Estimation of Auditory Thresholds in Cochlear Implant Subjects Using ASSR

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Dedicated
To
My Parents
&
Loving Friends
Venkat and Shrikanta

CERTIFICATE

This is to certify that this dissertation entitled **"Estimation of auditory thresholds in Cochlear Implant subjects using** ASSR "is a bonafide work in part fulfillment for the degree of Master of Science (Audiology) of the student **Register** No. 05AUD007. This has been carried under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore
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DECLARATION

This dissertation entitled **"Estimation of auditory thresholds in Cochlear Implant subjects using ASSR** " is the result of my own study under the guidance of Dr.Rajalakshmi K, Reader & HOD, 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

Scope of cochlear implantation is changing with the establishment of newborn hearing screening programs throughout the world. This has increased the need for reliable, objective techniques for determining candidacy and evaluating cochlear implant efficacy in infants and very young children. The measurement of auditory thresholds or comforts levels for HI subjects with cochlear implants currently requires their attention and active cooperation. Unfortunately, subjective methods are of little or no value for the assessment of very young children and other difficult- to-test population .Therefore, a more objective method could be valuable; a sufficiently robust method might have even broader applicability.

Neural response telemetry (NRT) is now well established in implant technology & is useful. Other electrophysiological response methods are also available including measurement of the electrical auditory brainstem response (EABR). Researchers have found NRT & EABR testing to be of some value in assessment of the functional status of implant (Gallego et al 1998, 1999; Truy et al 1998; Thai-Van et al 2002). However, these methods have potential limitation in truly objective threshold estimation. The algorithms for accurate response identification & detection are not straight forward (e.g., requiring response templates of putative responses); otherwise the examiner is compelled to rely upon subjective response detection (i.e. determination of the visual detection level of the responses, scored by the examiner). The realization of automatic detection of response thresholds to facilitate test efficiency (especially for testing over several electrodes) is similarly dissatisfied .The efficiency of testing in general is substantially reduced by existing methods that , in turn, require assessment of one electrode at a time . This is analogous to the inefficiency of objective audiogram estimation with conventional methods i.e., the problem of testing frequency by frequency and/or by ear-by-ear.

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). A faster modulation rate of between 75 - 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 al., 1996; Rickards et al., 1994).

Auditory Steady State Response (ASSR) is an evoked potential that measures frequency specific auditory sensitivity. The auditory steady state responses (ASSR) offer several advantages over transient evoked potentials like ABR. First, the response is easy to recognize, since the statistical techniques that distinguish the response from the background noise in which it is recorded (Dobie & Wilson, 1993, 1996; John & Picton, 2000) need not vary with the latency or morphology of the response. Second, thresholds can be estimated with about the same accuracy and the same frequency-specificity (Herdman, Picton & Stapells in review) as when using tone-evoked auditory brainstem responses. Third, multiple responses can be recorded at the same time (Lins, Picton & Boucher, 1996). Fourth, the presentation level can be up to 120 dBHL with a frequency range from 250 Hz to 8 kHz. A steady state response is evoked by regularly modulating the stimuli. After the initial few modulations of stimuli, the response stabilizes and there after contains constituent frequency components that remain constant in amplitude and phase over time (Regan, 1989). In the auditory system, these responses can be evoked by amplitude and frequency modulated tones, which are frequency specific. The responses are unlikely to be distorted when presented through a sound field speaker.

Several studies stated that auditory steady state responses (ASSRs) could be used to estimate the frequency specific auditory sensitivity. There was a strong correlation between the ABR, ASSR and behavioral thresholds in normal hearing children (Stueve & O'Rourke, 2003; Vander, Brown, Gienapp & Schmidt, 2002) and adults (Dimitrijevic et al., 2002). The audiogram can be reasonably well estimated in both sensorineural and conductive hearing impaired adults (Dimitrijevic et al., 2002; Herdman & Stapells, 2003) and in children (Stueve & O'Rourke, 2003). Finally, ASSR can be used to estimate pure-tone thresholds in infants and children at risk for hearing loss (Cone-Wesson et al., 2002; Ranee et al., 2005).

ASSR can also be useful to assess the frequency-gain characteristics of a hearing aid as there was a good correlation between the insertion gain and functional gain obtained through ASSR. From the results of the study it is inferred that, ASSR is a useful tool in hearing aid selection. (Vanaja & Manjula, 2004). Venkat (2005) reported that significant correlation between the functional gain obtained through ASSR (difference between aided and unaided ASSR response) and the real ear insertion gain. ASSR also enables determination of some basic properties of hearing aids, such as average gain, type of compression, compression factor and onset level (Zenker, 2005). Thus, ASSR serves as an objective tool in hearing aid selection process for difficult-to-test population such as infants, young children in whom reliable behavioral responses cannot be obtained.

Thus ASSR provides attractive features, making this response of potential interest in the assessment of cochlear implant function. It is also shown that there is a relationship between the thresholds estimated objectively via electrical ASSR measurement and the subjective thresholds of cochlear implantees (Menard et al., 2004). In determining post implant audiogram & to assess speech perception through cochlear implant by objective audiometry, ASSR is very useful. This information may be helpful in mapping process and post implant therapeutic rehabilitation & management.

*Need **for the** study:*

There is an imperative need to estimate the improvements in auditory thresholds and evaluate the benefit of achieving normal auditory behaviors using frequency specific objective audiometry in Cochlear Implant subjects.

- It would assist objectively in fitting, accurate programming and post-operative evaluation of cochlear implants in young and difficult-to-test population by providing frequency specific information.
- ASSR stimuli are similar to speech stimuli so this can objectively assess the speech perception abilities (Validating the cochlear implant fitting by showing that speech stimuli across the speech spectrum evoke a neural response and therefore likely to be perceived by the subject).
- The outcomes of this study would also document the efficacy of sound-field ASSR in estimating behavioral thresholds in children with CI.

Aim:

The present study aimed at determining the auditory thresholds in Cochlear Implant subjects using Auditory Steady State Responses and compares it with behavioral thresholds. So that, this technique may be useful for young cochlear implantees to whom behavioral thresholds could not be obtained.

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 t he 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 measurements is the Auditory Steady-State Response. Auditory steady state responses are recorded from the scalp in response to sinusoidal modulated tones (Amplitude or/and Frequency). It 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 FFR (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).

AUDITORY STEADY STATE RESPONSE (ASSR)

The auditory steady state response (ASSR) is a continuous scalp recorded potential that can be elicited by a range of stimuli including continuous amplitude modulated (AM) and frequency modulated (FM) tones (Cohen et al. 1991; Rickards & Clark, 1998; Stapells et al. 1984). Clinical testing typically employs a combined AM/FM stimulus which provides the frequency specificity required for audiogram estimation while optimizing response amplitude (Cohen et al. 1991).

Like the ABR, the fast rate ASSR recorded in sleeping infants primarily reflects activity in the auditory brainstem (Herdman, Lins, Van Roon, Stapells & Scherg 2002). ASSRs generated by amplitude modulated sinusoids were used to measure unaided versus aided hearing thresholds in children with hearing impairment. It was reported that aided thresholds for ASSR were approximately 13 to 17 dB higher than behavioral thresholds (Picton, 1998).

Types 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. Recent 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. Therefore, the present study employed mixed modulation.

Frequency of the Stimuli

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 and 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.

Subject Related Criteria

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

Subject state

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 tor 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 (Ranee et al., 1998; Rickards et al., 1994a). This may be due to the fact that modulation frequency higher than 60Hz is 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 improves the response detection.

Subject Age

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 lower 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, Rance 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. Rance 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.

Threshold Estimation

This section gives brief review of investigations carried out to check the efficiency of ASSR in threshold estimation. Several studies stated that auditory steady state responses could be used to estimate the frequency specific auditory sensitivity as accurate as other electrophysiological tests like ABR. These studies reported that there was a good correlation between behavioral thresholds and estimated ASSR thresholds.

