AC AND BC ASSR IN INDIVIDUALS WITH NORMAL HEARING AND HEARING IMPAIRMENT

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A Dissertation submitted in part fulfillment for the final year
M.Sc, (Speech and Hearing)
University of Mysore, Mysore

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MAY-2004

CERTIFICATE

This is to certify that the dissertation entitled "AC AND BC ASSR **IN INDIVIDUALS WITH NORMAL HEARING AND HEARING IMPAIRMENT"** is the bonafide work in part fulfillment for the degree of Master of Science (Speech and Healing) of the student with Register No. 02SH0022.

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May 2004

CERTIFICATE

This is to certify that the dissertation entitled "AC AND BC ASSR IN **INDIVIDUALS WITH NORMAL HEARING AND HEARING IMPAIRMENT"** as 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.

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May 2004

DECLARATION

I hereby declare that this dissertation entitled "AC AND BC ASSR IN INDIVIDUALS WITH NORMAL HEARING AND HEARING IMPAIRMENT" is the result of my own study under the guidance of Mr. Animesh Barman, Lecturer in Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at submitted earlier in any other university for the award of any Diploma or Degree.

Mysore
May 2004

Reg. No.02SH0022

Dedicated to

My Mummy, Daddy, *Akka,*
Chitu, Banu &
Animesh Sir

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/ would like expressing my sincere gratitude to my guide Animesh Sir for his constant guidance and support. I cannot forgot the day when kamala and I got stuck inside the 'D' room, which we didn't know and I was much worried about the impedence which was high, and (Sir) you came and rescued us. ***'Thank you Sir"*** *very much.*

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INTRODUCTION

Normal speech and hearing is important for effective communication. **One** can be deprived from this effective mode of communication due to hearing impairment especially if it occurs during childhood. About 100 children in 100,000 are born with a significant hearing impairment and approximately 30 children tend to develop hearing impairment with in their first few years of life. Without normal hearing during this period, speech and language do not develop as rapidly or as completely as normal (Lins et al. 1996).

Because of its devastating effect on speech and language development, hearing impairment in infancy must be detected as early as possible for effective treatment and training. One strategy for early identification of hearing loss is to screen infants who are at risk. However, approximately half of the infants with hearing impairment do not fall within the criteria of high-risk register. Thus the universal hearing-screening programme has been recommended by the National Institutes of Health (cited in Lins etal. 1996).

There are two methods of hearing screening. They are behavioral and objective methods. Since behavioral audiometry is neither accurate nor reliable before 6 months of age, hearing in babies is usually evaluated using otoacoustic emissions and or ABR. The two techniques provide complementary information: otoacoustic emissions evaluate the functioning of the outer hair cells and the auditory evoked potentials evaluate the functioning of the auditory system till the upper brain stem. **The** major drawback with OAEs is that it fails to determine the severity of hearing loss and the audiometric configuration when the OAE is absent] Auditory Brainstem Response

(ABR) has gained popularity in assessing hearing sensitivity in young children and difficult to test population, even in sleeping or sedated subjects. ABR is a reliable indicator of hearing thresholds in the high frequency range (> 2 kHz), but it is not useful for assessing hearing below 2 kHz, where the predominant energy in speech resides. Even at high frequencies the ABR cannot measure frequency specific deficits, since clicks contain energy over a wide range of frequencies. Further, the use of broadband click stimuli in neonatal hearing screening has been shown to miss infants with frequency specific hearing loss. Short duration tone burst are used to obtain frequency specific information. This would thought to maximize the frequency specificity, but fails to produce good frequency specificity due to spectral splatter and also requires neural synchrony (Hood, 1998). Thus obtaining frequency specific information from ABR has been a challenging task for an audiologist. Information regarding frequency specific thresholds would help to provide appropriate amplification. However clicked evoked ABR really fails to give such information.

/One of the more recent advances in the field of audiology to obtain frequency specific information in evoked potential testing is the use of Auditory Steady State Response (ASSR) (Rickards & Clark, 1984; cited in Rickards, Tan, Cohen, Wilson, Drew, & Clark, 1994). The ASSR may not require the degree of neural synchrony needed for identification of transient waveform (Rance. Dowell, Rickards, Beers & Clark, 1998). It is useful in getting frequency specific information. A continuous amplitude modulated tone at frequencies between 3 and 200 Hz evokes a steady state response at the frequency of modulation. Auditory Steady State evoked potential (SSEP) have been elicited with wide range of stimulation rates in both awake and sleeping individuals]

The SSEP is a periodic response to a periodically changing stimulus. Because of its periodic nature, it can be easily characterized by the amplitude and phase of the fundamental and second harmonic frequency components of the response] The response has the same period as the period of stimulus variation] Increased interest in auditory SSEPs followed the finding that at certain repetition rates the responses seemed to be quite strong particularly at 40 Hz. While the 40 Hz responses have been used to obtain good estimations of behavioral thresholds in normals and hearing impaired adults at low and high frequencies, the response is considerably affected by sleep or sedation. Response thresholds are reported to be elevated and less reliable during sleep (Rickards et al. 1994).

Amplitude Modulation Following Response (AMFR) was clearly detected at higher Modulation Frequencies (MFs) of 80 to 100 Hz, even in young children during sleep. AMFR elicited by MFs of 80 to 100 Hz are clearly detected in young children not only by phase spectral analysis but also by visual analysis. Where as visual detection of the response waveform is difficult in adults during sleep (Aoyagi et al. 1994).

j ASSR has been investigated in studies involving adults and children with varying degrees of hearing loss. ASSR thresholds in subjects with varying degrees of hearing loss have generally been highly correlated to behavioral hearing level particularly incase of significant sensorineural hearing loss. The strength of the relationship between behavioral and SSEP threshold increases with increasing degree of loss. The subjects with hearing loss of higher degree show better correlation than normals (Rance, Rickards, Cohen, Devidi & Clark, 1995; Hsu, Wc & Lin,2003).

The threshold estimation with the bone-conducted stimuli was similar to that with air conducted stimuli. Thus the auditory steady state responses would be quite accurate in assessing conductive hearing loss. But attention would have to be paid to the complexities of clinical bone conduction testing (Lins et al. 1996).

NEED

Children with risk factor might show lower degree of synchronous firing. Threshold estimation with the tone burst ABR in such population might be difficult, as it requires neural synchrony. Absence of tone burst ABR might mislead an audio logist in such subjects. Thus one can use ASSR to estimate hearing sensitivity in such population as it is reported to require lesser neural synchrony (Rance et al. 1998).

LA.SSR is expected to have good frequency specificity as it uses continuous signals. It can be recorded at lower SLs (5 to 10 dB) in normal subjects as well as hearing impaired (Aoyagi et al. 1999) and the maximum stimulus intensity at which it can be measured is till 120 dBHL. Hence, ASSR can be obtained even in individuals with profound hearing-impairment, which may not be possible with tone burst ABR.

Most of the ASSR studies have been carried out under headphones, but no systematic studies on BC ASSR in individual with hearing loss are reported yet, may be due to the problems with artifact (www.audiospeech.ubc/haplab/clinic.htm). Thus the validity of the ASSR results obtained through the BC mode needs to be checked. ASSR threshold obtained through both AC and BC mode will also help us know about the middle ear status or the type of hearing loss, which would help one to determine the line of management.

Unlike clicks and tone burst, the spectrum of AM tone is simple and contains energy only at the carrier frequency and the carrier frequency plus and minus modulation frequency, which means to say they are frequency specific. If we can obtain frequency specific threshold, appropriate amplification can be provided. These stimuli are more readily processed by hearing aids and cochlear implants so there are much less signal distortion in the amplifiers. Thus AM tone, which is used in ASSR, is more appropriate.)

It has been reported in the literature that the subjects with hearing loss of higher degree show better correlation than normals (Rance et al. 1995). However all these studies have been carried out in cases with SN hearing loss. It is also essential to administer the same in patients with conductive hearing loss to see the relationship between behavioral thresholds and ASSR thresholds. The ASSR results obtained from both in cases with conductive and SN hearing loss also might highlight some physiological basis of the hearing mechanism which would helps to understand why there are better agreement between the behavioral threshold and ASSR threshold with increase in severity of hearing loss.

Hence this study was taken up.

AIM

- To find out the relationship between the behavioral pure tone threshold (AC and BC) and ASSR (AC and BC) threshold with the different types and severity of hearing loss.
- To assess the efficiency of ASSR measurement in predicting the degree and type of hearing impairment.

REVIEW OF LITERATURE

A steady- state response is a repeating evoked potential with constituent frequency components that remain constant in amplitude and phase over time (Regan, 1989, cited in Lins, Picton, Picton, Champagne, & Durieux-Smith, 1995). These responses are usually evoked by stimuli that occur at a sufficiently rapid rate and the response to any one stimulus overlaps the response to preceding stimuli (Regan, 1982, cited in Lins et al. 1995)1 The typical example of an auditory steady- state response is the "40-Hz response" which is the steady state version of the middle latency transient response (Galambos, Makeig & Talmachoff, 1981; Stapells, Linden, Suffield, Hamel & Picton, 1984, cited in Lins et al. 1995). The middle latency response has peaks that are separated by about 25 ms, if we present the stimuli at a rate equal to the reciprocal of this interval, ie at 40 Hz, the peaks in the response to one stimulus align themselves with peaks in the responses to preceding stimuli and a large periodic response is recorded. The stimulus "drives" the brain at the same frequency as the rate of stimulation (Lins et al. 1995).

[Galambos (1981, cited in Jerger, Chmiel, Frost & Coker, 1986) first described the unique properties of the auditory steady- state evoke potential observed in response to stimulation at a relatively high rate, 40/sec. He initially labeled the response as "40 Hz event related potential". Regan (1977, cited in Jerger et al. 1986) and more recently Picton, Stapells, Linden, Suffield, and Hamel, 1984; Picton, Linden, Campbell and Hamel, 1985 (cited in Jerger et al. 1986) have suggested the term "SSEP" as a more general description of the phenomenon]

To understand the physiological basis for the better agreement between the behavioral threshold and ASSR threshold with increase in severity of hearing loss based on the results obtained from the subjects with different degree and type of hearing loss.

