was changed very minimally if the artifacts were more. The presence of tone-ABR in each condition was determined by replicability of the ABR V-V slow wave. The change in latency and amplitude with change in intensity and frequency of stimulus were also used confirm the presence of the response. In ASSR response detection was determined objectively. The instrument automatically determined the presence or absence of response based on the phase coherence of the responses.

Owing to the equipment limitations maximum stimulus intensity for tone-ABR testing was limited to 90 dBnHL at all the frequencies. The maximum intensity for ASSR and behavioral testing was 120 dBHL.

Results

To investigate the aims of the present study, statistical analysis using SPSS software (version, 10.0) was carried out for the data obtained. The statistical analysis includes descriptive statistics, paired sample t-test. and linear regression. Comparison of behavioral and tone-ABR threshold, behavioral and ASSR threshold and tone-ABR and ASSR thresholds are presented separately.

A) Comparison of behavioral and tone-ABR thresholds in subjects with normal hearing and hearing loss.

I) The relationship between tone-ABR and behavioral threshold.

ABR to tone burst could be recorded from all the subjects with normal hearing. However, it was absent at some of the frequencies in subjects with hearing loss. This was observed when degree of hearing loss more. The data was not considered for statistical analysis if there was no response for tone-ABR. After deletion of the no response data, the N was only nine for each frequency in the hearing loss group. Descriptive statistics of behavioral thresholds and tone-ABR thresholds for the two groups (normal and hearing loss) are presented in Table-3 and Table-4.

Table-3: Mean. SD of behavioral thresholds and tone-ABR thresholds for subjects with normal hearing.

Tests		500Hz	2000Hz	4000Hz
Behavioral threshold in dBHL	Mean	12	10.5	10.7
	SD	4.1	4.2	3.7
Tone-ABR threshold in dBnHL	Mean	40.5	26.5	23.7
	SD	9.0	7.7	7.4

TabIe-4: Mean. SD of behavioral thresholds and tone-ABR thresholds for subjects with hearing loss.

Tests		500Hz	2000Hz	4000Hz
Behavioral threshold in dBHL	Mean	43	50.9	55.7
	SD	15.3	16.3	19.1
Tone-ABR threshold in dBNHL	Mean	47.4	54.1	56.8
	SD	14.7	17.6	19.0

As shown in Table-3, in subjects with normal hearing the tone-ABR thresholds were higher than behavioral thresholds at all the frequencies. The mean thresholds were higher at low frequency (40.5dBnHL 500Hz) and show a gradual decline to lower value with increase in frequency (23.7dBnHL at 4000Hz). A sample of tone-ABR waveforms for 500Hz, 2000Hz and 4000Hz in subjects with normal hearing is presented in Fig-3.

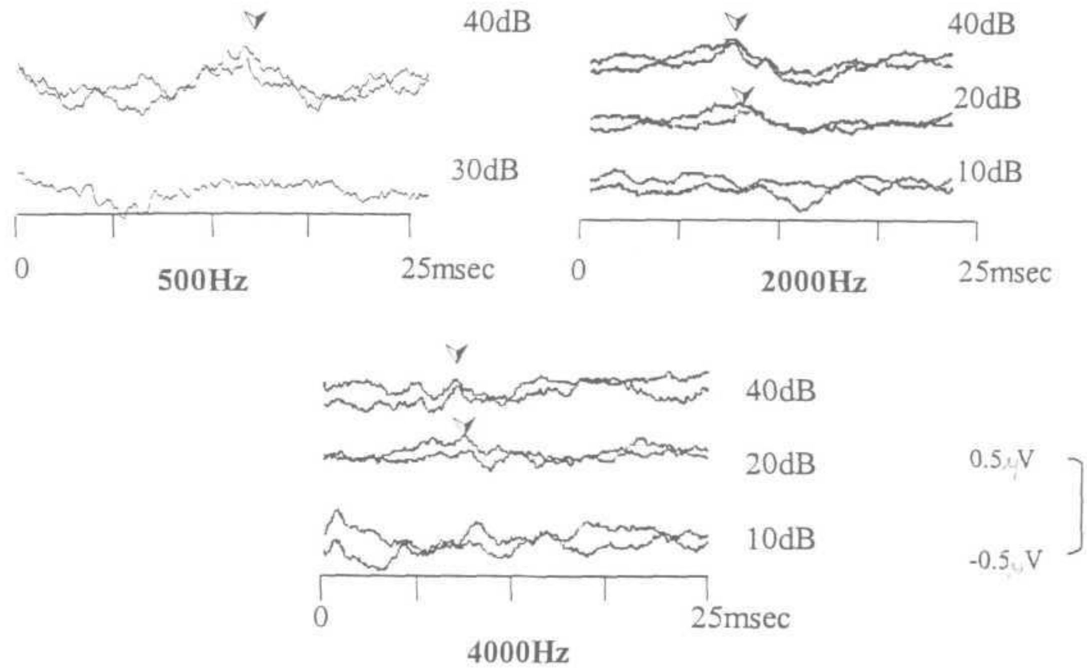


Fig-3: Tone-ABR waveforms of subjects with normal hearing at 500Hz (left), 2000Hz (right) and 4000Hz (below). For each frequency from the 40dB still no response in 10 dB steps. Response is shown by arrow mark.