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 a l5 dB above hearing threshold. Aoyagi et al. (1999) have published audiogram 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 l500 Hz and 34.5 dBHL at 4000 Hz. Similar results were reported by Aoyagi et al. (1994).

Rance and colleagues (1995) predicted hearing thresholds using ASSR in a sample that include children and adults. Participants had sensory neural 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.

ASSR can be used for assessing the cochlear implant candidacy. Swanepoel and Hugo (2004) studied the estimations of auditory sensitivity for young cochlear implant candidates using the ASSR. Preliminary results indicate that absent ABR and behavioral thresholds do not preclude the possibility of residual hearing, making the ASSR a primary source of information regarding profound levels of hearing loss, as ASSR can be measured even for 120 dBHL signal.

Dimitrijevic, John and Van Roon (2002) estimated the audiogram using multiple auditory steady state responses. The modulation frequencies varied from 80Hz to 95Hz and the carrier frequencies were 500Hz, 1000Hz, 2000Hz and 4000Hz. For air conduction, the difference between the physiologic thresholds and behavioral thresholds for sensorineural hearing impairment and normal hearing were 14±11,5±9, 5±9 and 9±10dB for the 500Hz,1000Hz, 2000Hz and 4000Hz carrier frequencies respectively. Similar results were obtained in simulated conductive hearing losses. For bone conducted stimuli presented through forehead showed the physiologic-behavioral threshold differences of 22 ± 8, 14 ± 5, 5 ± 8, and 5 ± 8dB for carrier frequencies 500Hz, 1000Hz, 2000Hz, and 4000Hz respectively. These results were comparable to other studies done by Lins, Picton and Boucher, 1996; Picton, Giguere, Beauregard, Durieux-Smith, Champagne, Whittingham and Moran, 1998; Herdman and Stapells, 2001; Perez-Abalo, Savio and Torres, 2001.

Stueve and Rourke (2003) compared thresholds from 76 children using ABR, ASSR and behavioral test methods. He stated that the correlations were strong between these measures and supported the inclusion of ASSR in the standard paediatric test battery. There was a strong and positive correlation for ASSR and behavioral thresholds depending on the frequency range from 500Hz to 4000 Hz. ASSR testing provides audiometric information that is essential in the management of children with severe-to-profound hearing loss. ASSR is also beneficial in patients who are especially difficult-to-test for a variety of reasons. Patients with developmental delays, language disabilities, and neurological delays, multiple genetic anomalies that are non-syndromic, oral disorders, motor disorders, feeding disorders, or blindness are good candidates for ASSR because testing is efficient, accurate and effective.

Roberson, O'Rourke and Stidham (2003) evaluated Auditory Steady-State Responses (ASSR) for determining frequency-specific hearing impairment and compared this technology with conventional auditory Brainstem Responses (ABR). The study was a prospective clinical trial. Twenty-eight paediatric patients ranging in age from 7 to 61 months who were undergoing sedated ABR testing for evaluation of hearing impairment were also evaluated using ASSR. Estimated audiograms of the ASSR were compared with the ABR results. In 20 ears in which an ABR tracing was absent at the maximum level of 90 dB, 13 ears had measurable ASSR thresholds with an average threshold of 98.9 dB at 250 to 8000 Hz. They stated that ASSR showed sensitivity equal to that of ABR for individuals with hearing levels (HL) from 0 to 90 dB HL. In patients with hearing impairment greater than 90 dBnHL, ASSR showed distinct advantage over ABR testing in that recordings were reliably produced up to 127 dBnHL

Cone-Wesson, Dowell, Tomlin, Ranee and Ming (2002) reported the findings of their study in which the threshold estimates from auditory steady-state response (ASSR) tests are compared to those of click- or tone burst-evoked auditory brainstem responses (ABRs). The first, a retrospective review of 51 cases, demonstrated that both the click-evoked ABR and the ASSR threshold estimates in infants and children could be used to predict the pure-tone threshold. The second, a prospective study of normal-hearing adults, provided evidence that the tone burst-evoked ABR and the modulated tone-evoked ASSR thresholds were similar when both were detected with an automatic detection algorithm and that threshold estimates varied with frequency, stimulus rate, and detection method. The study illustrates that ASSRs can be used to estimate pure-tone threshold in infants and children at risk for hearing loss and also in normal-hearing adults.

Recently, auditory steady-state responses (ASSRs) have been proposed as an alternative to the auditory brainstem response (ABR) for threshold estimation (Vander, Brown, Gienapp & Schmidt, 2002). They investigated the degree to which ASSR thresholds correlate with ABR thresholds for a group of sedated children with a range of hearing losses. They studied thirty-two children ranging in age from 2 months to 3 years and presenting with a range of ABR thresholds. Strong correlations were found between the 2000-Hz ASSR thresholds and click ABR thresholds (r =0.96), the average of the 2000- and 4000-Hz ASSR thresholds and click ABR thresholds (r =0.97), and the 500-Hz ASSR and 500-Hz tone burst ABR thresholds (r =0.86). Additionally, 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.

John, Brown, Muir and Picton (2004) examined the auditory steady-state responses evoked by amplitude-modulated (AM), mixed-modulated (MM), exponentially modulated (AM2), and frequency-modulated (FM) tones in 50 newborn infants (within 3 days of birth) and in 20 older infants (within 3-15 weeks of birth). Their hypothesis was that MM and AM2 tonal stimuli would evoke larger responses than either the AM or FM tones, and that this increased size would make the responses more readily detectable. Multiple auditory steady-state responses were recorded to four tonal stimuli presented simultaneously to each ear at 50 dB SPL. The carrier frequencies of the stimuli were 500, 1000, 2000, and 4000 Hz and the modulation rates were between 78 and 95 Hz. The responses to MM and AM2 tones were larger than those evoked by AM tones. Using these stimuli will increase the reliability and efficiency of evoked potential audiometry in infancy. Responses at 50 dB SPL are more easily detected at 3 to 15 weeks of age than in the first few days after birth. Comprehensive frequency-specific testing of hearing using steady-state responses will likely be more accurate if postponed until after the immediate neonatal period.

Gorga, Neely, Hoover, Dierking, Beauchaine and Manning (2004) determined the maximum stimulus levels at which a measured auditory steady-state response (ASSR) can be assumed to be a reliable measure of auditory thresholds. On an average, the ASSR thresholds were observed at 100 dB HL (SD= 5 dB). Because these responses were at least 18 to 22 dB below the limits of the equipment where all subjects had no behavioral responses, it is reasonable to conclude that the ASSRs were not generated by the auditory system, an artifact or distortion may be present in the recording of ASSRs at high levels. These data bring into question the view that there is a wider dynamic range for ASSR measurements compared with auditory brain stem response measurements, at least with current implementation.

Small and Stapells (2004) investigated, in hearing-impaired participants who could not hear the stimuli, the possibility of artifactual auditory steady-state responses (ASSRs) when stimuli are presented at high intensities. They stated that, high-intensity air- or bone-conduction stimuli can produce spurious ASSRs, especially for 500 and 1000 Hz carrier frequencies. High-amplitude stimulus artifact can result in energy that is aliased to exactly the modulation frequency. Choice of signal conditioning electroencephalogram, filter slope and low-pass cutoff) and processing (A/D rate) can avoid spurious responses due to aliasing. However, artifactual responses due to other causes may still occur for bone-conduction stimuli 50 dB HL and higher (and possibly for high-level air conduction). Because the phases of these spurious responses do not invert with inversion of stimulus, the possibility of non-auditory physiologic responses cannot be ruled out. The clinical implications of these results are that artifactual responses may occur for any patient for bone-conduction stimuli at levels greater than 40 dB HL and for high intensity air-conduction stimuli used to assess patients with profound hearing loss.