REVIEW OF LITERATURE

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Advantage of steady state technique over transient evoked potentials: -

1. The measurement of steady - state responses is simple (Regan, 1989 cited in Lins et al. 1995). The amplitude and phase of the response at the frequency of stimulation can be measured automatically by a computer and no judgment by an interpreter is needed since no peaks need to be identified.
2. There are clear statistical procedures to determine whether a response is present or not. These techniques compare the response at the particular modulation frequency to the noise at adjacent frequencies or assess the reliability of replicable responses.
3. Steady-state responses allow the use of steady state stimuli such as a continuous tone with a sinusoidally modulated amplitude (Kuwada, Batra & Maher 1986; Picton, Skinner & Champagne, 1987, cited in Lins et al. 1995). The frequency content of such an amplitude modulated (AM) tone is concentrated at the carrier frequency of a tone and at two sidebands separated from the carrier frequency by the frequency of modulation. This energy spread is much less than the spread of energy into frequencies other than the nominal frequency when using a brief *tone.*

4 Steady-state stimuli can probably provide a better evaluation of hearing aids than brief transient stimuli. Because hearing aid amplifiers are quite nonlinear, transient stimuli undergo significant distortion and it is often difficult to relate responses to these stimuli with the ability of the hearing aid to transfer information from that change less rapidly (eg. speech))

Auditory steady state evoked potentials can be recorded at many different rates of stimulation (Rickards et al. 1994). The 40 Hz responses is the steady state version of the middle latency evoked potentials. Unfortunately, the 40 Hz responses are not reliable in young infants (Stapells, Galambos, Costello & Makig, 1988, cited in Lins et al. 1995) probably because the auditory cortex and its connections are not fully developed and the response is attenuated during sleep (Klein, 1983, cited in Lins et al. 1995; Linden, Campbell, Hamel & Picton 1985) Recently, several laboratories have reported auditory steady state responses to stimulus rate of 80-100 Hz (Cohen. Rickards & Clark, 1991; Aoyagi et al. 1993; Levi, Folsom & Dobie, 1993). These responses may represent the steady state version of the transient brainstem ABRs. These 80 Hz auditory steady state responses are less affected by sleep than 40 Hz responses (Cohen et al. 1991) and can be recorded reliably in sleeping children (Aoyagi et al. 1993\

Modulation frequency and neural generators: -

'The frequency of modulation and the neural generators of the SSEP are thought to be closely linked,' Measurement of the response phase spectrum (relative to the MF) can be used to estimate response latency. The predominant phase is used to characterize the latency range of the response, and hence the generators are assumed to be the same as those for the transient evoked response of similar latency (Katz, 2002)

Modulation rates of 20 Hz or less will result in a response dominated by those generators that are responsible for the late cortical evoked potential, specifically primary auditory cortex and association areas (Katz, 2002).

For modulation rates higher than 20 Hz but lower than 50 Hz, the response characteristics are similar to those found for the middle latency auditory evoked potential, with generators generally thought to be auditory midbrain, thalamus, and primary auditory cortex (Katz, 2002).

Modulation rates higher than 50 Hz will be dominated by evoked potentials from brainstem sites, including wave V and the negativity following wave V, some times identified as SN-10 (Katz, 2002).

Unfortunately, there is a very little research on the neural generators of SSEP as a function of modulation rate. It is known that neurons at eight nerve (Ruggero, 1992, cited in Katz, 2002) inferior colliculus (Irvine. 1992, cited in Katz, 2002) and primary auditory cortex (Clarely, 1992, cited in Katz. 2002) are responsive to AM and FM signals. The effects of selective lesioning of the auditory pathway upon SSEPs have not been determined, nor have neuropathological variables been explored. For the purposes of using SSEP for threshold estimation, it must be emphasized that the presence of an SSEP (at any MF) is determined in large part by the integrity of the cochlea and the eighth nervel

The neuropathologic and subject related variables (such as sleep or age) that affects ABR. middle latency auditory evoked potential and late cortical potential responses to transient stimuli are expected to affect the SSEPs in the congruent latency ranges (Katz, 2002).

Effects of stimulus factors: -

1. .Carrier frequency (CF):

Kuwada et al. (19S6) found that the Amplitude Modulation Following Response (AMFR) showed a decrease in amplitude as a function of carrier frequency, the ASSR amplitude at 250 Hz being three times larger than at 4000 Hz (Ross, Draganova, Picton & Pantev, 2003).

Rance et al. (1995) found that the higher frequency thresholds were accurately predicted than lower frequency thresholds. The responses to carriers of higher frequencies being more reliable than the responses to carriers of lower frequencies (Linsetal. 1996)),

Lins et al. (1995) they reported that the amplitude of the response did not vary significantly with the CF. There were a small but significant increase in phase from 500 Hz to 2 kHz. Since the period of the 91 Hz modulation envelopes is 11 ms, an increase of 42 degree in the phase of the response (from 500 Hz to 2k Hz) or equivalently, a decrease of 42 degree on the phase delay corresponds to a decrease of 1.3 ms in latency.

2. Modulation frequency (MF):

Modulation Frequencies (MFs) of 60 Hz or lower resulted in response latencies (calculated from phase delay data) in the range of 28 to33 ms, clearly similar to the range of Middle Latency Auditory Evoked Potential. For MFs 90 Hz and above, the latencies ranged from 11.6 ms for a likely homology to tone burst evoked ABRs (Cohen et al. 1991).

The largest AMFRs occur between 25 and 50 Hz. The amplitude of the AMFR decline by about a factor of three at 75 Hz modulation, but small AMFRs are present at 350 Hz (Kuwada et al. 1986).

Higher modulation rates can produce latencies of less then 10 msec (Kuwada et al. 1986; Cohen et al. 1991).

Latencies of about 10 msec are considered to be most effective when using SSEPs to assess the hearing of sleeping infants and young children (Cohen et al. 1991).

3. Modulation depth:

The amplitude of the AMFR increases monotonically as a function of modulation depths was AMFRs are presents (11-91%); the phase lag decreases slightly as a function of depths. To avoid onset effects, modulation depths of less than 100% should be used (Kuwada et al. 1986p

The amplitude of the response rose from 0% to 50% of modulation and did not change significantly between 50% and 100%. From 25% to 100% of modulation the phase did not change significantly. The waveform is more distorted at larger modulation depths. This distortion is expressed by energy at the harmonics of the fundamental frequency depth of 100%and 75% the second and the third harmonics can be easily visualized. At 50% only the first and the second harmonics and at 25% only the first harmonics (or fundamental) can be visualized (Lins et al. 1995..

4. Intensity effects:

The amplitude of the response increases and the phase delay decreases with increasing intensity (Rodriguez, Picton, Linden, Hamel & Laframboise, 1986).)

At threshold levels only fibres with the characteristics frequencies near the CF are activated. As intensity increases above 60-70 dB SPL, a large number of fibre with higher characteristics frequencies are activated as the tails of the tunning curves of the High Frequency (HF) fibres will increase the amplitude of the response and probably add to the distortion. This effect would be more evident at lower CFs than in higher CFs and would be attenuated by high pass masking which would present the response of the HF fibres (Lins et al. 1995).

5. Interaction between intensity and CF:

AMFR systematically increases as a function of intensity and decreases as a function of frequency (Kuwada et al. 1986).

The amplitude did not change significantly with the frequency and there was no significant interaction between the frequency and intensity. The slope of the amplitude intensity function decreased significantly at higher frequencies. The slope of the phase intensity function decreased significantly at higher frequencies (Rodriguez et al. 1986)

Slope of the amplitude - intensity function below 70 dBSPL were significantly smaller than the slope above 70 dBSPL for all CFs. The difference was more evident for lower CFs although the interaction was not statistically significant (Lins et al. 1995).

6. Monaural vs binaural presentation:

The binaural response was not significantly different from the sum of responses obtained by presenting the stimuli monaurally to the right and left ears. The mean and standard deviation for the right ear and left ear response are 0.09 + 0.03 µv, 0.07 + 0.04 µv respectively, sum of the left ear and right ear responses 0.16 + 0.04 µv, and the binaural response are 0.16 + 0.04 µv, the amplitude of the responses to the right ear stimulation was slightly larger than the responses of the left ear but this difference was not significant (Lins et al. 1995.

7. **Combination** of AM **and** FM **stimulus:**

Amplitude was larger for AM/FM than for AM with CFs of 2 kHz and 4 kHz at MFs of 80 Hz and above. A combination of amplitude and frequency modulation in the stimulus yielded larger amplitude responses at low (30 dBHL) levels in both awake and asleep adults (Cohen et al. 1991)

Responses to AM/FM tones may be larger because these stimuli excite larger regions of the basilar membrane. A possible central mechanism to account fir the larger response amplitude for AM/FM tone may be that they activate additional processing channels associated with frequency modulation. The existence of systems in the auditory neural pathways selectively sensitivity to frequency changes rather than the amplitude modulation. The introduction of FM may produce additional response components due to such systems and these components may add algebraically with in the volume conductor of the head to give larger total responses (Cohen et al. 1991)

Effects of subject factors:-

1. State of arousal:

The background (electroencephalogram) noise levels reported to be much higher in awake adults than in sleeping adults, regardless of MF, but the difference in background noise into two stages was greatest for MFs above 80 Hz. In the 80-110 Hz range, there was lower background noise level and large response amplitude during sleep state (Cohen et al. 1991).

In both the awake and sleep conditions, using a stimulus levels of 30 dB HL and for CFs at Ik Hz or lower a MF of 45 Hz yielded responses with larger SNRs: however, the advantage for 45 Hz was not obvious for sleeping subjects tested with CFs at 2 or 4 k Hz, MFs of 80 Hz and above yielded response with SNRs that are equivalent to those at lower MFs in sleeping subjects (Cohen et al. 1991; Aoyagi et al. 1994).