To study the relationship between behavioral thresholds and tone-ABR thresholds. Threshold difference scores i.e difference between tone-ABR threshold and behavioral threshold were computed in subjects with normal hearing and hearing loss. Mean, SD of the threshold difference scores are presented in Table-5.

Table-5: Mean and SD of difference score in subjects with normal hearing and hearing loss.

Groups		500Hz	2000Hz	4000Hz
Normal	Mean	25	16.3	13.4
	SD	10	10.4	10.6
Hearing loss	Mean	18.1	16.1	14.S
	SD	8.2	12.9	12.2

It can be observed from **the** table that, the mean difference **score** is higher at low frequency i.e 500Hz and gradually declines with increase in frequency in subjects with normal hearing as well as those with hearing loss. The paired sample t-test showed a significant difference ($p<0.01$) between the values obtained at 500Hz and high frequencies (2000Hz and 4000Hz) but there was no significant difference between the values obtained at 2000Hz and 4000Hz for both the groups. The mean difference scores were slightly lower in subjects with hearing loss than those with normal hearing. This difference between groups was statistically significant at 0.05 level.

It can be noted that the difference between tone-ABR thresholds and behavioral threshold was within 40 dB of behavioral threshold in 96% of subjects at 500 Hz, with in 25 dB in 93% of subjects at 2000 Hz and with in 20 dB in 96% at 4000 Hz. Overall, in 70% of the subjects the difference between tone-ABR and behavioral threshold was less than 15dB in both the groups.

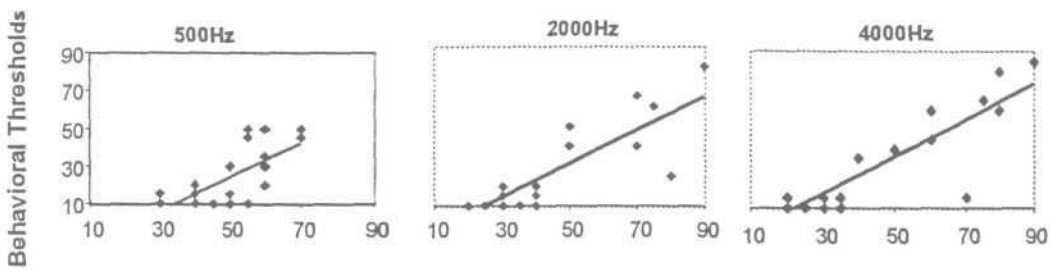
Pearson product movement correlation demonstrated a significantly ($p<0.01$) high correlation between behavioral threshold and tone-ABR threshold. The values of correlation coefficients are given in Table-6.

Table-6: Correlation coefficient values between tone-ABR and behavioral threshold.

Frequencies	500Hz	2000Hz	4000Hz
Correlation coefficient (r)	.74	.87	.90

II) ***Prediction of Behavioral thresholds***

To predict the behavioral thresholds (dBHL) from the tone-ABR thresholds (dBnHL) two procedures were used. One is linear regression wherein equations were estimated for each frequency with data from the two groups. The regression lines were fitted in a scatter plot and presented in graphical from in the Fig-4. The regression equations and their standard error were given Table-7.



Tone-ABR thresholds

Fig-4: A scatter plot for behavioral thresholds (Y-axis) and tone-ABR threshold (X-axis) fitted with regression line for 500Hz (left), 2000Hz (middle), and 4000Hz (right).

Table-7: Regression equation and standard error for prediction of behavioral thresholds from ASSR.

Frequency	500Hz	2000Hz	4000Hz
Regression equation*	Y= X (.89) - 20.69	Y=X(.84)- 10.6	Y= X (.92) -10.4
Standard error	7.3	3.8	3.7

* X' is the tone-ABR threshold and ' Y' is the predicted behavioral threshold of the respective frequencies.