The auditory steady state responses can be recorded using free field stimuli presented to subjects using hearing aids (Picton et al., 1998). This study showed that the aided thresholds could be reasonably well estimated from the thresholds for steady state responses in a group of children using aids. One obvious difficulty with using aided thresholds to assess how well a hearing aid is working is that the assessment is occurring at levels that are not relevant to the perception of amplified speech. One does not fit a hearing aid to allow the patient to listen to faint sounds. Furthermore, given the non-linear amplification functions of modern hearing aids, it is difficult to extrapolate from threshold levels to the levels at which normal speech occur. Aided thresholds are not uninformative. But if the aided thresholds are below the intensities at which speech normally occurs, the aid can not improve speech perception. Nevertheless some measurement of supra-threshold discrimination would be more helpful in terms of adjusting a hearing aid or monitoring its performance.

According to Picton et al, (2002) the auditory steady responses to amplitude modulated tones with modulation frequencies between 80 and 105 Hz can be recorded when multiple stimuli presented simultaneously through a sound field speaker and amplified using a hearing aid. The aided thresholds for the auditory steady state responses were on average between 13 and 17 dB higher than the behavioral thresholds. The physiologic-behavioral difference is less than that found in normal subjects. The effect was probably related to recruitment. In the hearing impaired, the response reaches a level where it is recognizable at intensity closer to threshold than in normal subjects.

Hearing aid selection by ASSR has certain potential limitations. Gorga, Neely, Hoover, Dicking, Beauchaine and Manning (2004), reported that ASSR gets contaminated with artifacts above lOOdBHL. Hence, care must be taken while evaluating individuals with high gain hearing aids. The other limitations being that, with ASSR it is difficult to distinguish between mild hearing loss and normal hearing (Ranee, Rickards, Cohen, De Vidi & Clark, 1995), which is critically important for determination of amplification needs. Last and the most important limitation is that ASSR measures are done using tonal stimuli and not speech stimuli. Therefore, ASSR does not provide information about the perception of the amplified speech, i.e. if the aided thresholds are below the speech spectrum; it implies that the aid will not be beneficial in improving the speech perception.

In order to overcome the last disadvantage Dimitrijevic, John & Picton (2004) investigated the correlation between the number and amplitude of ASSR components evoked by Independent Amplitude and Frequency Modulation (IAFM) of tones and the word recognition scores in adults. The IAFM parameters were selected such that the stimulus had acoustic properties similar to that of everyday speech. Dimitrijevic et al. (2004) finally concluded that the ASSR evoked by the IAFM stimulus may provide an objective tool for examining the brain's ability to process the auditory information needed to perceive speech. But research is still going on and depending on the progress of this research; this approach may be useful for infant hearing instruments evaluation at some stage in the future.

There are many other benefits of ASSR. Vanaja and Manjula (2004) studied the benefit of ASSR as an objective method for hearing aid fitting by comparing aided ASSR responses with the behavioral functional gain. Results indicated that there was a positive correlation between these two measures suggesting that ASSR can be used for fitting hearing aids .Venkat (2005) further investigated the correlation between the gain obtained in real ear measurements and gain obtained through ASSR. The study was carried out on 20 participants with mild to moderately severe sensori-neural hearing loss and in the age range of 15- 50 years. The results revealed that there was a significant correlation between the gain obtained through real ear insertion gain and gain measured through ASSR at all test frequencies i.e. 500Hz, 1000Hz, 2000 Hz and 4000Hz.

Zenker, Delgado and Barajas (2001) investigated the relationship between amplitude and intensity of the ASSR in a group of adults with normal hearing and varying degrees of sensori-neural loss. They examined this relationship assuming that growth of loudness is related to the amplitude growth of the ASSR. Particularly, they proposed a method to derive information of hearing aid characteristics from the amplitude-intensity function of the steady-state responses. This procedure enables determination of some basic properties of hearing aids, such as average gain, type of compression, compression factor and onset level.

METHOD

Subjects

In total 9 subjects (3 females & 6 males) who used cochlear implant system in one ear participated in this study. Their age ranged between 4-15 years. The subjects were recruited from the Listening Training Unit, Dept of Audiology, AIISH, Mysore. They are continuing listening therapy after implant for 1 to 4yrs duration. All the subjects have congenital hearing impairment. Each of them were using Nucleus24 multi-channel cochlear implant with body level speech processor (except Case no 4 & 9), using ACE strategy. They have a recent and stable mapping. The descriptive data of these children are given in Table 1.

Instrumentation

Calibrated diagnostic audiometer (OB922) was used for estimation of auditory thresholds for frequencies 500 Hz to 4000Hz in free field set-up. 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: Sound field audiometry

Free field behavioral threshold estimation was carried out in sound treated rooms using standard test protocols. Subjects were instructed to raise their finger whenever the tone was heard. For this measurement, FM tone ranging from 500 to 4000 Hz were presented through calibrated loudspeakers .Standard ascending descending method was followed for threshold estimation and the intensity levels were varied according to the responses obtained.

Serial Number	Age/sex	Ear of implantation	Age of implantation	Duration of Cl used	Strategy	Contour or straight	Mode of stimulation	No of active electrode	Company
1	7yrs/M	L	5.5 yrs	1.5yrs	ACE	Contour	Monopolar	22	N24 Freedom
2	6 yrs/M	R	4 yrs	2 yrs	ACE	Contour	Monopolar	22	N 24
3	15yrs/M	R	11 yrs	4 yrs	ACE	Contour	Monopolar	22	N 24
4	4.5 yrs	L	4 yrs	0.5 yrs	ACE	Straight	Monopolar	22	N 24 Feedom
5	7 yrs/M	R	6.5yrs	0.5 yrs	ACE	Contour	Monopolar	22	N 24
6	7yrs/M	L	6yrs	lyr	ACE	Contour	Monopolar	22	N 24
7	7yrs/F	R	5.5yrs	1.5yrs	ACE	Contour	Monopolar	22	N 24
8	7yrs/F	R	5yrs	2yrs	ACE	Contour	Monopolar	22	N 24
9	7.5yrs/F	R	6.5yrs	lyr	ACE	Contour	Monopolar	22	N 24

Table 1: The descriptive data of all the children participated in the study.

The ISO 8253-3 standard prescribes a loudspeaker set- up as shown in figure 1. The subject should be positioned on an axis in front of the loudspeaker from which the test signal is emitted (shown on figure 1). Noise is emitted from two loudspeakers placed symmetrically at a 45° angle on each side of the subject. The loudspeaker should be placed in level with the head of the subject in sitting position. The speaker should face towards the reference point, which is defined as the middle point of a straight line between the openings of the subject's ear canals. The distance between the reference point and the loudspeaker should be at least 1 m.

It should be ensured that the sound pressure (from the loudspeaker) at the reference point doesn't differ more than +/- 2dB from the sound pressure 15cm to the left, right as well as 15cm above and below the reference point (this is valid for all test frequencies).

FM tones were used for the assessment of the hearing threshold in free-field. Due to disturbances caused by reflections and standing waves conventional pure-tone stimuli could not be used in free field, except in an anechoic chamber.