40 Hz SSR shows robust potential in awake adult and decreases in amplitude by 50- 60% during sleep. 40 Hz SSR is difficult to obtain in newborns and young children and infants show no consistent amplitude peak in SSR evoked by tone bursts at any rate between 9-59 Hz (Aoyagi et al. 1994).

Dobie and Wilson (1998) also determined the detectability of SSEPs in adults tested both in awake state and during sedated sleep. Amplitude Mfs of 40 Hz and 90 Hz yielded peaks in the detection function for awake and sedated sleep state states for higher level stimulus, but less than 75% of the trials conducted at 38 dB SPL resulted in detectable response, regardless of MF. Detectability was considerably reduced in the sedated state compared to awake state, particularly for MFs at 50 Hz or lower but its thresholds were not elevated (Linden, Campbell, Hamel & Picton 1985; Jerger et al. 1986).

The results obtained by Dobie and Wilson (1998) indicated that both lower (40 to 50 Hz) and higher (90 Hz) are effective in evoking an SSEP for a CF below 1 kHz in awake or sleeping adults.

The phase coherence (PC) of the SSEP recorded from subjects with various states of arousal does not markedly differ. Since PC is presumably an indirect measurement of the SNR of the recorded waveform, one must assume that the amplitude of the response is reduced even the background noise also decreases (muscle artifact and spontaneous brain activity). Thus, it is the signal to noise ratio, which determines the recording ability of the response. Recordings with the same ratio should have equivalent threshold detectability. Nevertheless/ since phase coherence is not affected by level of subject arousal, it may be more useful in threshold prediction than the amplitude measure (Jerger et al. 198a).

(The thresholds estimated using phase data were significantly lower and less variable than those estimated using amplitude data (Rodriguez et al. 1986))

For low CFs at near threshold levels there may be some advantage of using MFs lower than 80 Hz, atleast in sleeping adults subjects with normal hearing. Whether or not the advantage of 40 to 50 Hz MFs would be borne out in sleeping infants is likely, given that the 40 Hz SSEP is thought to be generated at the cortical level. Empirical evidence indicates that the higher Mfs are more suitable for testing infants (Katz, 2002).

2. Gender:

There is no significant difference in the response as a function of gender or duration of the testing period (Linden et al. 1985) and also in the amplitude and the phase of the steady state response analysed at suprathreshold levels (Rodriguez et al. 1986).

3. **Effects** of age:

Finding of Levi et al. (1993) indicated that MFs above 40 Hz and particularly at 80 Hz are preferable for testing young infants with AM tones. The largest coherence values were obtained at 80 Hz, regardless of CF. When a 500 Hz CF was used the coherence values indicating that the statistical significance were obtained at MFs of 40, 50 and 80 Hz but not at 10, 20 or 30 Hz. For the 2 kHz CF, only the 80 Hz MF yielded statistically significant results for all infants. When adults were tested in the sedated- sleep state, the largest mean coherence values for responses to 500 and 2 kHz were also obtained at an MF of 80 Hz. However, coherence values were well above statistical significance level for 30 and 40 Hz MFs. When the coherence value as a function of MF for sleeping infants were compared with those for sleeping adults, coherence values were greater for the adults, but the trends for the growth of coherence with increasing MF were clear for both groups.

Aoyagi et al. (1994) showed that MFs in the 80 Hz range resulted in the most stable and reliable SSEP results among normal hearing infants and children (aged 4 months to 15 years) tested while sedated. Measures of phase coherence were highest for 80 Hz, although peaks were also found at 120 and 160 Hz for infants and children less than 4 years of age; these additional peaks in the coherence functions were not clear for older children or a group of normal hearing adults. The 80 Hz MF had a clear

The threshold patterns of 80-Hz AMFR very closely resembled the corresponding audiogram patterns in all types of hearing impairment. The measurement of 80-Hz AMFR in children during sleep thus appeared to be more accurate in hearing prediction than that by ABR elicited with tone pips and to have good frequency specificity (Aoyagi et al. 1996).

Rance and Rickards (2002) found that the results for infants with normal or near-normal hearing did, however, differ from those reported for older subjects, with behavioral thresholds typically 10 to 15 dB better than would have been predicted from their ASSEP levels.

4. SSEP Tests in subjects with hearing impairment: -

The studies illustrate that ASSRs can be used to estimate pure-tone threshold in infants and children at risk for healing loss and also in normal-hearing adults. (Cone -Wesson, Dowell, Tomlin, Rance, Ming, 2002)

Vander Werff, Brown, Gienapp and Schmidt Clay (2002) found that it was possible to measure ASSR thresholds for several children with hearing loss that was great enough to result in no ABR at the limits of the equipment. The results of this study indicate that the ASSR may provide a reasonable alternative to the ABR for estimating audiometric thresholds in very young children.

The strength of the relationship between behavioural and SSEP threshold increases with increasing frequency and increasing degree of loss. The subjects with hearing loss of higher degree show better correction than normals (Rance et al. 1995; Hsu et al. 2003).

advantage over the 40 Hz MF for all age groups except children older than 9 years or adults.

Amplitude Modulation Following Response (AMFR) was clearly detectable at higher MFs of 80 to 100 Hz, in young children during sleep. AMFR elicited by MFs of 80 to 100 Hz were detected in young children not only by phase spectral analysis but also by visual analysis, where as visual detection of the response waveform is difficult in adults during sleep (Aoyagi et al. 1994).

Spectral amplitude analysis demonstrates 80 Hz AMFR to have a high S/N ratio in all children. The detectability of 80 Hz AMFR was high for all carrier frequencies. The component synchrony measure of AMFR at MF of 40 Hz was high at lower carrier frequencies, but 40 Hz AMFR at higher carrier frequencies were unreliable (Aoyagi et al. 1994).

A large scale study of newborns completed by Rickards (cited in Katz, 2002) provides compelling evidence for the efficacy of modulation rates higher than 60 Hz for obtaining responses with both AM (100%) and FM (20%) tone. As CF increased, so did the best MF for response detection and clearly MFs in the 65 to 100 Hz range yield the best detection efficiencies in sleeping newboms. In addition, latencies calculated from the response phase were in the 11 to 14 ms range, with a systematic decrease in latency with increased frequency. Both the range and the type of latency change suggest that the SSEPs recorded at high MFs in sleeping newborns are generated at the brainstem.

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In patients with hearing impaired greater than 10 dB normal HL, ASSR showed distinct advantage over ABR testing in that recordings were reliably produced up to 127nHL (Roberson, O'Rourke & Stidham 2003).

ASSR testing provides audiometric information that is essential in the management of children with severe to profound HL (Stueve & O'Rourke, 2003).

SSEP can be used as a reliable and objective tool to assess auditory threshold in patients with NIHL with high frequency dips (Hsu et al. 2003).

Behavioral and multiple-ASSR thresholds were significantly correlated (r = 0.75-0.89). There were no significant differences between behavioral and multiple-ASSR measures of the audiogram configuration. In subjects with steep - sloping > or = 30 dB/ octave) hearing losses, multiple-ASSR thresholds did not underestimate behavioral thresholds revealing good place specificity. (Result indicated the MASTER (Multiple Auditory Steady state Response) method provide good estimation of the degree and configuration of hearing in individuals with SNHL (Herdman & Stapells, 2003))

In hearing-impaired subjects, the AMFR amplitudes as a function of carrier frequency accurately reflect the pattern of hearing loss on a frequency -by-frequency basis. In most subjects, the threshold for evoking the AMFR was within 0-25dB of hearing threshold. AMFR most accurately reflects the pattern of HL at low stimulus intensities. High stimulus intensities obscure the pattern of HL (Kuwada et al. 1986).

In patients with sensorineual hearing loss the amplitude increased more with increasing intensity above threshold than in patients with conductive hearing loss, but these differences were not significant. At 500 Hz the difference in amplitudes between hearing loss patients and normals were not significant. At 2 kHz the amplitudes between sensorineural HL were significantly larger than the normal subjects. Amplitudes were significantly larger than in patients with greater hearing impairment. *The* phenomenon may be related to the presence of recruitment in those cases with cochlear impairment. The phase of the hearing impaired subjects was not significantly different from the normal subjects (Rodriguez et al. 1986).

Patients with symmetrical pure tone audiograms with near-normal responses in the lower frequencies but with a hearing loss of greater than 65 dB HL at 8 kHz were tested. None showed a response to the high frequencies, as the hearing loss was greater than 65 dB HL. At the lower frequencies 18 patients showed clear responses and the threshold was 16 to 27 dB above the psychoacoustical threshold. The remaining four cases showed responses at the lower frequencies but only at higher threshold levels. These evoked potentials may provide a rapid method to assess hearing in those subjects unable to provide a reliable volitional response (Milford & Birchall, 1989).

Thresholds for the AMFR, were consistent with the behavioral threshold estimation in both the normal and the hearing-impaired subjects (Griffiths & Chambers, 1991).

AMFR thresholds obtained were strongly correlated to behavioral thresholds. The average absolute difference between the AMFR and behavioral thresholds was 7.3 dB and 6.4 dB for 500 Hz and 1000 Hz, respectively (Chambers, Meyer, 1993).

In the hearing-impaired subjects, AMFR thresholds were between 0 and 25 dB above the behavioral threshold at all carrier frequencies. The threshold patterns of AMFR detected by phase spectral analysis very closely resembled the corresponding audiogram patterns in all types of hearing impairment. AMFR is thus shown to have very good frequency specificity (Aoyagi et al. 1993; Aoyagi et al. 1996; Lins et al. 1996).

The steady state response thresholds in hearing impaired were on average 12 dB above the behavioral thresholds or 23 dB HL. The subjects with hearing loss showed a smaller difference between steady state response thresholds than those with normal hearing The amplitude of the responses to suprathreshold stimuli at the same physical intensity was similar between normals and hearing impaired adolescents (Linsetal. 1996).