From the regression equation it can be noted that the gradient is close to one and ihe constant is less which indicate that tone-ABR threshold is close to the behavioral threshold. Standard error is low indicating that the variability is less. The same can also be observed in the graphs presented in Fig-4 where scores are distributed around regression line. The difference between predicted threshold and the actual behavioral threshold were calculated and rounded to nearest 5 dB. The percentage of subjects having thresholds which correspond within ±5 dB to ±20 dB of the behavioral threshold was computed from the two groups.

In the second procedure, behavioral threshold were computed by simple correction method from the mean threshold difference scores obtained. The correction values were -25 for 500 Hz, -16.3 for 2000 Hz and -13.4 for 4000 Hz in subjects with normal hearing. For subjects with hearing loss the correction factors were -18.1 for 500 Hz, -16.1 for 2000 Hz and -14.8 for 4000 Hz. The difference between this predicted threshold and actual behavioral threshold were calculated for two groups based on appropriate correction factor given above. The percentage of subjects whose predicted threshold was with in ±5dB to ±20dB of actual threshold was calculated. These percentage scores estimated in the two procedures are presented in Table-8.

Table-8: Percentage of subjects whose predicted threshold fall with in ±5 dB to ± 20 dB of behavioral threshold in both the groups.

Procedures		500 Hz	2000 Hz	4000 Hz
Percentage predicted from the simple correction method	±10 ±15 ±20	79.3% 96.5% 100%	89.6% 93.1% 93.1%	79.3% 86.2% 89.6%
Percentage predicted from linear regression equation	±10 ±15 ±20	75.8% 93.1% 100%	93.1% 93.1 % 93.1%	82.8% 93.1% 96.5%

*Y' = predicted threshold behavioral threshold.

It is evident from the table that, the total predicted behavioral thresholds fall with in ±10dBHL of the actual behavioral thresholds in 75% to 93 % of the subject when linear regression was used and in 70% to 90% of the subjects for the simple correction method. Liner regression analysis was more accurate in predicting the behavioral threshold especially at high frequencies.

Ill) Estimating the configuration of audiogram

The audiogram configuration was predicted in ten hearing loss subjects in whom the tone-ABR threshold was available for at least one frequency. A no response was considered as l00 dBnHL and thresholds were estimated from the regression equation and audiogram configuration was drawn from the thresholds. This configuration was compared with audiometric configuration estimated with behavioral method of that subject. Results showed tone-ABR could accurately predict the configuration in eight out often subjects.

B) Comparison of behavioral and ASSR thresholds in subjects with normal hearing and hearing impairment.

I) Relationship between behavioral threshold and ASSR

ASSR could be recorded from all the subjects with normal hearing except from one subject at 500 Hz and 2000 Hz. However, it was absent at some of the frequencies in subjects with hearing loss. This was observed when degree of hearing loss more. The data was not considered for statistical analysis if there was no response for ASSR. After deletion of the no response data the N was only eight for 500 Hz, seven for 2000

Hz and five for 4000 Hz hearing loss group. Descriptive statistics of behavioral thresholds and ASSR thresholds in two groups (normal and hearing loss) are presented in Table-9 and Table-10.

Table-9: Mean. SD of behavioral thresholds and ASSR thresholds in subjects with normal hearing.

Tests		500Hz	2000Hz	4000Hz
Behavioral threshold in dBHL	Mean	12	10.5	10.7
	SD	4.1	4.2	3.7
ASSR threshold in dBHL	Mean	49.7	35.0	35.7
	SD	13.9	16.4	15.0

Table-10: Mean, SD of behavioral thresholds and ASSR thresholds in subjects with hearing loss.

Tests		500Hz	2000Hz	4000Hz
Behavioral threshold in dBHL	Mean	43	50.9	55.7
	SD	15.3	16.3	19.1
ASSR threshold in dBHL	Mean	61.8	.74.2	76.0
	SD	14.1	23.7	32.0

As shown in Table-9, in subjects with normal hearing the ASSR thresholds were higher than behavioral thresholds at all three frequencies. The mean thresholds were higher at low frequencies (49.7dBnHL at 500Hz) and showed a gradual decline to lower value with increase in frequency (35.7dBnHL at 4000Hz).

To study the relationship between behavioral thresholds and ASSR thresholds, Threshold difference scores i.e difference between ASSR threshold and behavioral were calculated in subjects with normal hearing and hearing loss. Mean and SD of the difference scores are presented in Table-11.

Table-ll: Mean and SD of difference score in subjects with normal hearing and hearing loss.

Groups		500 Hz	2000 Hz	4000 Hz
Normal	Mean	37.5	23.3	23.4
	SD	12.3	12.3	12.4
Hearing loss	Mean	20.0	31.4	23.7
	SD	14.6	22.1	6.2

It can be observed from the table that, the mean difference score is higher at low frequency (37.5 at 500Hz) and gradually declines with increase in frequency (23.4 at 4000 Hz) in subjects with normal hearing as well as those with hearing loss. Paired sample t-test showed a significant difference ($p<0.01$) between the values obtained at 500Hz and 4000Hz but no significant difference between 500Hz and 2000Hz in both the groups. The mean difference scores were lower in subjects with hearing loss than those with normal hearing. This difference between groups was statistically significant at 0.01 level.