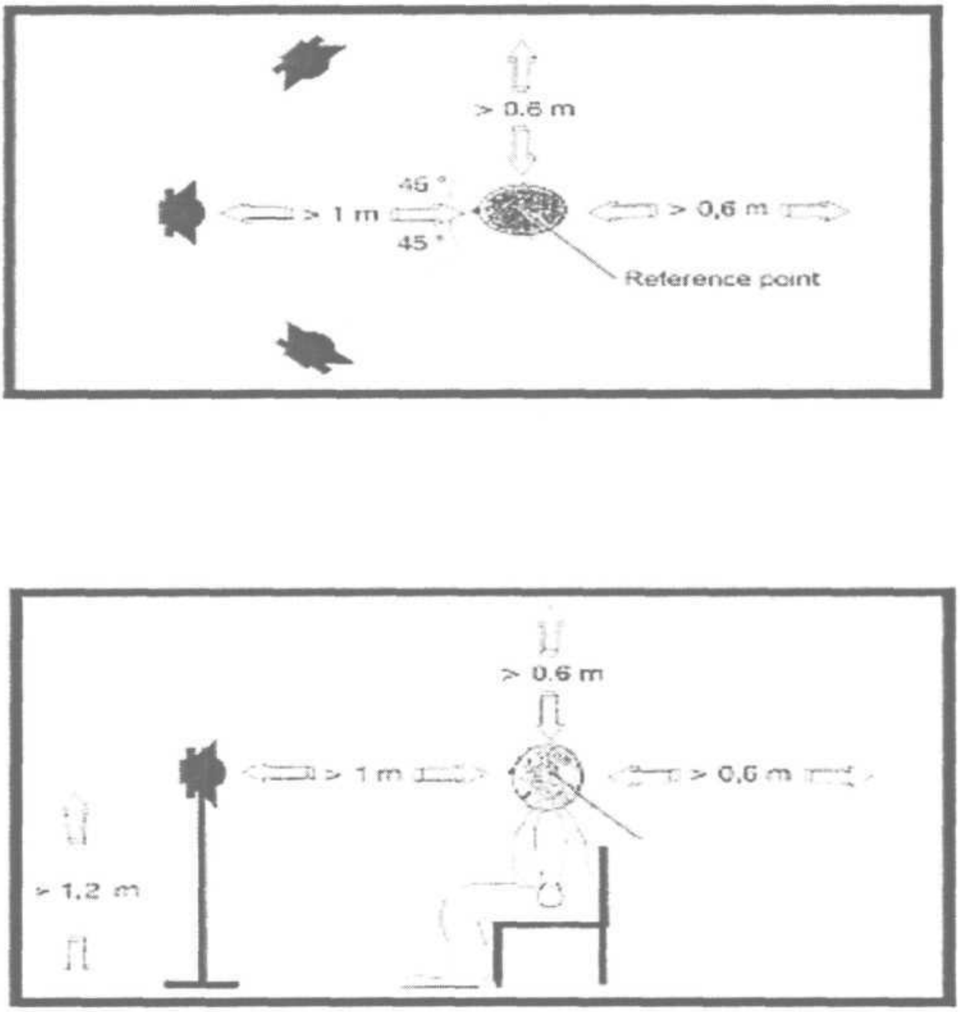

Figure 1 Free field set up in accordance with the ISO 8253-3 standard, as seen from above and from the side

ASSR: *Recording of Auditory Steady State Response*

For ASSR threshold measurement, subjects were reclined on the bed and were instructed to relax, close their eyes and sleep if possible. ASSR thresholds were recorded in single channel. The site of electrode placement was prepared with skin preparing gel. Silver chloride (AgCl) electrodes were placed with conducting gel.

sleeping subjects with stimuli presented at lower (<70 Hz) modulation frequencies .An amplitude modulation depth of 100% & a frequency modulation depth of 10% were combined to maximize response amplitude(Cohen et al 1991).

For this measurement, stimuli were presented through calibrated loudspeakers placed at an angle of 45 degree of ear level & maintaining 1 feet distance from the ear level. ASSR were recorded using the test protocol given in the Table2.

Stimulus	**Recording**
Stimuli: AM/FM tones	***Electrode montage:*** **FPz (+), Cz (-)** and ground on neck.
Carrier Frequency: 500, 1000, 2000 and 4000Hz	***Subject state:*** awake
Modulation frequency: **78, 81, 88, 95 Hz**	***Number of samples:*** maximum of 64
Modulation depth: 100% **AM & 10% FM**	
Transducer: loudspeaker at 45 degree angle.	

Table 2: Shows the ASSR stimulus and recording parameters.

Thresholds were obtained 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 testing was carried out in only in one ear implanted ear. Then threshold was defined as the minimum level at which the phase coherence was significant.

RESULTS & DISCUSSION

The ASSR determined thresholds and measured behavioral thresholds were statistically analyzed using descriptive statistics and linear regression. Statistical evaluations were carried out using SPSS for windows (Version 14.0).

Initial calculations assessed the mean and standard deviations of the two different measures i.e., behavioral threshold and auditory steady state responses (ASSR) or ASSR thresholds. The Table 3 shows mean and standard deviations of ASSR and Behavioral thresholds at all the test frequencies.

Frequency (Hz)	*ASSR threshold (dB HL)*	***Behavioral threshold (dB HL)***
500	33.89 ±4.859	25.56 ± 4.640
1000	36.11 ±7.407	25.56 ±4.640
2000	32.78 ± 7.949	24.44 ± 4.640
4000	38.33 ± 7.906	26.67 ± 5.000

Table 3: Mean and standard deviation of ASSR thresholds, behavioral thresholds at each test frequency.

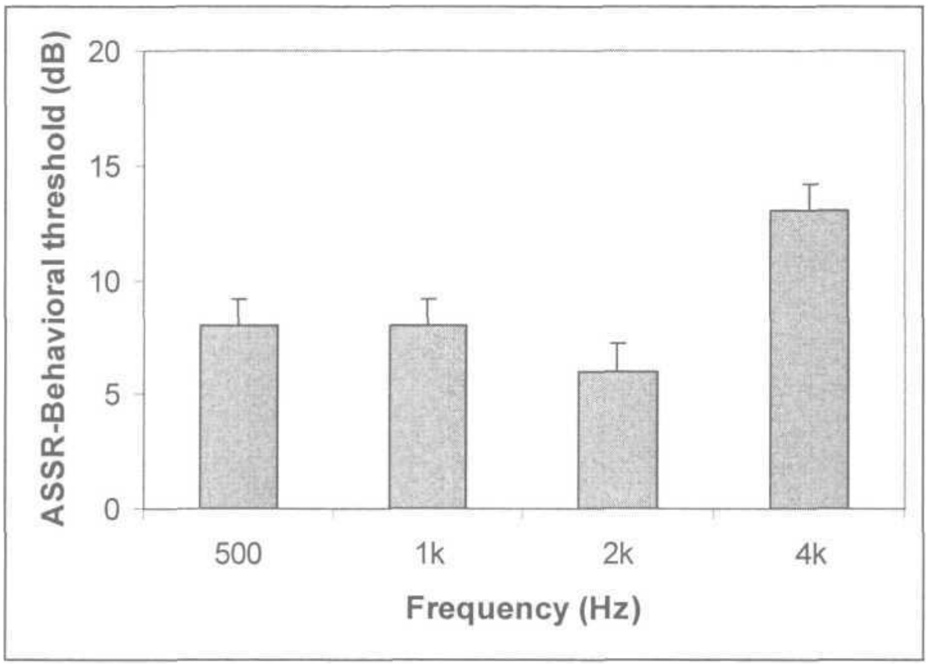

Figure 2: Mean differences between auditory steady state responses and behavioural thresholds at each test frequency. Error bars represent the standard error of mean.

It can be observed in the figure 2, the mean differences are more for 4 kHz compared to other frequencies and it is less for 2 kHz. There was a good correlation ($p<0.001$) between ASSR thresholds and behavioural thresholds.

Independent t-test was run to test the significant difference between behavioral thresholds and ASSR thresholds. No significant differences were found between two groups. Although the mean data did not reach the significance, the difference between behavioral threshold and ASSR threshold does exist.

Frequency	Pearson's correlation	Significance
500 Hz	0.862	0.001**
1000 Hz	0.798	0.010**
2000 Hz	0.894	0.001**
4000 Hz	0.632	0.34*

**. Correlation is significant at the 0.001 level (2-tailed)
*. Correlation is significant at the 0.05 level (1- tailed)

Table 4: The correlation and significance values between the ASSR thresholds and behavioral thresholds at each test frequency.