ASSR can be recorded at lower SLs (5 to 10 dB) in normals subjects as well as hearing impaired and the stimulus intensity can be increased till 120 dB HL (Aoyagi et al. 1999).

The difference between the behavioral threshold and the ASSR threshold were significantly smaller in the hearing-impaired (5 to 13 dB). Also a close correspondence was found between the subjective and objective audiogram curves in both groups. The binaural multiple frequency auditory steady state responses (MF SSRs) were proven to be a valid technique for the estimation of an objective audiogram, in a large sample of hearing-impaired children and normal-hearing subjects. With this method, frequency-specific thresholds at 0.5, 1, 2, and 4 kHz could be determined in all subjects (and both ears) with no appreciable loss in accuracy and a considerable reduction in testing time (average recording time = 21 minutes) when compared with other frequency-specific techniques (Perez-Abalo et el. 2001).

SSEP IN NORMALS:

Kudawa et al. (1986) reported that the SSEP thresholds were obtained in normals with a range of 15 to 25 dB. For one of their normal hearing subject AMFRs could only be detected with in 40 to 45 dB of his hearing threshold.)

The difference between behavioral threshold and the thresholds of the SSEP at 1 kHz was, on an average of 16 dB (Cohen et al. 1991).

The thresholds of AMFR were distributed within 30 dB nHL at all carrier frequencies in normal subjects (Aoyagi et al. 1993)

Aoyagi et al. (1994) reported steady state thresholds for normal hearing adults of29dBSPL or l9dBHL.

The mean response threshold for 500 Hz, 1.5 kHz and 4 kHz were found to be 41.36 dB HL, 24.41 dB HL, 32.6 dB HL and 34.51 dB HL respectively (Rickards et al. 1994).

The mean and standard deviation of the difference between 80-Hz AMFR and pure-tone thresholds was 4.3 and 12.1 dB, respectively, and that between ABR and pure-tone thresholds was 6.6 and 14.2 dB, respectively (Aoyagi et al. 1996).

In the normal-hearing subjects, the response thresholds were detectable, on average, between 11 and 15 dB above the behavioral thresholds (Perez-Abalo et el. 2001).

The dichotic MF ASSR estimated normal hearing to be, on average, 30-34 dB HL across the range 0.5-4 kHz. The mean estimate of normal hearing for 0.5 kHz using tone burst ABRs was 30 dB nHL and the mean click ABR threshold was 16 dB nHL, i.e. 14-18 dB better than the ASSR thresholds. The dichotic MFASSR technique recorded 8 thresholds (4 in each ear) in a mean time of 23 min. The ABR protocol recorded 4 thresholds (2 in each ear) in a mean time of 25 min. Both the dichotic MF ASSR and ABR protocols provided a time-efficient estimation of normal hearing. There was no significant difference between the tone burst ABR and MF ASSR techniques in terms of estimation of normal hearing at 0.5 kHz. The dichotic MF ASSR technique proved more time-efficient by determining more thresholds in a shorter time compared to the ABR protocol (Swanepoel, Schmulian & Hugo, 2004).

(Wang, Zhou and Huang (2004) observed an average threshold of ASSR about 40 to 60 dBHL between 0.25-8.0 kHz, and they became higher from low frequency to high frequency. Average threshold of MFSSR were 40 dBHL at 0.25-0.5, 1 kHz, and about 45 dB HL at 2 kHz, and about 50 dB HL at 4 kHz, and about 60 dB HL at 8 kHz. Difference values were about 25 to 55 dB HL between average threshold values of ASSR and hearing, and they became higher from low frequency to high frequency, those were about 25 dBHL at 0.25 kHz, 30 dBHL at 0.5 kHz, 35 dBHL at 1 kHz, 40 dB HL at 2 kHz, 50 dB HL at 4 kHz, 55 dBHL at 8 kHz. There is a definite numeral value between threshold of ASSR and hearing in young adults with normal hearing. And the pure tone hearing threshold can be conferred by examining the threshold of ASSR and by using the definite numeral values.

BC ASSR:

Determining bone conduction thresholds is not an easy task even when thresholds are determined behaviorally. Thresholds vary with where the vibrator is located on the scalp, how much tension is used to hold it in place and whether the external ear canals are occluded. Even when all of these variables are held constant, bone conduction thresholds are more variable from one subject to the next than air conduction thresholds. Two main factors that affect behavioral thresholds for the bone conducted stimuli: the occlude ears and location of the vibrator. When the vibrator is located on the forehead, the thresholds are higher than when located on the mastoid which is about 14, 9, 12 and 8 dB at frequencies of 500, 1 k, 2 k, 4 kHz (Frank, 1982; ANSI, 1992, cited in Dimitrijevie et al. 2002). Stimuli presented via bone conduction are transmitted to both ears. When the vibrator is placed on the mastoid, there is a slightly greater activation of the ipsilateral cochlea for higher frequencies although the difference is very small. When the vibrator is placed on the forehead, the activation of the two ears should be more exactly equal. It there is an asymmetry in the thresholds of the cochleae or asymmetry in the transmission of sound from the forehead to the cochleae, the bone-conducted sound will cause greater activation of the cochlea with the lower threshold, and the sound will be localized to that ear (Dimitrijevie et al. 2002).

In normal adults the thresholds for steady state to tones of 0.5, 1,2, and 4 kHz were 11 ± 5, 14 ± 8, and 9 + 8 and 10 + 10 dB above the behavioral thresholds for bone conducted stimuli. The response to bone conducted 500 Hz tone showed larger responses and better thresholds relative to behavioral thresholds than air conducted tones. Because of the complexities of masking the multiple stimuli, it would seem most efficient to use unmasked bone conducted stimuli to assess sensorineural hearing in the best ear (Lins et al. 1996). They found that the binaural bone conducted response was actually larger then the sum of the monaural responses (obtained by masking one ear via air conduction).

Cone -Wesson, Rickards, Poulis, Parker, Tan, and Pollard (2002) their study illustrates the use of the auditory steady-state response (ASSR) in the pediatric clinical audiology setting. A protocol for estimating bone-conduction thresholds from ASSR was developed. Bone-conducted narrow-band noise was used to mask the ASSR for a 1.0-kHz modulated tone. The amount of bone-conducted noise needed to mask the ASSR may distinguish between infants and children with conductive hearing losses and those with sensory losses. The amount of bone-conducted noise may also be used to estimate bone-conduction thresholds. However, the accuracy of this technique needs verification with behavioral methods to determine thresholds for bone-conducted pure tones in infants. When ASSR tests are used as part of the diagnostic evaluation for infants and children at risk for hearing loss, the results yield information about the audiometric contour and residual hearing, which aid in treatment and habilitation decisions.

Jeng, Brownt, Johnson and Vander Werff (2004) Results showed that the ASSR and behavioral ABGs were strongly correlated with each other (r = .81). However, ASSR-estimated ABGs slightly overestimated the magnitude of the behavioral threshold. Reproducibility of the BC ASSR electrophysiological thresholds was good. Data from the five subjects with profound hearing loss, however, demonstrated that the levels where stimulus artifact became problematic were relatively low. This means BC stimulation may be appropriate only for subjects with normal or mildly impaired cochlear sensitivity.

The above review indicates that the ASSR can be used to predict both AC and BC behavioral threshold. However the efficacy of the results obtained from ASSR is yet to get established. As the results can be affected by severity and type of hearing loss. Thus the current study has been taken up.

METHOD

The present study was taken up with the aim to compare AC and BC ASSR thresholds and behavioral thresholds in subjects with normal hearing and in subjects with conductive and sensorineural hearing loss of different degrees to see the efficiency of ASSR to predict degree and type of hearing impairment and also to understand the physiology basis of hearing mechanism for better agreement between behavioral and ASSR thresholds with increase in severity of hearing loss.

Subjects:

Three groups of subjects were taken.

1. **Group** I:

The first group consisted of subjects with normal hearing (n = 20 subjects) with age ranging from 17 to 24 years (for AC, n = 40 ears; for BC, n = 20 ears).

Selection **criteria:**

- The physical condition of the subjects during assessment was good.
- All were devoid of any neurological or otological symptoms or history.
- All had pure-tone thresholds within 15 dB HL across frequencies from 250 Hz to 8 kHz
- Immittance showed 'A' type tympanogram with reflexes present at normal levels.

2. **Group II:**

The second group consisted of subjects with different degrees of conductive hearing loss (n = 17 subjects) with age ranging from 13 to 50 years. This group was further divided into three sub groups based on their severity of hearing loss. They were as follows:

a). Mild hearing loss: n = five ears

b). Moderate hearing loss: n = seven ears

c). Moderately severe hearing loss: n = five ears

Selection criteria:

- Initially all the subjects underwent pure tone and immittance testing to decide about the degree and type of hearing loss.
- All of them have been diagnosed to have conductive hearing loss by an experienced audiologist.
- Otological evaluation did report of having middle ear abnormality.
- The physical condition of the subjects during assessment was good.
- All were devoid of any neurological symptoms or history.

3. Group HI:

The third group consisted of subjects with different degrees of sensorineural hearing loss (n = 15 subjects) with age ranging from 8 to 73 years. This group was further divided into three sub groups based on their severity of hearing loss. They were as follows:

a). Mild hearing loss: n = five ears

b). Moderate hearing loss: n = five ears

c). Moderately severe hearing loss: n = five ears .

Selection criteria:

- Initially all the subjects had undergone pure tone and immittance testing to decide about the degree and type of hearing loss.
- All of them have been diagnosed to have sensorineural hearing loss by an experienced audiologist.
- Otological evaluation did not report of having any external or middle ear abnormality.
- The physical condition of the subjects during assessment was good.
- All were devoid of any neurological symptoms or history.

INSTRUMENTATION

Calibrated diagnostic audiometer was used to estimate the pure tone threshold for all the subjects for both air and bone conduction.

Calibrated middle ear analyzer GSI- 33 (version-2) was used to assess the middle ear status.

Audera GSI ASSR system (ASSR DSP software version - SSEP GSI ver 2) was used to record AC and BC ASSR threshold.