It was noted that the difference between ASSR threshold and behavioral thresholds was within 40dB of behavioral threshold in 75% of subjects at 500Hz, within 25dB in 93.1% of subjects at 2000Hz and within 20dB in 96.3% at 4000Hz.

Pearson product movement correlation demonstrated a significantly ($p<0.01$) high correlation between behavioral threshold and ASSR threshold. The values of correlation coefficients are shown in Table-12.

Table-12: Correlation coefficient for ASSR thresholds and behavioral thresholds

Frequency	500Hz	2000Hz	4000Hz
Correlation coefficient (r)	.49	.75	.87

II) Prediction of behavioral thresholds from ASSR thresholds.

To predict the behavioral thresholds (dBHL) from the ASSR thresholds (dBHL) two procedures were used. One is linear regression wherein equations were estimated for each frequency for the data obtained from both the groups. The regression lines are fitted in a scatter plot and presented in graphical from in the Fig-5. The regression equations are shown in Table-13.

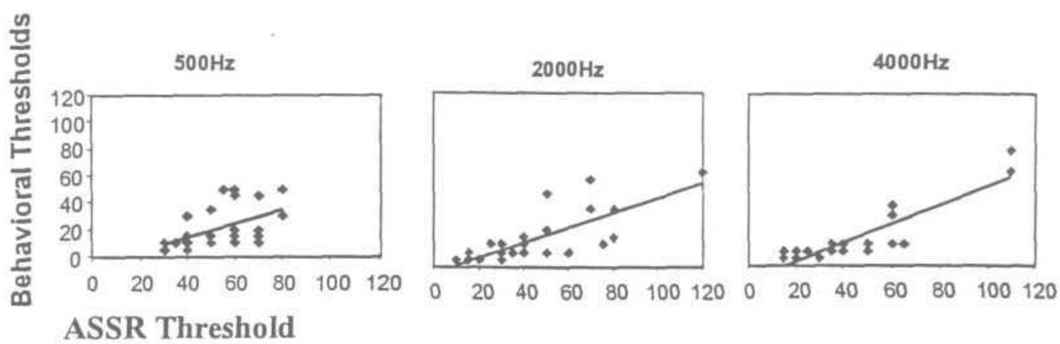


Fig-5: A scatter plot for behavioral thresholds (Y-axis) and ASSR threshold (X-axis) fitted with regression line for 500Hz (left), 2000Hz (middle), and 4000Hz (right).

v

Table-13: Regression equation and standard error for prediction of behavioral thresholds from ASSR.

Frequency	500Hz	2000Hz	4000Hz
Regression equation *	Y= X (0.499) -20.66	Y=X (0.51)-4.91	Y= X (0.65) -10.6
Standard error	9.6	4.7	3.7

* 'X' is the ASSR threshold and ' V is the predicted behavioral threshold of the respective frequencies.

From the regression equation and fig-5, it can be observed that the gradient is not very close to one which indicates that ASSR threshold is far from behavioral and high standard error scores indicates more variability at low frequency. The difference between predicted threshold and actual behavioral threshold was calculated and rounded to the nearest 5 dB. The percentage of subjects having thresholds within ±10 dB to ±20 dB of behavioral thresholds was computed.

In the second procedure, behavioral thresholds were computed by simple correction method from the mean threshold difference scores. The correction factor was -37.5 for 500 Hz, -23.3 for 2000 Hz and -23.4for 4000Hz in subjects with normal hearing. For subjects with hearing loss the correction factors were -20.1 for 500 Hz, -31.4 for 2000 Hz and -23.7 for 4000 Hz. The difference between this predicted threshold and actual behavioral threshold were calculated for two groups based on appropriate correction factor given above. The percentage of subjects having thresholds which correspond with in ±10dB to ±20dB of the behavioral threshold was computed. These percentage scores estimated in the two procedures were presented in Table-14.

Table-14: Percentage of subjects whose predicted threshold was with in ±10 to ±20 of actual threshold.

Procedure	Y'*	500Hz	2000Hz	4000Hz
Percentage predicted from simple correction method	±10 ±15 ±20	41.3% 86.2% 93.1%	59.0% 77.7% 88.8%	55.3% 85.2% 95.6%
Percentage predicted from linear regression equation	±10 ±15 ±20	55.0% 75.8% 86.3%	72.4% 79.3 % 82.7%	74.8% 86.1% 96.5%

*Y'= predicted threshold behavioral threshold.