Frequency (Hz)	**t- Value**	**Significance**
500	2.931	.430
1000	0.638	.220
2000	2.326	.127
4000	0.636	.099

Table 5: t- value and level of significance between behavioral thresholds and auditory steady state response thresholds at each of the test frequencies.

Linear regression analysis was performed at each of the test frequencies to predict behavioural thresholds from ASSR thresholds. Linear regression curves for 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz and combined for all frequencies are shown in figures 3, 4, 5, 6 and 7 respectively. In figure 3 through 7 linear regressions is shown as the solid line. Dotted line represents equal values in dB HL. Correlation coefficients (r), regression equations, and standard error of regression (se) are shown in the upper left of each graph

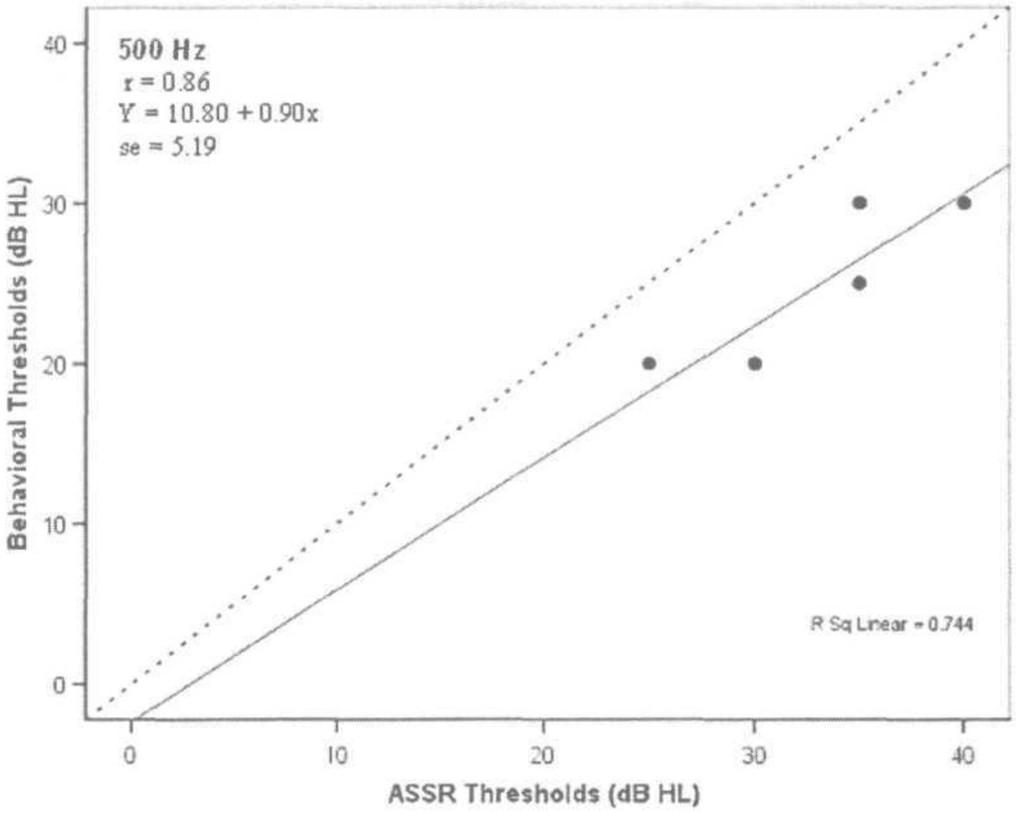

Figure 3: Relationship between auditory steady state responses thresholds (x axis) and behavioural thresholds (*y* axis) at 500 Hz.

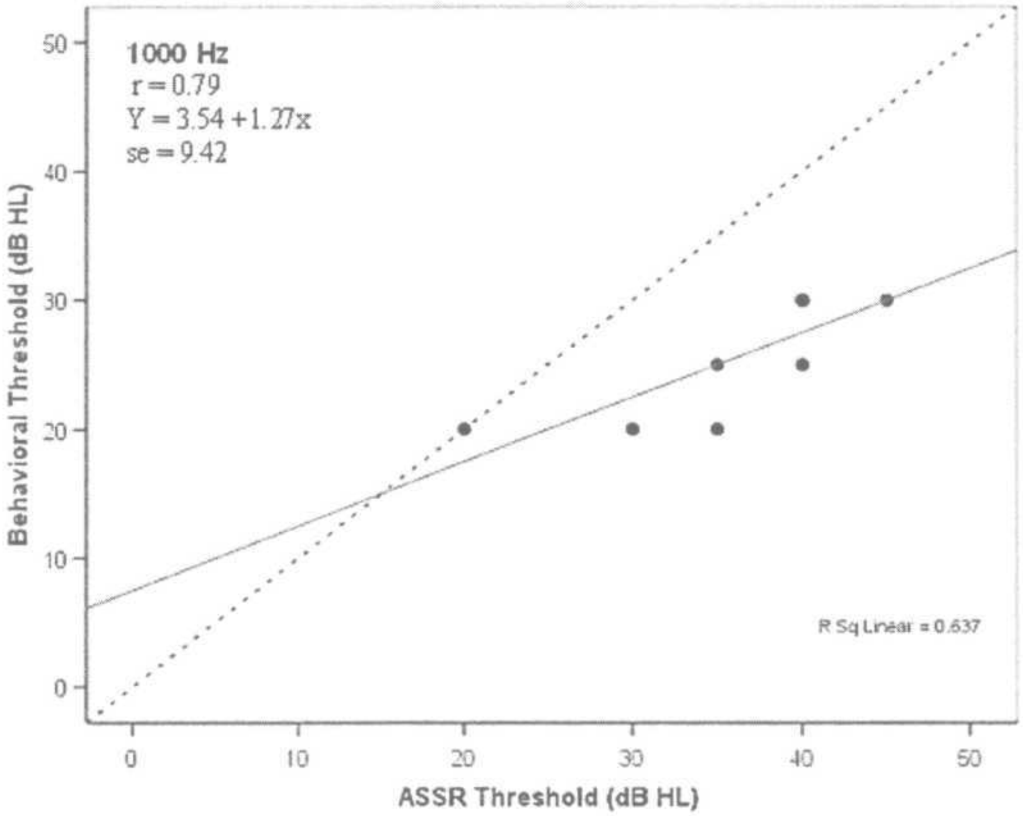

Figure 4: Relationship between auditory steady state responses thresholds (x axis) and behavioural thresholds (*y* axis) at 1000 Hz.