TEST ENVIRONMENT

All the tests were carried out in sound treated rooms.

TEST PROCEDURE

1. Pure tone thresholds was obtained using modified version of Hughson and Westlake procedure (Carhart & Jerger, 1959; cited in Silman & Silverman, 1991) across octave frequencies from 500, 1.5kHz, 2kHz and 4kHz Hz for both air conduction and forehead bone conduction. Forehead placement was selected to estimate BC threshold as ASSR threshold was obtained with fore head place to minimize the artifact.

2. Tympanometry and reflexometry were carried out to know the status of the middle ear for all the subjects. The subjects were made to sit comfortably and asked not to swallow during the testing period. Initially tympanometry and then the acoustic reflex threshold were checked for all the subjects.
3. ASSR recording: The subjects were instructed to sit comfortably and relax. They were also asked to close their eyes and sleep. Instructions were given to avoid extraneous movements of head, neck and jaw while recording the test in the language familiar to the subjects.

Three silver chloride electrodes were used with the following electrode montage.

For air conduction:

- Non-inverting electrode: high forehead
- Inverting electrode: test ear mastoid
- Common electrode: non-test ear mastoid

For bone conduction:

- Non-inverting electrode: vertex (as the bone vibrator was placed on the fore head)
- Inverting electrode: test ear mastoid
- Common electrode: non-test ear mastoid

Before placing the electrodes the sites were cleaned using skin preparation paste and electrodes were placed with the conduction gel to increase the conductivity. The electrode impedance was checked and it was ensure that the impedance at each electrode site was less than 10 k ohm and inter electrode impedance was with in 5 k ohm

ASSR recording was then carried out with the following protocol:

- Type of stimuli: amplitude and frequency modulated tones.
- Transducer: earphone (TDH 39P), bone vibrator (Radio ear B-70A)
- Test frequency: 500, 1.5k, 2k and 4k Hz
- Modulation frequency: 80 Hz (as the threshold estimation using 80 Hz is not affected by sleep Aoyagi et al, 1994 and Dobie, 1993)
- Amplitude modulated percentage: 100%
- Frequency modulated percentage: 10 % (combination of amplitude and frequency modulation in the stimulus yields larger amplitude, Cohen, et al. 1991)
- Intensity: intensity was varied to estimate the threshold.

The ASSR recording was initiated at 20 dB above the behavioral threshold. If the response was not obtained then the intensity level was increased in 10 dB steps till the phase locked response was obtained. Once the phase locked response was obtained the intensity level was decreased in 10 dB steps (to save time) till no response was obtained. At the last two intensity levels ASSR measurement was repeated to confirm the presence or absence of the phase locked response. The lowest level at which phase locked response obtained was considered as the threshold. The same procedure was administered at each frequency. The recording was done in the following order: 4 kHz, 2 kHz, 1.5 kHz and 500 Hz for all the subjects to estimate both air and bone conduction ASSR threshold.

ANALYSIS:

The AC and BC thresholds obtained from both behavioral pure tone audiometry and ASSR for all the subjects were noted and tabulated.

The mean was found out for the AC, BC and Air Bone Gap (ABG) for pure tone threshold and ASSR threshold to find out the relationship between the pure tone and ASSR thresholds with different types and severity of hearing loss.

Comparison between the behavioral pure tone threshold (AC and BC) and ASSR threshold (AC and BC) were performed using Independent t- test, to see whether there is significant difference between the pure tone threshold obtained using pure tone audiometry and ASSR threshold. Independent t- test was done to see whether there is any significant difference between the pure tone thresholds and ASSR thresholds for subjects with sensorineural hearing loss and conductive hearing loss.

One-way ANOVA was administered to see whether there is any significant difference between different degrees of hearing loss and normal hearing subjects between the pure tone thresholds and ASSR thresholds. Then post- hoc multiple comparisons were assessed using Duncan test, which test the difference between each pair of means. It tests whether the means of the different groups differ significantly from each other or not at 0.05 level.

RESULTS AND DISCUSSIONS

The data was statistically analysed and the mean, standard deviation and range was calculated. Independent t test and one-way ANOVA was used to see the significant difference between the means of the different groups.

Table I: Depicts the mean, standard deviation (SD) and range (R) for the AC behavioral pure tone (P) threshold and ASSR (A) threshold for normals, mild, moderate and moderately severe hearing loss (HL) subjects and't' values between the subgroups across the frequencies.

A			500 Hz				1.5 kHz				2 kHz				4kHz			
			mean	SD	**R**	t	mean	SD	R	t	mean	SD	R	t	mean	SD	**R**	t
Normals	**P**		10	3.8	0-15	-19.29 (**)	5.5	5.97	10-15	-14.85 (**)	6.3	5.5	-10-15	-11.80 (**)	6.3	6.95	-10-15	-11.49 (**)
	A		43.4	10.3	30-60		36.4	11.7	20-60		32.6	13	10-65		34.1	13.7	15-60	
Mild HL	SN **HL**	P	30	7.9	20-40	-5.66 (**)	37	5.7	30-45	-1.32 NS	40	14.4	20-60	-3.72 (**)	58	21.7	25-85	-1.83 NS
		A	64	10.8	50-80		45	12.2	30-60		70	7.90	60-80		81	14.4	60-90	
	Cd HL	P	36.7	13.7	25-45	-4.83 (**)	33.3	4.1	30-40	-4.64 (**)	35.9	12.4	25-35	-2.22 NS	42.5	14.4	20-55	-5.03 (**)
		A	68.8	14.4	60-90		52	7.6	35-60		62	30.9	35-110		86	16.4	70-110	
Moderate HL	SN HL	P	48	8.4	35-55	-3.72 (**)	48	5.7	40-55	-3.81 (**)	50	3.5	45-55	-5.65 (**)	56	9.6	40-65	-4.94 (**)
		A	80	17.3	65-105		73	13.5	60-95		83	12.5	65-95		84	8.2	70-90	
	Cd HL	**P**	50	6.5	40-60	-5.42 (**)	45.7	7.31	35-55	-6.05 (**)	46.4	7.5	35-55	-5.26 (**)	42.6	**10.4**	25-55	**-4.17** (**)
		A	85	15	70-100		79.3	12.7	60-95		80	14.6	60-95		73	14.9	60-95	
Moderately severe HL	SN HL	P	55	10	45-70	-2.21 NS	59.1	4.9	55-65	-3.95 (**)	60.8	5.9	60-85	-2.54 (*)	66.7	10.3	65-100	-2.34 (*)
		A	70	12.2	60-90		78.3	10.8	70-100		86.7	24.2	65-120		90	22.1	55-110	
	Cd HL	P	57	2.7	55-60	-5.77 (*•)	55	7.9	45-65	1.47 NS	57	6.7	50-65	-5.42 (**)	56	6.51	50-65	-2.32 (*)
		A	86.7	11.5	80-100		66	14.7	50-90		83	8.4	75-95		82	24.1	60-115	

$*p < 0.05$, $**p < 0.01$, NS = Not Significant

Table 2: Depicts the mean, standard deviation (SD) and range (R) for the difference between the behavioral pure tone threshold (AC) and ASSR (AC) threshold and also the F value with reference to normal hearing subjects with different degree and type of hearing loss subjects.

AC	500 Hz					1.5 kHz					2 kHz					4 kHz				
	N	mean	SD	R	F	N	mean	SD	R	F	N	mean	SD	R	F	N	mean	SD	R	F
Mild SNHL	5	34	17.81	15-60	0.19	5	8"	6.7	0-15	9.68	5	28	9.08	20-40	0.23	4	30	4	25-35	3.08
Mild Cd HL	4	37.5	19.36	20-65	NS	5	18"	11.51	5-35	*	5	31	31.1	5-80	NS		47	14	35-65	NS
Normals	40	33.62	10.06	15-55		40	31.12"	12.68	10-60		40	26	12.79	5-55		40	28	16	5-65	
Mod SNHL	5	32	16 0-1	10 55	**0.35**	**5**	25	12.74	10 40	0 65	5	33	9.74	2040	**1.43**	5	26	5.47	20-35	**0.11**
Mod Cd HL	3	38.33	2.88	35-40	NS	7	35.57	15.73	20-60	NS	5	35	17.67	10-55	NS	5	31	22.19	10-55	NS
Normals	40	33.62	10.06	15-55		40	31.12	12.68	10-60		40	26	12.79	5-55		40	28	16.86	5-65	
Modsev.SNHL	5	17"	4.47	10-20	6.43	6	20*	10.95	10-40	7.45	6	16.66	19.91	0-55	1.36	5	20	17.32	5-45	0.49
Modsev.cdHL	3	31.66"	11 54	25-45		5	11"	8.21	5-25	*	5	26	5.47	22-35	NS	5	26	18.84	10-55	NS
Normals	40	33 62th	10.06	15-55		40	31.121'	12.68	10-60		40	26.25	12.79	5-55		40	28	16.86	5-65	

Means with different letters (a, b) are significantly different from each other. As indicated by DMRT (Duncan Multiple Range Test)

• $p<0.05$, NS = Not Significant

N- number of ears evaluated

Comparison between the AC behavioural pure tone thresholds and ASSR thresholds for normals, mild, moderate and moderately severe sensorineual and conductive hearing loss (HL) subjects

As seen in the Table 1, the behavioral pure tone threshold obtained for all the groups were much lesser than the threshold obtained in ASSR at all frequencies. .The threshold differences between the two methods are almost the same across the frequencies, type and degree of hearing loss. However independent't' test revealed no significant difference only at 1.5 kHz and 4 kHz for mild SN HL and at 2 kHz for mild conductive HL group. It has also failed to reach significant level in moderately severe SN HL group at 500 Hz and moderately severe conductive HL group at 1.5 kHz. Rest of the frequencies, sub groups showed significant difference.