It is evident from table that, the predicted behavioral thresholds were within ±10dBHL of actual behavioral thresholds in 55% at 500 Hz to 80 % at 4000 Hz of the subjects for the regression equation. In general thresholds prediction by linear regression equation is better than simple correction method. The predictions were better when regression equation was used especially at high frequencies.

Ill) Estimating the configuration of audiogram

The audiogram configuration was predicted in ten hearing loss subjects in whom the ASSR threshold was available for at least one frequency. A no response at maximum level was considered as 120dBHL and thresholds were estimated from the regression equation and audiogram configuration was drawn from the thresholds. This configuration was compared with audiometnc configuration estimated with behavioral method of that subject. Results showed ASSR could accurately predict the configuration in seven out often subjects.

C) Comparison of tone-ABR and ASSR.

The results described in the previous sections shows that the ASSR threshold was higher than tone-ABR thresholds in both groups. The standard deviation was also higher for ASSR threshold (ranges from 13-16) when compared to tone-ABR threshold (ranges from 7-9). Paired sample t-test showed a significant difference ($p<0.001$) between ASSR threshold and tone-ABR threshold obtained in both the groups.

The results of regression analysis revealed that both ASSR and tone-ABR can be used to predict behavioral threshold. However the present data indicates that tone-ABR is a better indicator of behavioral threshold when compared ASSR. But in estimating configuration of audiogram both are almost equally efficient. Samples of audiogram configurations predicted by tone-ABR and ASSR in hearing impaired subjects were presented in Fig-6.

The time required for recording both potentials were also comparable. The time required per trail in Audera instrument is 64x 1.486msec, plus 8sec or 104sec i.e around 2 min. Tone- ABR for 2000 sweeps also require similar amount of time.