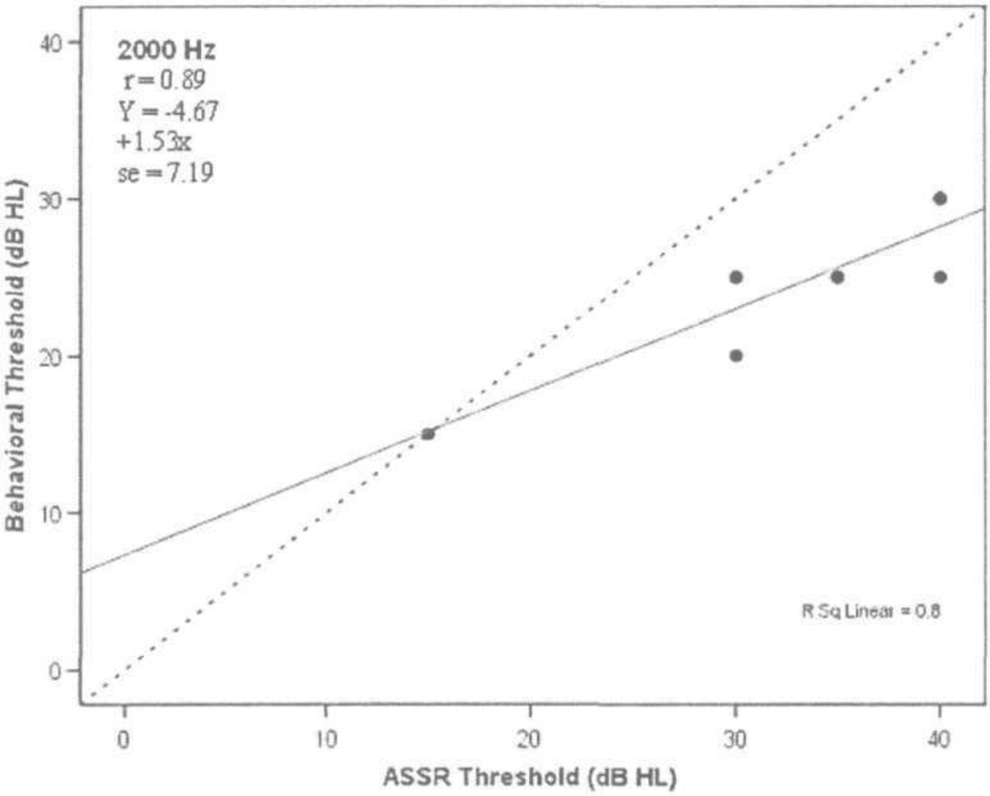

Figure 5: Relationship between auditory steady state responses thresholds *(x* axis) and behavioural thresholds (y axis) at 2000 Hz.

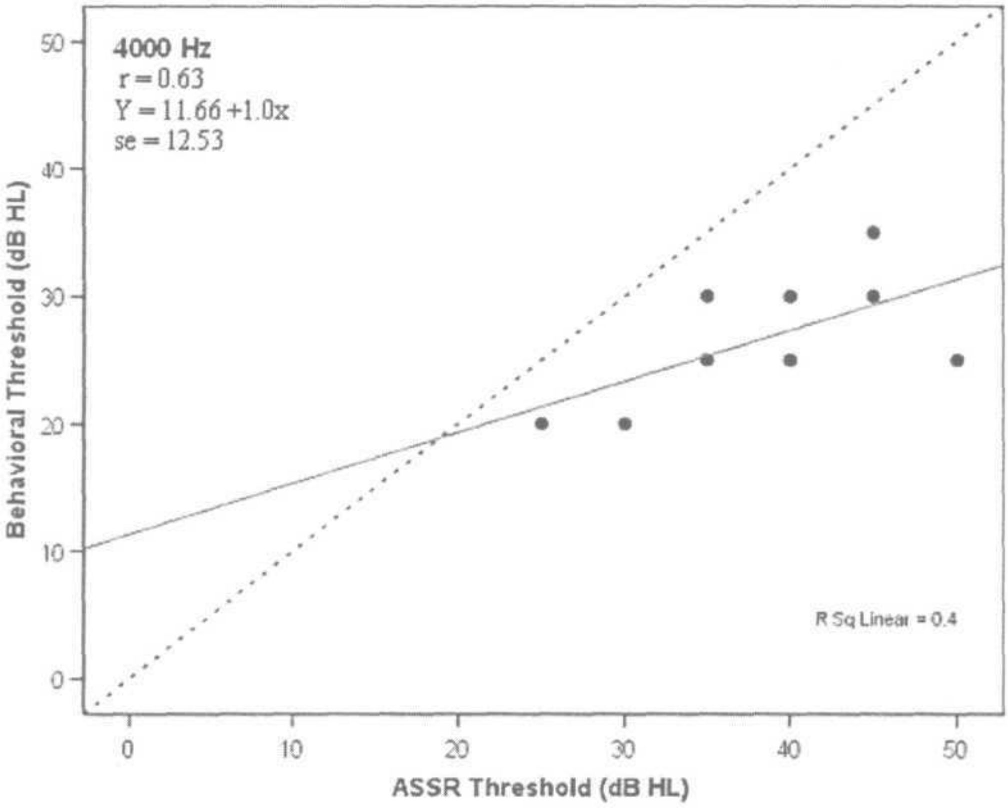

Figure 6: Relationship between auditory steady state responses thresholds (x axis) and behavioural thresholds *(y* axis) at 4000 Hz.

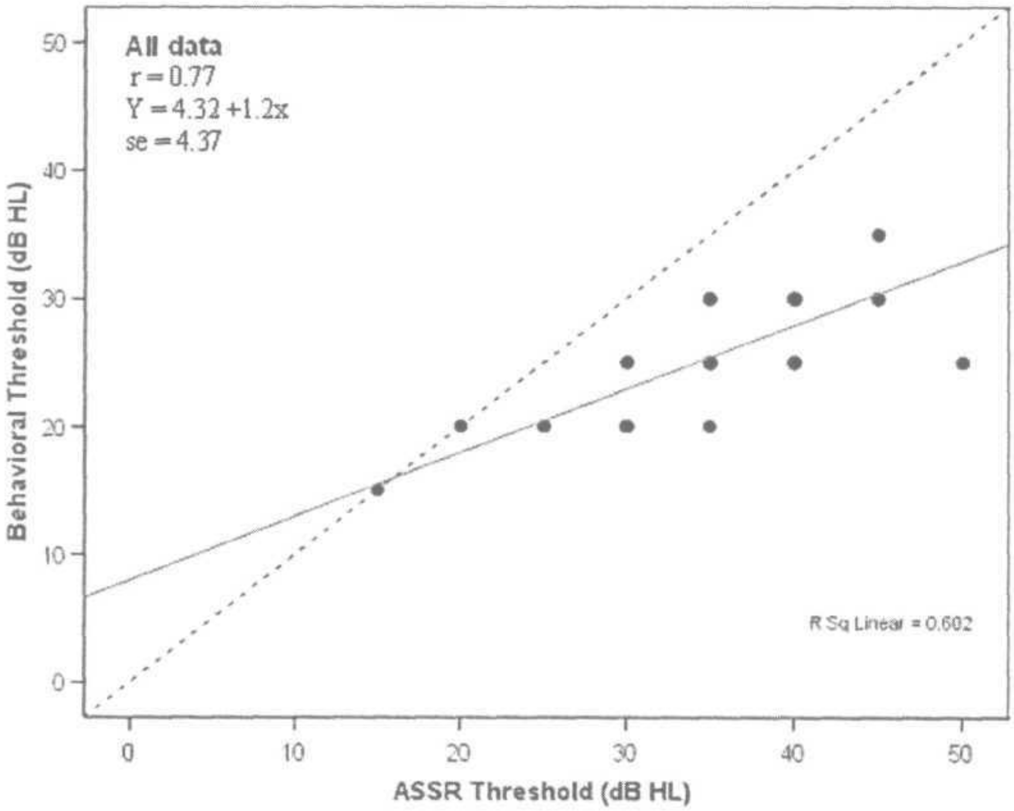

Figure 7: Relationship between auditory steady state responses thresholds *(x* axis) and behavioural thresholds *(y* axis) at all the test frequencies.

Relationship/distribution of auditory steady state responses thresholds (x axis) and behavioral thresholds *(y* axis) at each test frequency and for all frequencies. Dotted lines represent equal values in dB HL. Linear regression is shown as the solid lines. Correlation coefficients (r), regression equations, and standard error of regression (se) are shown in the upper right of each graph.