Difference between AC ASSR threshold and behavioral threshold was calculated for all the groups and one-way ANOVA was administered to see the significant difference between the degree and type of hearing loss with normal hearing group, which can be seen in the table .2. Significant difference was obtained between normals and mild SN HL and mild conductive HL subjects only at 1.5 kHz. There was no significant difference between normals and moderate SN HL and moderate conductive HL subjects at any frequencies. There was significant difference between moderately severe SN HL with moderately severe conductive HL and normal hearing subjects at 500 Hz. Significant difference was also seen between moderately severe conductive HL and normal hearing subjects at 1.5 kHz. At the other frequencies there was no significant difference between the groups.

ASSR threshold could not obtained in all the ears with hearing loss even at maximum level (with in the UCL). It failed to obtain threshold in one out of five ears at 4 kHz for mild SN HL group, at 500 Hz for mild conductive HL group. Four out of seven ears for moderate conductive HL group at 500 Hz, one out of six ears at 500 Hz and 4 kHz for moderately severe SN HL group, two out of seven ears at 2 kHz and 4 kHz moderate conductive HL ASSR threshold could not be obtained.

It can also be seen from the table 2, that the threshold difference between the behavioral pure tone threshold and ASSR threshold was more for normals. Similar results were reported by Rance et al. 1995; Lins et al. 1996; Picton et al. 1998; Perez-Abalo et al. 2001. Where as the difference reduces with increase in severity of hearing loss, which is seen in SN HL group. In conductive HL group no such specific pattern was observed. Between the sensorineural and conductive hearing loss group the thresholds were higher for conductive HL subjects than SN HL subjects across the degree of HL. This could be due to the active and passive mechanism of the inner ear. In SN HL subjects where the active mechanism is affected, passive mechanism of the inner ear might have played a role in exciting more number of auditory nerves which leads to higher amplitude of ASSR, resulting in better relationship between ASSR and behavioral threshold. Where as in conductive HL group active mechanism still play a role as conductive component, mainly act as plug in effect. Thus resulting in less number of auditory nerve firing at near threshold level causing more difference between the two thresholds. This phenomenon in SN HL group has been related to recruitment. Lins et al. (1996) and Dimitrijeric et al. (2002) also attribute the same results with same phenomenon.

The mean ASSR threshold was larger for 500 Hz in normals (range 15 to 60). This large difference may be due to the physiological noise or ambient noise that is seen more in low frequencies. Other studies have also found the similar elevated thresholds for this frequency (Aoyagi et al. 1994; Ranee et al. 1995; Lins et al. 1996; Herdman and Stapells, 2003; Perez-Abalo et al. 2001).

This 500 Hz discrepancy may also be related to the issues of neural synchrony. There is likely more latency jitter in the neurons responding to the low frequency sounds caused by both the slowly changing stimulus and the broader region of activation on the basilar membrane. The jitter would decrease the time locked summation of responses (Dimitrijeric et al. 2002).

It has been reported in the literature that there is good agreement between behavioral threshold and ASSR threshold, which falls within 5 to 15 dB (Cohen et al. 1991; Lins et al. 1996; Aoyagi et al. 1996, 1999) even in normals. Where as the current study has failed to achieve that close agreement between the two thresholds. Slight better agreement is observed only in the case of higher degree of SN HL individuals where the mean threshold difference 17 dB at 500 Hz and 20 dB at 4 kHz. It can be seen that for the moderately severe SN HL subjects the lower limit of the range is 0 to 10 dB and the upper limits ranges from 20 to *55.* In mild conductive HL group the range (5 to 80) is large at 2 kHz. In normals though the range is large at 4 kHz (5 to 65) compare to other frequencies, the mean threshold value (34.12) is lesser than the 500 Hz (43.37) mean threshold as seen in table 1. This irregular trend observed in HL group could be due to the number of subjects taken in each group. The number of ears in which ASSR threshold could be obtained has still reduced, as the

ASSR could not be recorded even at the maximum limit. Thus it makes it more difficult to generalize. However, there is clear trend seen in SN HL group inspite of having less number of subjects and that justifies the physiological basis for the difference in threshold, which is discussed earlier.

The mean AC ASSR threshold for 500 Hz, 1.5 kHz, 2 kHz and 4 kHz were found to be 43.4 dB HL, 36.4 dB HL, 32.6 dB HL and 34.1 dB HL respectively for normal hearing subjects. Similar results were obtained by Rickards et al. (1994); Swanepoel et al. (2004); Wang et al. (2004)

This high difference in ASSR AC threshold and behavioral AC threshold also could be due to the modulation frequency, which has been used in the study. Several researchers (Cohen et al. 1991; Aoyagi et al. 1994) reported that 40 Hz modulation frequency is best to estimate threshold in normals and hearing impaired (awake adults) than the higher modulation frequency.

Table 3: Depicts the mean, standard deviation (SD) and range (R) for the BC behavioral pure tone threshold for forehead (PTF) placement and ASSR threshold for normals, mild, moderate and moderately severe hearing loss (HL) subjects and 't' values between the subgroups across the frequencies.

BC			500 Hz				1.5 kHz				2 kHz				4kHz			
			mean	SD	R	**t**	mean	SD	R	t	mean	SD	R	t	mean	SD	R	t
Normals	PTF		3.75	8.09	-10-15	-14.76	1.25	7.92	-10-10	-12.11	1	9.40	-10-15	-13.07	-5.25	6.97	-10-10	-9.05
	ASSR		43,75	9.01	15-60	* *	35.5	9.85	20-50	**	45.25	11.86	20-65	**	32.75	17.43	0-60	**
Mild HL	**SN**	PTF	29.1	6.51	20-35	-6.5	33	7.58	20-40	-1.26	43	14.4	20-60	-4.08	43.33	16.07	25-55	-1.58
	HL	ASSR	55	6.12	50-65	**	41	11.93	25-55	NS	74	8.94	60-80	**	62	3.53	60-65	NS
	Cd	PTF	1	9.61	-10-15	-8.6	0	7.9	-10-10	-5.01	2	4.47	-5-5	-4.87	-4	6.51	-10-5	-5.42
	HL	ASSR	42	4.47	35-45	**	27	908	15-35	+ •	33	13.5	20-55	**	29	11 93	10-40	**
Moderate	SN	PT	39	6.5	30-45	-4.64	43	4.47	40-50	-8.48	48	6.5	35-50	-8.42	48	8.36	35-55	-3.59
HL	HL	ASSR	57	5.74	50-65	**	67	4.47	60-70		78.33	2.88	55-80	**	63	2.5	60-65	NS
	Cd	PTF	10	7.63	0-20	-12.97	7.85	3.93	5-15	-4.89	11.42	4.75	5-15	-9.12	5	8.16	-10-15	-9.76
	HL	ASSR	52.14	3.93	45-55	*•	42	17.72	20-75	**	56.57	12.14	40-75	**	50.71	9.32	40-65	**
Moderate!	SN	PTF	43.33	2.88	40-55	-4.6	54	4.18	50-60	-3.96	57.5	2.88	55-60	-2.39	51.66	5.77	45-55	-4
y severe	**HL**	ASSR	57	4.47	50-60	*	68	6.7	55-75	**	70	10	55-80	**	65	0	60-65	*
HL	Cd	PTF	7	2.88	5-10	-11.18	10	4.08	5-15	-9.66	12	8.6	5-25	-5.73	8.7	6.29	0-15	-16.76
	HL	ASSR	45	6.12	35-50	**	40	5	35-45	**	56	12.94	40-75	**	56	7.41	55-65	**

*p < 0.05, $**_p$ < o.oi, NS = Not Significant

BC	500 Hz					1.5 kHz					2 kHz					4 kHz				
	N	mean	SD	R	F	N	Mean	SD	R	F	N	mean	SD	R	F	N	mean	SD	R	F
Mild SNHL	5	22^a	11.51	5-35	4.04 *	5	8"	10	0-25	18.64 *	5	37	15.24	10-45	0.48 NS	2	20	2.21	545	0.56 NS
Mild Cd HL	5	41^b	11.41	25-55		5	25"	3	20-30		5	41	11.93	25-55		5	30	8.94	20-45	
Normals	20	39.75^b	13.52	0-65		20	34^b	9	15-50		20	44	15.83	20-80		20	34.50	20.12	0-65	
Mod.SN HL	5	17	5.7	10-25	8.36	5	24	10.83	5-30	1.6 NS	3	18.33^a	12.58	5-30	4.55 *	4	17.5	14.43	5-30	3.2 NS
Mod. Cd HL	7	42.14^b	8.59	30-55		7	32.28	18.12	15-70		7	47.14^b	11.12	25-60		7	45.71	9.75	30-60	
Normals	20	39.75^b	13.52	0-65		20	34.25	907	15-50		20	44.25^b	15.83	20-80		20	34.5	20.12	0-65	
Modsev. SNHL	3	6.66^a	5.77	0-10	6.41 *	5	8^a	6.70	5-20	20.68 *	4	17.5^a	2.88	15-20	6.31 *	4	7.5^a	3.53	5-10	4.7 *
Modsev. CdHL	5	37^b	4.47	30-40		5	32^b	447	25-35		5	44^b	8.21	30-50		5	53^b	7.58	45-65	
Normals	20	$39.75^{1'}$	13.52	0-65		20	34.25^b	907	15-50		20	44.25^b	15.83	20-80		20	34.5^b	20.12	0-65	

Means with different letters (a, b) are significantly different from each other. As indicated by DMRT (Dimcan Multiple Range Test)

*p 0.05, NS = Not Significant

N= number of ears evaluated

Comparison between the BC behavioural pure tone thresholds and ASSR thresholds for normals, mild, moderate and moderately severe sensorineual and conductive hearing loss (HL) subjects

As seen in the Table 3, there was no significant difference between the pure tone thresholds (BC) and ASSR (BC) thresholds at 1.5 kHz and at 4 kHz for mild and at 4 kHz for moderately SN HL group. Rest of the group showed significant difference at all frequencies.

Difference between BC ASSR threshold and behavioral threshold was calculated for all the groups and one-way ANOVA was administered to see the significant difference between the degree and type of hearing loss with normal hearing group, which can be seen in the table 4.