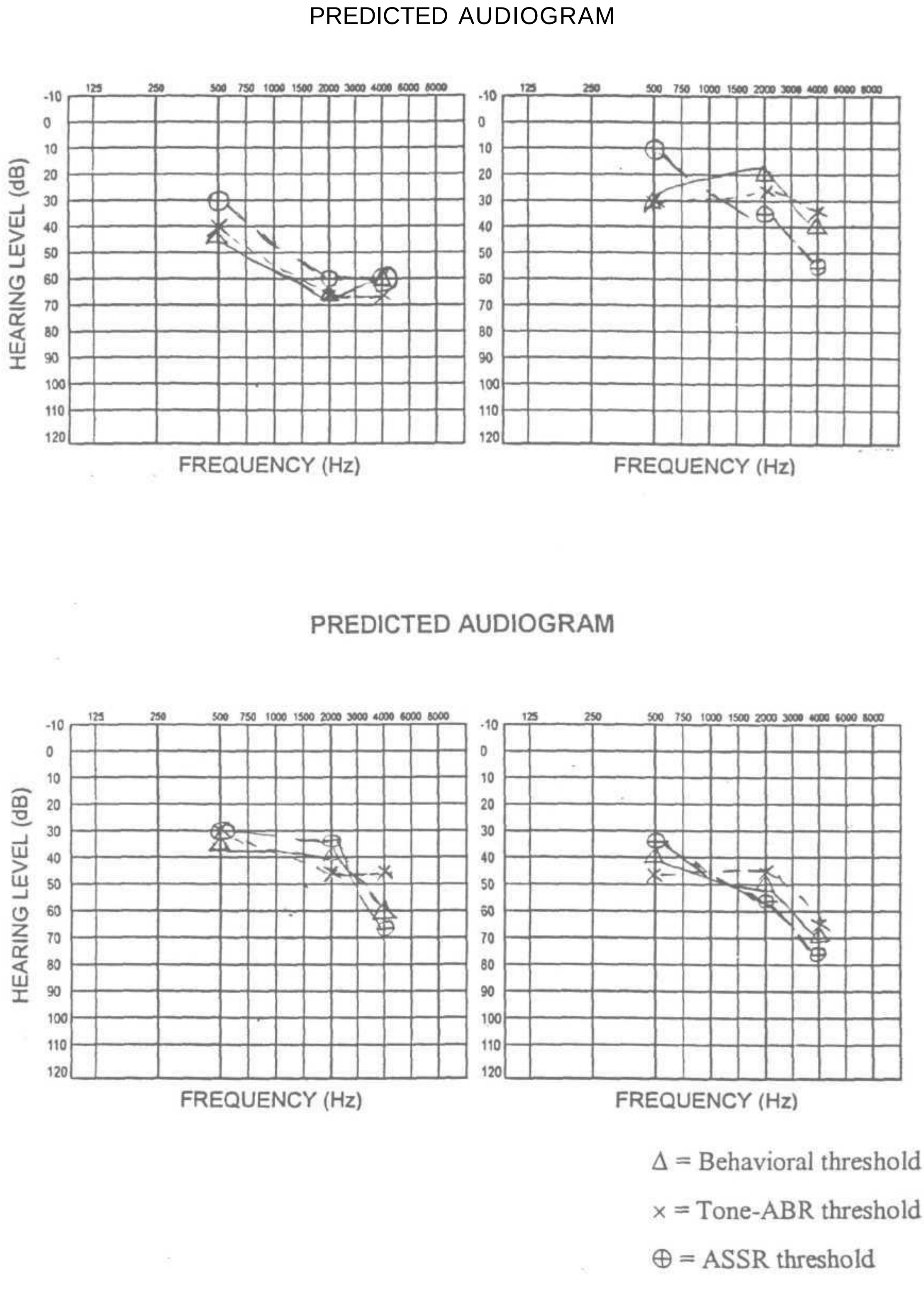


Fig. 6: A sample of predicted audiograms for subjects with hearing loss

Discussion

A) Comparison of tone-ABR and behavioral threshold.

Results in the present study shows that tone-ABR thresholds were higher than behavioral thresholds, The mean and SD obtained in the present study are similar to those reported by some of the investigators in literature (Groga et al., 1988; Beattie & Torre, 1997; Snayukta, 1996; Pant & Vanaja 2003). However tone-ABR threshold lower than those reported in the present study have been reported by other investigators (Stapells et al., 1990; Stapells et al., 1995; Groga et al., 1993). The SD in the present study is also similar to those reported in literature (Groga et al., 1988: Beattie & Torre, 1997; Snayukta, 1996; Pant & Vanaja 2003; Stapells et al., 1990: Stapells et al., 1995; Groga et al., 1993), which indicates the variability is same across the studies. This difference in mean scores may be attributed to the procedural variability. Some of the investigators used more number of averages at threshold level. This would have leads to lower estimation of threshold. Although mean thresholds; are higher in tone-ABR, the thresholds were within 15dB of behavioral threshold in 60% to 93% of subjects. Similar results were presented by Stapells et al. (1995) in infants and children.

The difference between tone-ABR threshold and behavioral thresholds for **low** frequencies is higher when compared to high frequencies (Stapells et al., 1990; **Beame** & Torre, 1997; Stapells et al 1995; Gorga et al., 1993). Present study also shows similar results. Gorga et al. (1988) attributed this to broader displacement of **basilar** membrane for low frequency stimuli, leading to temporally more diffuse response **and** reduce neural synchrony. Also the tone-ABR waveform for low frequencies is **broader** than that of high frequency and has more low frequency spectrum (Stapells et al., 1990) therefore it is more affected by the background electrical activity. Thus response detection is more difficult at low frequency than at high frequency (Stapells et al., 1995).

The difference between tone-ABR threshold and behavioral threshold were little higher for subjects with normal hearing than those obtained for subjects with hearing loss. This can be explained by phenomena of recruitment or softness imperception seen in subjects with hearing loss (Gorga et al., 1988).

The clinical relevance of the any objective measure of hearing lies in its ability to predict behavioral threshold. A high correlation coefficient and near unity gradient in regression equation indicate similar changes in both measures over a wide range of hearing loss. Similar results were reported by earlier investigators (Stapells et al., 1990; Stapells et al., 1995). But the constant is little higher at low frequencies in the present study. The higher constant may be due to higher estimate of thresholds in the present study, which may be because of limited number of averages used. The thresholds predicted by linear regression were similar to those given by Stapells et al., (1995). The threshold predicted from the regression equation fall within ±10dB in 70% of subjects at 500Hz and 90% of subjects at 4000Hz. Similar results are reported by Beattie and Torre, (1997). Threshold predicted from the threshold simple correction method is almost similar to those reported in regression equation at high frequencies. Audiogram configuration was predicted correctly in eight out often subjects. These results were similar to those reported by Stapells et aL, (1995).

In general, the results of the study complement and confirm the results of large number of studies which have indicated that ABR to 500Hz to 4000Hz brief tones provided reasonable estimates of behavioral threshold. (Beattie & Torre, 1997; Satpells et al., 1995; Gorga et al., 1988; Groga et al., 1993; Sanyukta, 1996; Pant & Vanaja, 2003).

B) Comparison of behavioral and ASSR threshold.