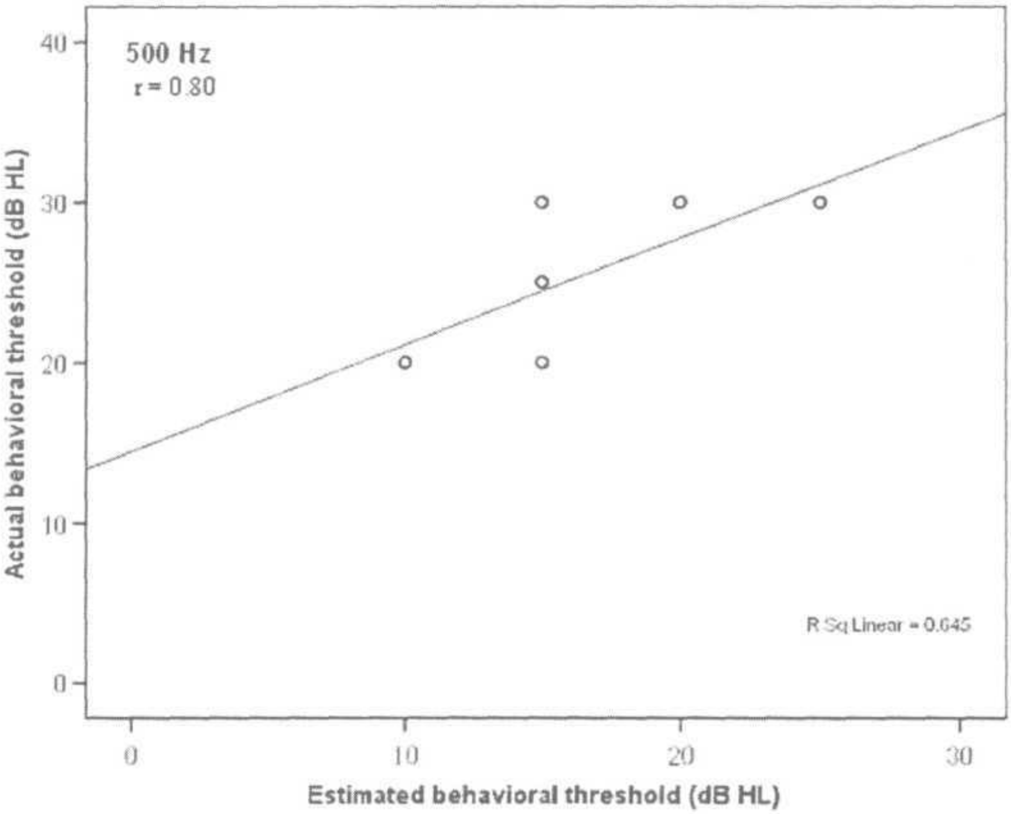

Figure8: Estimated behavioural thresholds compared with actual measured behavioural thresholds at 500 Hz.

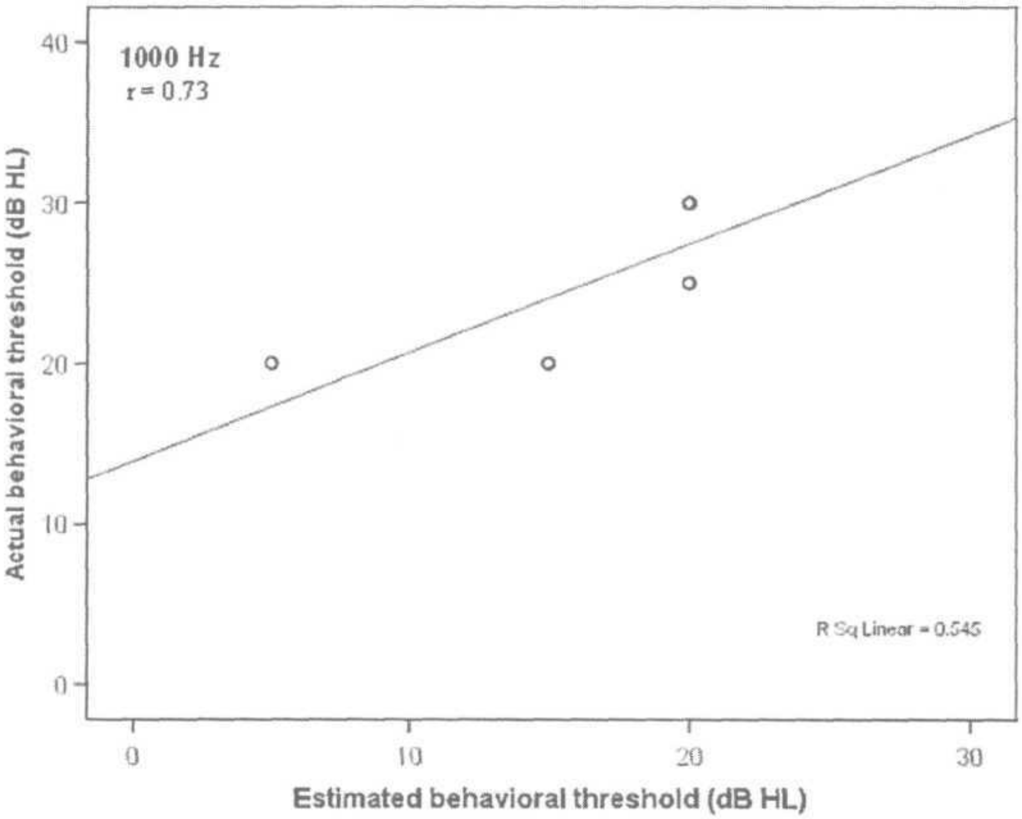

Figure9: Estimated behavioural thresholds compared with actual measured behavioural thresholds at 1000 Hz.

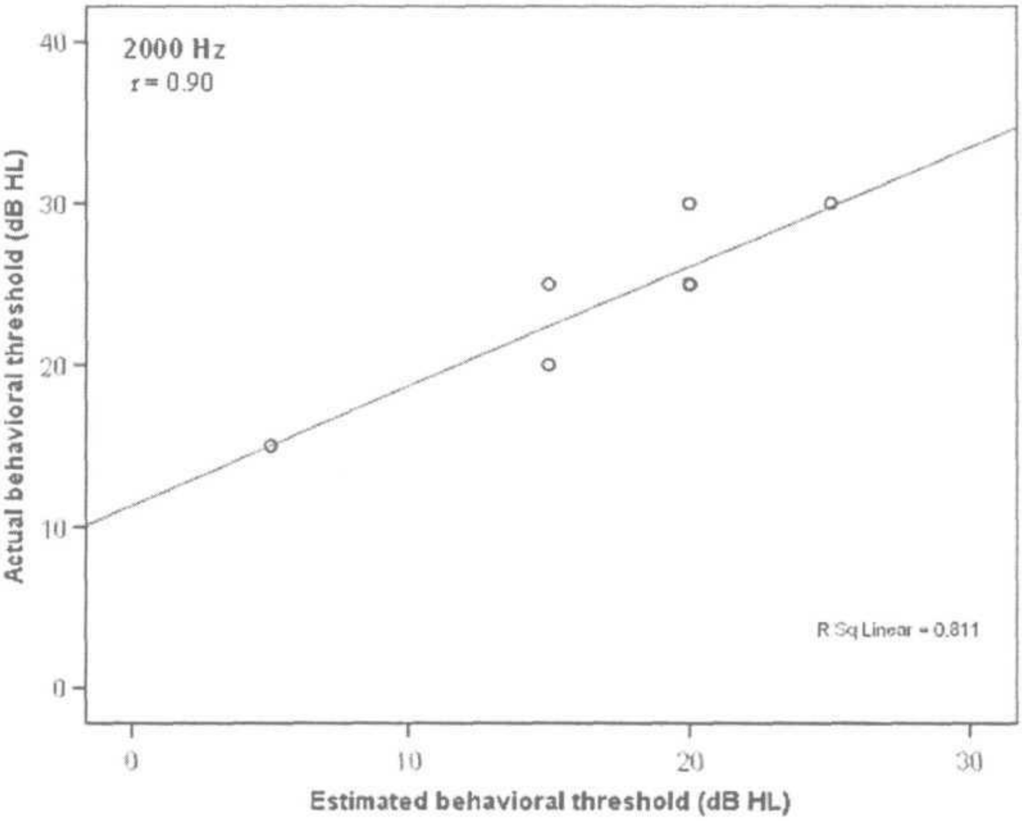

Figure 10: Estimated behavioural thresholds compared with actual measured behavioural thresholds at 2000 Hz.