As seen in the Table 4, mild SN HL subjects differ significantly from both mild conductive HL and normal hearing subjects at 500 Hz and 1.5 kHz, moderate SN HL differ significantly from both moderate conductive HL and normal hearing subjects at 500 and 2 kHz, moderately severe SN HL subjects differ significantly from both moderately severe conductive HL and normal hearing subjects at all frequencies (500, 1.5 k, 2k, 4 kHz).

ASSR threshold could not obtained in three out of five ears even at the maximum level (with in the UCL) for mild SN HL group, two out of five ears at 2 kHz, at 500 Hz for moderate and moderately severe SN HL group respectively. One out of five ears at 4 kHz for moderate and at 2 kHz and 4 kHz for moderately severe SN HL group also ASSR threshold could not be obtained.

From the above results it can be seen that the BC ASSR thresholds of subjects with normal hearing and conductive HL were better than that of the subjects with sensorineural HL.

From the above results it is seen that the threshold difference for pure tone (BC) and ASSR (BC) was smaller for SN HL subjects when compared to conductive HL and normal hearing subjects. And there was no significant difference between conductive HL and normal hearing subjects.

The range was more in normals compared to SN HL and conductive HL across the frequency. Between the HL groups, SN HL group has lesser range than the conductive HL group. Smallest range was seen for moderately severe SN HL at 4 kHz (5 to 10). This could be due to the difference in the inner ear physiology for normals, conductive and sensorineurai hearing loss individuals that has been explained earlier. A similar observation was also made by Lins et al. (1996), whereas they also got good agreement between BC ASSR threshold and behavioral threshold. However the difference between the two thresholds what Lins et al. (1996) observed were lesser than the present study. This high difference in ASSR BC threshold and behavioral BC threshold also could be due to the modulation frequency, which has been used in the study as explained earlier.

Table 5: Depicts the mean, standard deviation (SD) and range (R) for the difference between the behavioral pure tone threshold (AC) and ASSR (AC) threshold and also the F value for sensorineural hearing loss (SN HL) and conductive hearing loss (Cd HL) subjects across the different degrees of HL.

AC		500 Hz					1.5 kHz					2 kHz					4 kHz				
		N	mean	SD	R	F	N	mean	SD	R	F	N	mean	SD	R	F	N	mean	SD	R	F
SN HL	Mild HL	5	34	17.81	15-60	2.17 NS	5	8^{A}	6.7	0-15	3.49 NS	5	28	9.08	20-40	1.88 NS	4	30	4.08	25-35	0.92 NS
	ModHL	5	32	16.04	10-55		5	25^{B}	12.74	10-40		5	33	9.74	20-40		5	26	5.47	20-35	
	Mod.sev. HL	5	17	4.47	10-20		6	20^{AB}	10.95	10-40		6	16.66	19.91	0-55		5	20	17.32	5-15	
Cd HL	Mild HL	4	37.5	19.36	20-65	0.20 NS	5	18^{ab}	11.51	5-35	4.96 *	5	31	31.01	5-80	0.23 NS	5	47	14.40	35-65	1.71 NS
	ModHL	3	38.33	2.88	35-40		7	33.57^{b}	15.73	20-60		5	35	17.67	10-55		5	31	22.19	20-55	
	Mod.sev. HL	3	31.66	11.54	25-45		5	11^{a}	8.21	5-25		5	26	5.47	22-35		5	26	18.84	10-55	

Means with different letters (a, b) are significantly different from each other. As indicated by DMRT (Duncan Multiple Range Test)

Means with different letters (A, B) indicates different between the means, but it is not significant

•$p < 0.05$, NS = Not Significant

N= number of ears evaluated

Table 6: Depicts the mean, standard deviation (SD) and range (R)for the difference between the pure tone threshold (AC) and ASSR threshold (AC) for sensorineural hearing loss (SN HL) and conductive hearing loss (Cd HL) subjects and 't' values between the groups for the same degree of HL.

AC	500 Hz					1.5 kHz					2 kHz					4 kHz				
	N	mean	SD	R	t	N	mean	SD	R	t	N	mean	SD	R	t	N	mean	SD	R	t
MSN	5	34	17.81	15-60	-0.28	5	8	6.7	10-15	-1.67		28	9.08	20-40	-0.20	4	30	4.08	25-35	-2.25
MCD	4	37.5	**19.36**	20-65	NS	5	18	11.51	5-35	NS	5	31	31.10	5-80	NS	5	47	14.40	35-65	NS
MODSN	5	32	16.04	10-55	-0.65	5	25	12.74	10-40	-1		33	9.74	20-40	-0.22	5	26	5.47	20-35	-0.48
MOD CD	3	38.33	2.88	35-40	NS	7	33.57	15.73	20-60	NS	5	35	17.67	10-55	NS	5	31	22.19	10-55	NS
MOD S. SN	5	17	4.47	10-20	-2.64	6	20	10.95	10-40	-1.51	6	16.66	19.91	0-55	-1	5	20	17.32	5-45	-0.52
MOD S. CD	3	31	11.54	25-35	*	5	11	8.21	5-25	NS	5	26	5.47	20-35	NS	5	26	18.34	10-55	NS

*$p < 0.05$, NS= Not Significant

N- number of ears evaluated

Comparison between the AC threshold difference between the behavioral pure tone and ASSR threshold obtained in subjects with mild, moderate and moderately severe SN HL and conductive HL

As seen in the Table 5, though there was mean threshold difference between mild SN HL and moderate SN HL subjects at 1.5 kHz, it was not significant. And at other frequencies there was no significant difference obtained between the different degrees of SN HL. Significant difference was seen between moderate conductive HL and moderately severe conductive HL at 1.5 kHz. And at other frequencies significant difference was not observed between the different degrees of conductive HL.

Difference between AC ASSR threshold and behavioral threshold was calculated for all the groups and independent t-test was administered to see the significant difference between the sensorineural hearing loss and conductive hearing loss within same degree of hearing loss as seen in table 6.

As seen in the Table 6, there was significant difference between moderately severe SN HL subjects and moderately severe conductive HL only at 500 Hz. And at other frequencies there was no significant difference between the SN HL subjects and conductive HL subjects. And there was no significant difference between the SN HL subjects and conductive HL subjects in mild and moderate degree of HL at any frequencies.

The range was more for conductive HL group when compared to SN HL group across frequency and across degree of HL except at 500 Hz.

However one can note that the AC threshold difference (between behavioral and ASSR) is lesser for SN HL group than conductive HL group at any frequency. There is also clear trend that this difference for SN HL group reduces with the increase in severity of hearing loss. This also suggests that the physiological mechanism difference between the SN and conductive HL group. Reduction in threshold gap (between behavioral and ASSR) with increase in severity does suggest, that the importance of active mechanism reduces with increase in frequency and passive mechanism tend to dominate with increasingly broadens the peak of the traveling wave. This result in increase in number of fibers takes part in the generation of potential thus reducing the gap.

Table 7: Depicts the mean, standard deviation (SD) and range (R) for the difference between the behavioral pure tone threshold (BC) and ASSR (BC) threshold and also the F value for sensorineural hearing loss (SN HL) and conductive hearing loss (Cd HL) subjects across the different degrees of HL.

BC		500 Hz					1.5 kHz					2 kHz					4 kHz				
		N	Mean	SD	R	F	N	mean	SD	R	F	N	mean	SD	R	F	N	mean	SD	R	F
SN	MildHL	5	22^{B}	11.51	5-45	3.04	5	8^{a}	10.36	0-25	4.74	5	37	15.24	10-55	3.78	2	20	21.21	5-35	0.42
HL	ModHL	5	17^{AB}	5.7	10-25	NS	5	24^{b}	10.83	5-30	*	3	18.33	12.58	5-30	NS	4	17.5	14.43	5-30	NS
	Mod.sev.HL	3	6.66^{A}	5.77	0-10		5	8^{a}	6.7	5-20		4	17.5	2.88	15-20		2	7.5	3.53	5-10	
Cd	MildHL	5	41	11.40	25-55	0.54	5	25	3.53	20-30	0.86	5	41	11.93	25-55	0.49	5	31^{a}	8.94	20-45	7.90
HL	ModHL	7	42.14	8.59	30-55	NS	7	34.28	18.12	15-70	NS	7	47.14	11 12	25-60	NS	7	45.71^{b}	9.75	30-60	*
	Modsev.HL	5	37	4.47	30-40		5	32	4.47	25-35		5	44	8.21	30-50		5	53^{b}	7.58	45-65	

Means with different letters (a, b) are significantly different from each other. As indicated by DMRT (Duncan Multiple Range Test)

Means with different letters (A, B) indicates different between the means, but it is not significant

$^{*}p < 0.05$, NS = Not Significant

N= number of ears evaluated

Table 8: Depicts the mean, standard deviation (SD) and range (R) for the difference between the pure tone threshold (BC) and ASSR threshold (BC)for sensorineural hearing loss (SN HL) and conductive hearing loss (Cd HL) subjects and 't' values between the groups for the same degree ofHL.