The ASSR thresholds for the subjects with normal hearing and hearing loss obtained in the present steady are higher than the behavioral thresholds. The results of the current study are similar to some of the earlier investigators (Aoyagi et al., 1994a; Ranee et al., 1995; Richards et al., 1994). However a few investigators (Rance et al., 1998; Aoyagi et al., 1999) have reported lower ASSR thresholds than obtained in the present study. Although mean value varied across these studies the SD is similar across these studies (Aoyagi et al., 1994a; Richards et al., 1994,&, Aoyagi et al., 1999), indicating similar variability across the studies. However, Rance et al. (1995 and 1998) reported lower SD than the present study. These variation in mean and SD across studies may be attributed to the methodological variability such as subject state. Cohen, Rickards & Clark (1991) observed that in REM sleep state (sedated sleep) the background EEG noise level was lower than in relaxed or first few stages of sleep. This high noise level in relaxed or first stage of sleep may obscure the response. In the present study subjects are requested to relax or sleep. Some of the subjects slept during testing but their stage of sleep was not controlled. This would have caused more variation and higher threshold than Rance et al., (1998) who studied sedated subjects.

In total the ASSR thresholds were within 25dB of behavioral threshold in 50-70% of the subjects.

The difference between ASSR threshold and behavioral threshold was higher at low frequency when compared to at high frequency. These results are similar to those reported earlier in the literature (Aoyagi et al., 1994a; Rance et al., 1995; Richards et al., 1994). Cohen, Rickards & Clark (1991) observed that amplitude of the response to steady state stimuli is lower at low frequency and Picton et al. (2003) reported that higher noise floor is seen in EEG wave for low frequency. These factors may pose difficulty in response detection at low frequency. These may account for the higher threshold estimation in low frequency. The difference between ASSR threshold and behavioral threshold was lower in subjects with hearing loss than normal this may be attributed to soft ness imperception or recruitment (Rance et al., 1995).

There was a significant correlation between ASSR and behavioral threshold and correlation coefficient ranged from 0.45 to 0.72. However the correlation values were lower than those reported by Rance et al. (1995). This discrepancy may be attributed to the subject state as explained before. It is observed in the present study, that in the regression equation the gradient value was less and there was more scatter of scores around regression line in scatter plot than those reported by Rance et al. (1995). Thresholds estimated from linear regression shows that estimated threshold was within ±10 dB of behavioral threshold in 50% of subjects at 500 Hz, 70% of subjects at 2000 Hz and 70% of the subjects at 4000 Hz. Simple correction scores shows lower value than linear regression value. ASSR could estimate the audiometric configuration in seven out often subjects which is similar to those reported by Aoyagi etal. (1999).

C) Comparison of tone-ABR and ASSR in prediction of behavioral threshold.

Limited data exists comparing tone-ABR and ASSR in estimating behavioral thresholds. The mean tone-ABR threshold compared to ASSR threshold favored tone-ABR by l0 dB in the present study. Tone-ABR threshold was significantly lower than ASSR threshold. Cone-Wesson et al., (2002a) reported a study by Kosmider, (1997) which supports the present study. Cohen, Rickards & Clark (1991) reported that EEG level was higher in awake and initial stages of sleep than REM state. The more background electrical activity was due to myogenic activity at these sleep states than REM state. The amplitude of steady state response is lower than the tone-ABR response (John et al., 2003). Lower amplitude and high background electrical activity may pose difficulty in response detection for ASSR than tone-ABR. This may explain the higher thresholds seen in ASSR for the present study where subjects are not in deep sleep. However Aoyagi et al. (1999) said that there is no significant difference between ASSR and tone-ABR but ASSR thresholds were little lower than tone-ABR. The study by Aoyagi et al. (1999) was carried out on children under sedated sleep, where EEG activity was lower and comparison was done only at 1000 Hz. This would have caused the discrepancy among two the studies. A comparison of the audiogram configuration predicted by tone-ABR and ASSR show that prediction audiometric configuration was almost similar in both the procedures. In the present study ASSR could not be obtained for adult subjects with severe hearing loss which might be because of subject state. To cross check this, four subjects with profound hearing loss were tested by play audiometry to obtain behavioral threshold and ASSR was carried out under sedation. Results showed that for one subject ASSR could predict threshold within 5 dB of behavioral threshold. For all the other subjects it was absent and the behavioral threshold ranged from 115 dB to 120 dBl Similar results are reported in sedated children by Rance et al. (1998). This supports the above statement that subject state is the main factor which is affecting the present study.

The thresholds predicted in the present study by tone-ABR fall within ±10dB of behavioral threshold in 75%- 85% of subjects whereas those predicted by ASSR falls within 55% to 75% of subjects. There fore it can be noted that ASSR threshold prediction is more variable than tone-ABR in the present study. More variability in ASSR threshold may be attributed to subject state as explained before.