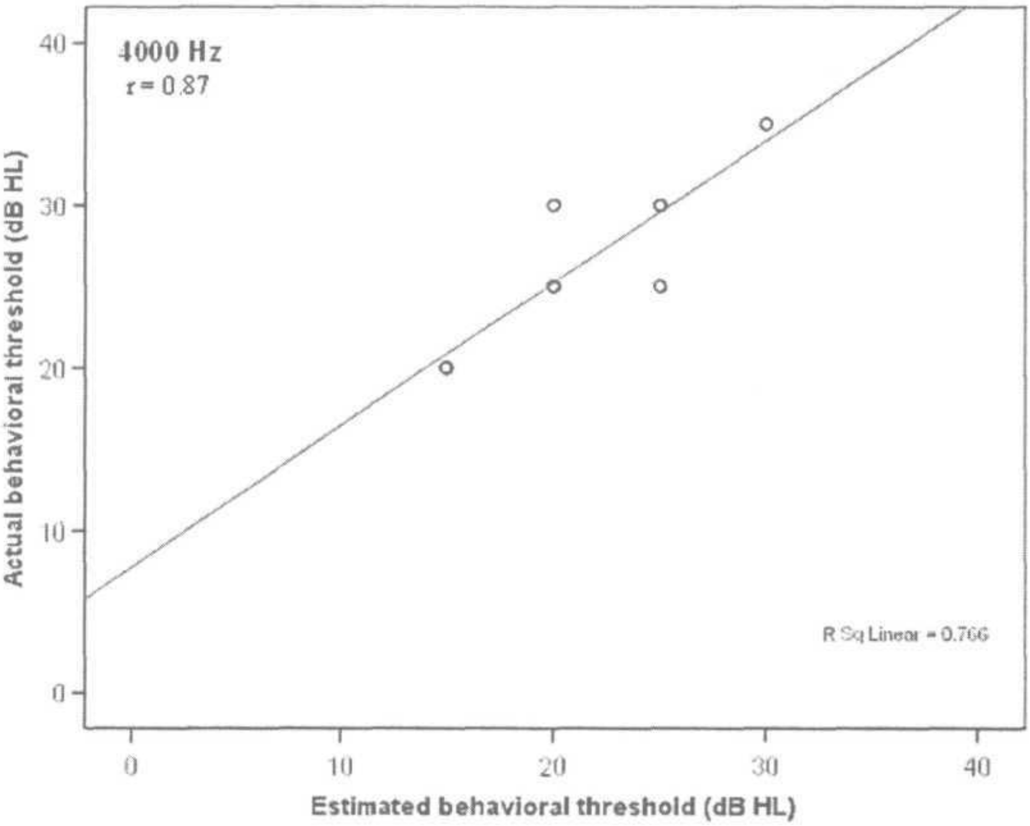

Figure 11: Estimated behavioural thresholds compared with actual measured behavioural thresholds at 4000 Hz. As can be seen in the graphs 8 through 11 the AUDERA estimated behavioral thresholds are significantly correlated with actual measured behavioral thresholds.

DISCUSSION

The aim of the study was to estimate the auditory thresholds in cochlear implanted children using an objective technique (auditory steady state responses) and compare that with behavioral thresholds.

Comparison of behavioral and ASSR threshold

The ASSR thresholds for the subjects with cochlear implant obtained in the present steady are higher than the measured behavioral thresholds. The results of the current study are similar to some of the earlier investigators with normal and hearing impaired population (Aoyagi et al., 1994a; Rance et al., 1995; Rickards et al., 1994). The difference between ASSR threshold and behavioral threshold was lower in subjects with hearing loss than normal this may be attributed to softness imperceptions or recruitment (Rance et al., 1995).

The difference between ASSR threshold and behavioral threshold was higher at high frequency compared to that of low frequency. These findings are not in consistence with the earlier findings showing strong correlation at high and poor correlation at low frequencies in hearing impaired population (Aoyagi et al., 1994a; Rance et al., 1995; Rickards et al., 1994). The poor correlation at low frequencies could be because of normal biological and environmental noise which centers on low frequency that might affect ASSR measurement at lower frequencies.

Strength of prediction

Truy et al. (1998) using other electrophysiological methods to estimate behavioral thresholds observed linear decrease in strength of prediction as test frequency increases. In other words, the prediction is more accurate at low frequencies compared to high frequencies.

The results of the present study followed the same trend as observed in Truy's (1998) study, however, in the present study, linearity in prediction was not observed. Prediction at 2000 Hz was the best of the all test frequencies.

The following explanations describe why prediction is high at low and mid frequencies and vise versa,

- First, reduced dynamic range at high frequency compared to that at low frequencies (Menard et al 2004).
- Second, it can be hypothesized that as the current level required is lower for low frequency so threshold prediction is better at low & mid frequencies as compared to higher frequencies. This might be due to the larger neuronal survival of low and mid frequency fibers leading to better synchrony.
- Third, Picton et.al (2003) reported that at threshold level there is more jitter seen in neural responses and require more number of averages for estimation of thresholds.

As observed from the threshold (T) level of Cochlear implant (CI) subjects, participated in the present study T level are high at high frequencies as compared to low & mid frequencies which would have contributed more threshold variations. However, it is difficult to understand the basic physiology owing to less number of subjects participated in the present study.

There was a significant correlation between ASSR and behavioral threshold and correlation coefficient ranged from 0.632 to 0.894. 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 ASSR >70 Hz are efficient in threshold prediction of CI population and estimating audiogram configuration of the same population. However, the conclusions should be taken with caution as the total number of participants was less. It's important to control the subject state while recording ASSR for higher modulation frequency.

SUMMARY AND CONCLUSIONS

Scope of cochlear implantation is changing with the establishment of newborn hearing screening programs throughout the world. This has increased the need for reliable, objective techniques for determining candidacy and evaluating cochlear implant efficacy in infants and very young children. The measurement of auditory thresholds or comforts levels for HI subjects with cochlear implants currently requires their attention and active cooperation. Unfortunately, subjective methods are of little or no value for the assessment of very young children and other difficult- to-test population .Therefore, a more objective method could be valuable; a sufficiently robust method might have even broader applicability.

The present study evaluated the efficacy of an objective technique i.e., auditory steady state response (ASSR) in determining auditory thresholds in children with cochlear implants. Total nine children, age ranged between 4-15 years, participated in the study. The experiment was carried out in 2 stages. First, ASSR threshold measurement was done. Second, behavioral thresholds were obtained with appropriate behavioral techniques. ASSR and behavioral thresholds were obtained for the test frequencies 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

The results showed that, there was a good correlation between the acoustical ASSR and behavioral thresholds. In addition, there was no statistical difference between the two data, suggesting acceptable accuracy of behavioral threshold estimation with the use of ASSR. Thus, ASSR technique shows great promise as a way to assess auditory sensitivity in subjects with cochlear implants who can not reliably respond on behavioral testing.

Moreover, the results of the present study suggests need for an in depth investigation into efficacy of some measurement of supra threshold processes, which would be much more helpful in terms of monitoring device performance and adjust mapping. Finally the results need to be confirmed in a greater number of subjects, not only for further validation of the method, but also to acquire sufficient data to support the development of an expert system, allowing the automated assessment of cochlear implantees and the programming of these processors. The present study highlights the potential implications of ASSR instead of behavioral methods in fitting of young children and other difficult-to-test to test patients.

FUTURE RESEARCH DIRECTIONS:

1) The present study can be replicated on large population for standardized normative data.
2) Development of normative data across age wise in CI users.
3) Should include others company product like (Medel, Advance Bionics etc.) with different strategy users like (CIS, Hire-solution).
4) To find out correlation between ASSR threshold changes with Comfortable (C) & Threshold (T) levels.
5) Effect of subject state of activity on threshold estimation can be studied.

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