BC	500 Hz					1.5 kHz					2 kHz					4 kHz				
	N	mean	SD	R	t	N	mean	SD	R	I	N	mean	SD	R	t	N	mean	SD	R	t
MSN	5	22	11.51	5-35	-2.62	5	8	10.36	0-25	-3.47	5	37	15.24	10-45	-0.46	2	20	21	5-35	-1.05
MCD	5	41	11.40	25-55	*	5	25	3.53	20-30	**	5	41	11.93	25-55	NS	5	31	8.94	20-45	NS
MODSN	5	17	5.7	10-25	-5.67	5	24	10 83	5-30	-1.12	3	18.33	12.53	5-30	-3.62	4	17.4	14 43	5-30	-3.90
MOD CD	7	42.14	8.59	30-55	**	7	34	18.12	15-70	NS	7	47.14	11.12	25-60	**	7	45.7	9.75	30-60	**
MOD S. SN	3	666	5.77	0-10	-8.40	5	8	6.7	5-20	-6.65	4	17.5	2.88	15-20	-6.08	2	7.5	3.53	5-10	-7.80
MOD S. CD	5	35	4.47	30-40	**	5	32	4.47	25-35	**	5	44	3.21	30-50	**	5	53	7.58	45-65	**

*p < 0.05, NS = Not Significant

N= number of ears evaluated

Comparison between the BC threshold difference between the behavioral pure tone and ASSR threshold obtained in subjects with mild, moderate and moderately severe SN HL and conductive HL

As **seen** in the Table 7, though there were mean threshold difference between mild SN HL subjects and moderately severe SN HL subjects at 500 Hz, it has failed to reach significant level. At 1.5 kHz, moderate SN HL subjects differ significantly from both mild SN HL and moderately severe SN HL subjects. Mild conductive HL subjects differ significantly from both moderate conductive HL and moderately severe conductive HL at 4 kHz. At other frequencies there was no significant difference between the different degrees of conductive HL.

Difference between BC ASSR threshold and behavioral threshold was calculated for all the groups and independent t-test was administered to see the significant difference between the sensorineural hearing loss and conductive hearing loss within the same degree of hearing loss as seen in table 8.

A significant difference was seen between the subjects with mild SN HL and mild conductive HL at 500 Hz and 1.5 kHz. There was significant difference between the subjects with moderate SN HL and moderate conductive HL subjects at 500, 2 k, 4 kHz. Significant difference was also seen between the subjects with moderately severe SN HL and moderately severe conductive HL at all frequencies.

The range of the threshold difference (behavioral and ASSR) seen to reduce as the degree of HL increased for both the groups. The range for SN HL group for mild (5 to 35), moderate (10 to 25), moderately severe (0 to 10) degree of HL at 500 Hz. The range for conductive HL group for mild (25 to 55), moderate (30 to 55), moderately severe (30 to 40) degree of HL at 500 Hz. The reason for such reduction in threshold difference with increase in severity in sensorineural hearing loss group is mainly due to the physiological variation between sensorineural and conductive hearing loss individual which is explained earlier.

Table 9: Depicts the mean Air Bone Gap (ABG) for behavioral pure tone threshold (P) and ASSR (A) threshold obtained in normals, SN III. and conductive III. with different degrees (mild, moderate, moderately severe HL).

ABG			500 Hz	1.5 kHz	2 kHz	4 kHz
			mean	mean	mean	mean
Normals	P		6.12	3.5	5	10
	A		2.87	2.5	5.87	5.87
SNHL	Mild	P	3	4	3	10
		A	5	4	8	5
	Mod	P	9	5	6	8
		A	8	10	3	8.75
	Mod.s	P	8.75	5	5	8
		A	10	8.33	5.83	10
Conductive HL	Mild	P	31	34	29	52
		A	26.25	26	25	56
	Mod	P	40	37.85	35	37.85
		A	33.3	37.85	28	26
	Mods	P	49	45	45	47
		A	38.3	26	27	28

Comparison between the Air Bone Gap (ABG) for behavioral (P) and ASSR (A) threshold for normals, sensorineural hearing loss and conductive hearing loss with mild, moderate, moderately severe degrees

It is evident from the table 9 that there is one to one correlation between ABG obtained in behavioral pure tone audiometry and ASSR measure. Inspite of having larger difference between the behavioral threshold and ASSR threshold for both AC and BC. The mean ABG obtained in ASSR for normals and SN HL group were well within 10 dB. And the ABG obtained in conductive HL was larger than 10 dB at all the frequency and almost closer to ABG obtained in behavioral pure tone audiometry. However we can notice that ABG for ASSR threshold obtained in SN HL group was minimally higher than the behavioral ABG whereas in conductive HL group it is lesser than the ABG obtained in behavioral pure tone audiometry. This could be due to forehead placement of the bone vibrator to establish ASSR threshold where as to determine ABG for behavioral pure tone threshold mastoid BC was considered. It is well established that the mastoid BC is more sensitivity than the forehead BC thus resulting in reduced ABG obtained for ASSR. Larger ASSR ABG in SN HL could be due to better agreement between ASSR threshold and behavioral threshold due to passive mechanism.

For the above results one can clearly say that ASSR can predict ABG effectively. One can expect smaller ABG in sensorineural hearing loss and larger ABG in conductive hearing loss subjects. Jeng et al. (2004) also indicated that the ASSR and behavioral pure tone ABGs strongly correlated in their study. Lins et al. (1996) also stated that the ASSR would be quite accurate in assessing conductive hearing loss.

SUMMARY AND CONCLUSION

Obtaining frequency specific thresholds in young children and difficult to test population even with tone bust ABR is a challenging task for audiologists. The tone burst ABR fails to produce good frequency specificity due to spectral splatter and it also requires neural synchrony.

One of the more recent advances in the field of audiology to obtain frequency specific information in evoked potential testing is the use of Auditory Steady State Response (ASSR). The ASSR may not require the degree of neural synchrony needed for identification of transient waveform. A continuous amplitude modulated tone at frequencies between 3 and 200 Hz evokes a steady state response at the frequency of modulation. Auditory Steady State evoked potential (SSEP) have been elicited with wide range of stimulation rates in both awake and sleeping individuals. While the 40 Hz responses have been used to obtain good estimations of behavioral thresholds in normals and hearing impaired adults at low and high frequencies, the response is considerably affected by sleep or sedation. Response thresholds are reported to be elevated and less reliable during sleep. Amplitude Modulation Following Response (AMFR) was clearly detected at higher Modulation Frequencies (MFs) of 80 to 100 Hz, even in young children during sleep. AMFR elicited by MFs of 80 to 100 Hz are clearly detected in young children not only by phase spectral analysis but also by visual analysis.

Hence this study has been taken up with the aim to find out the relationship between the behavioral pure tone threshold (AC and BC) and ASSR (AC and BC) threshold in subjects with normal hearing and in subjects with conductive and sensorineural hearing loss of different degrees to see the efficiency of ASSR to predict degree and type of hearing impairment and also to understand the physiology basis of hearing mechanism for better agreement between behavioral and ASSR thresholds with increase in severity of hearing loss.

In this study three groups of subjects were taken. The first group consisted of normal hearing subjects (n = 20 subjects) with age ranging from 17 to 24 years (for AC, n = 40 ears; for BC, n = 20 ears). The second group consisted of subjects with different degrees of conductive hearing loss (n = 17 subjects) with age ranging from 13 to 50 years. They were divided in to subgroups as mild hearing loss (n = five ears), moderate hearing loss (n = seven ears) and moderately severe hearing loss (n = five ears). The third group consisted of subjects with different degrees of sensorineural hearing loss (n = 15 subjects) with age ranging from 8 to 73 years. They were also had subgroups of mild hearing loss (n = five ears), moderate hearing loss (n = five ears) and moderately severe hearing loss (n = five ears).

Calibrated diagnostic audiometer was used to estimate the pure tone threshold for all the subjects for both air and bone conduction. Calibrated middle ear analyzer GSI- 33 (version-2) was used to assess the middle ear status. Audera GSI ASSR system (ASSR DSP software version - SSEP GSI ver 2) was used to record ASSR.

The ASSR recording was done for all the subjects to estimate both air and bone conduction ASSR threshold, in the following order: 4 kHz, 2 kHz, 1.5 kHz and 500 Hz.

The AC and BC thresholds obtained for both behavioral pure tone thresholds and ASSR thresholds for all the subjects were noted and tabulated. The data was statistically analysed and the mean, standard deviation and range was calculated. Independent t test and one-way ANOVA was used to see the significant difference between the means of the different groups.

Results indicate that there is increase in ASSR threshold with the increase in behavioral threshold. Thus suggesting a good agreement between the two thresholds. However, the thresholds difference between the behavioral pure tone (AC and BC) threshold and ASSR (AC and BC) threshold is more for normals than the hearing loss groups. Where as the difference reduces with increase in severity of hearing loss, which is seen in sensorineural hearing loss. In conductive hearing loss group no such specific pattern was observed. Between the sensorineural and conductive hearing loss group the thresholds were higher for conductive hearing loss subjects than sensorineural hearing loss subjects across the degree of hearing loss.

There was strong relationship between the behavioral threshold and ASSR threshold with increasing frequency and increasing degree of loss. The subjects with hearing loss of higher degree show better agreement than the normals.

The number of ears in which the ASSR threshold could be obtained was reduced with the increase in hearing loss especially at 500 Hz. Thus it is difficult to generalize. However, there is clear trend observed in SN HL group inspite of less number of ear in which ASSR threshold could be obtained and **that justifies the** physiological basis for the difference in threshold. This could be due to the dominance of the passive mechanism of the inner ear in the sensorineural hearing loss **individuals.**

In sensorineural hearing loss subjects where the active mechanism is affected, passive mechanism of the inner ear might play a role in exciting more number of auditory nerves which leads to higher amplitude of ASSR, resulting in lowering in threshold and better relationship between ASSR and behavioral threshold.

This high difference in ASSR AC threshold and behavioral AC threshold also could be due to the modulation frequency, which has been used in the study. Several researchers (Cohen et al. 1991; Aoyagi et al. 1994) reported that 40 Hz modulation frequency is best to estimate threshold in normals and hearing impaired (awake adults) than the higher modulation frequency.

The ABG obtained in the behavioral pure tone audiometry and in ASSR showed good agreement i.e ABG within 10 dB for normals and sensorineural hearing loss group and greater than 10 dB for conductive hearing loss group. It suggests that the ASSR is a good predict, of the type of hearing impairment.

Thus it can be concluded that AC and BC ASSR threshold can be used effectively to estimate the behavioral threshold and also to predict type of hearing impairment.

IMPLICATION:

ASSR can be used to estimate the frequency specific threshold for infant with risk factors. The frequency specific information obtained from ASSR also would help to provide appropriate amplification at each frequency. AC and BC ASSR can be helpful in threshold estimation in subjects with conductive hearing loss which would assist for appropriate management.

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