Although the threshold estimation is important factor in comparison of ASSR and tone-ABR, it can be noted from that literature that the threshold prediction by both methods shows variability across studies. So other factors need to be considered. One such factor is frequency specificity. As seen from the review, both have equal frequency specificity with respect to threshold estimation. The time taken for threshold estimation is another critical factor. If single frequency is tested at a time, ASSR requires same time as tone-ABR. The advantage of ASSR lies in use of high intensity up to 120dBHL which help in differentiating severe and profound loss as reported by Rance et al., (1995) and also seen in our study. With respect to response detection both ASSR and tone-ABR has objective procedures. ASSR detection involves only objective procedures which restrict the audiologist's role. Sometimes artifactual responses may be considered as response in objective procedures. This could lead to spurious results and hence may be drawback for clinical use of ASSR.

From the discussion it can be concluded that both tone-ABR and ASSR to 80Hz are equally efficient in threshold prediction and estimating audiogram configuration. It's important to control the subject state while recording ASSR for higher modulation frequency.

Summary and Conclusions

Obtaining frequency specific threshold information by objective procedures has been an important issue in diagnostic as well as rehabilitative Audiology. Frequency specificity can be achieved in short latency AEPs by using tone ABR and ASSR. Tone ABR is said to have good frequency specificity (Gorga, 1999). However, spectral splatter cannot be completely eliminated in tone-ABR. ABR to tonal stimuli is obtained only at 20 to 30dBSL especially when low frequency tones are used. Stimulus artifacts interfere with the response when high intensity tone is used. So maximum intensity that can be used reliably for tone ABR is less (60 to 70 dBnHL) as compared to click stimuli (Pant and Vanaja, 2002). On the other hand, ASSR is expected to have good frequency specificity as it uses continuous signals and stimulus intensity can be increased till 120dBnHL. In other words ASSR can be recorded from subjects with profound hearing-impairment. ASSR gives an objective estimation of threshold. ASSR have a limited database and there is a need for more peer reviewed research in adults and infants with hearing loss of varying degrees, configurations and etiologies (Stapells, 2004). There is dearth of studies comparing ASSR and ABR and limited research shows equivocal results. Hence the present study was undertaken.

This investigation was designed to study the following aims:

1) Comparison of tone-ABR and behavioral thresholds in normal and hearing impaired subjects.
2) Comparison of ASSR and behavioral thresholds in normal and hearing impaired subjects.
3) Comparison of ASSR and ABR thresholds in normal and hearing impaired subjects.

Twenty normal hearing adults and fifteen sensori-neural hearing impaired adults were selected for the study. Thresholds were estimated by tone-ABR and ASSR for higher modulation frequency (>70 Hz) at 500 Hz, 2000 Hz and 4000 Hz. Nicolet Bravo (version 4.0) was used for recording tone-ABR and GSI Audera ASSR (Version 1.0.2.2) was used for recording ASSR. Results were analyzed using statistical software SPSS (version 10.0).

The results of the present study reveal that tone-ABR and ASSR estimate the behavioral thresholds reasonably well and both the procedures predicts audiogram configuration accurately. However, tone-ABR thresholds were lower than ASSR thresholds and this difference was statistically significant. It was observed that state of the subject affected ASSR more than tone-ABR. This may be because amplitude of ASSR is smaller than that of tone-ABR. The advantage of ASSR lies in its application to differentiate severe and profound hearing loss.

Thus it can be concluded that either tone-ABR or ASSR can be used to estimate thresholds in difficult to test population. However, tone-ABR is preferred to ASSR for 80 Hz if the subject state is awake during testing.

Future directions to research:

1) Effect of subject state of activity on threshold estimation can be studied.
2) The present study can be replicated on large population.
3) Studies can be carried out on subjects with different degrees, configurations and type of hearing impairment.

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Appendix

Calibration of intensity of the stimuli

In conventional pure tone behavioral audiometry, behavioral thresholds are expressed in dBHL units where as ABR thresholds are expressed in dBnHL units. Stimulus for ASSR is calibrated in dBHL as given in the GSI manual. Stimulus for tone-ABR was calibrated using the following procedure:

A group often normal hearing subjects were taken. The behavioral thresholds for tone burst of 500Hz, 2000Hz and 4000Hz was estimated in sound pressure level (SPL). The behavioral threshold estimation was done using the same instrument and same test environment as the actual ABR testing. The threshold was determined as the lowest level at which 50% of the time the response was observed. The average behavioral threshold was taken as 0 dBnHL for that stimulus. The obtained values are;

	500Hz	2000Hz	4000Hz
0 dBnHL =	50 dBSPL	28 dBSPL	29 dBSPL