COMPARISON OF CLICK AND CHIRP EVOKED ABR IN NORMAL AND HEARING IMPAIRED INDIVIDUALS

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PARENTS & TEACHERS

CERTIFICATE

This is to certify that this dissertation entitled ***"Comparison of click and chirp evoked ABR in normal and hearing impaired individuals"*** is the bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student (Registration No. 06AUD017). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

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

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I. INTRODUCTION

The Auditory Evoked Potentials are the electrical responses of the auditory nervous system to auditory stimuli (Stapells, Picton, Abalo Read & Smith, 1985). Auditory evoked potential's (AEP's) that are recorded from the scalp represents the contribution of neural events that arise from many discrete and neural generating sites along the auditory pathway. They are usually grouped in to various categories based on the time of occurrence after the onset of the stimuli and this grouping corresponds roughly to the site of generation. Short latency AEP's like ABR are used clinically for threshold estimation and neurodiagnosis and are elicited by using click and tone bursts. The click evoked auditory brainstem response (ABR) waveform generally consists of seven peaks, all occurring within the first 10 ms after the signal onset. Of the seven peaks, wave I, III, and V are significantly robust for clinical use. The most robust peak can be elicited near threshold level is wave V.

It is generally assumed that ABR are the best evoked by stimulation with clicks. Clicks are commonly used in electrophysiological tests of the human auditory system to elicit synchronized auditory brainstem responses (ABR). Because of its abrupt onset, the acoustic click is often thought to be an ideal stimulus for eliciting a detectable ABR. Clicks or impulsive stimuli are also used under the assumption that their wide spectral spread, inherent in transient signals, elicits synchronous discharges from a large proportion of cochlear fibers (Kodera, Yamane & Suzuki, 1977; Gorga & Thornton, 1989).

But in cochlea the response of a click is not entirely synchronous, that is the peak of the response occurs several milliseconds later in the low frequency channels than it does in high frequency channels (Bekesy, 1960). As a consequence ABR responses are largely generated by synchronized activity of high frequency region (Dau, Wegner, Mellert & Kollmeier, 2000). Also when a transient stimuli progresses apically along the basilar membrane, single unit activity is less synchronous with the preceding activity from basal units (Tsuchitani, 1983) because of the temporal delays imposed by the traveling wave. This results in an asynchronous pattern of neural firing along the length of cochlear partition. In addition it is likely that the activity generated from single units is more synchronous at basal regions and would be out of phase with activity from some apical units. As a consequence the combination of phase cancellation and loss of synchronization bias the evoked potentials to reflect the activity from more basal, high frequency regions of cochlea (Neely, Norton, Gorga, & Jesteadt, 1988). Thus, it suggests that the click may not be the optimal stimuli for ABR recording.

Dau et al. (2000) demonstrated that ABR is not an electrophysiological event that is purely evoked by the onset or the offset of the acoustic stimulus, but rather an appropriate temporal organization, determined by basilar membrane traveling wave properties which in turn can significantly increase synchrony of neural discharges. They examined ABR elicited using rising frequency chirps which was optimized to match the basilar membrane group delays in cochlea. So researchers generated different stimuli (based on formulas based on models) to compensate the basilar membrane characteristic frequency delay and to get synchronous response in ABR. One of such stimuli is chirp.

ABR elicited by the rising chirp showed larger wave-V amplitude than did click-evoked responses for most stimulation levels tested (Dau et al. 2000). Since the ABR wave V reflects a neural response from the brainstem, the effect of an optimized synchronization at the peripheral level thus can also be observed at the brainstem level. Studies done on chirp evoked ABR stimuli were focused in individuals with normal hearing and in limited number of subjects.

Need for the study:

Since studies done so far on comparison of click and chirp evoked ABR on a limited number of subjects it is necessary to study in large population on normal hearing individuals using to elicit ABR threshold for generalization and clinical use. This could be further used to compare with click evoked ABR in individuals with normal hearing and sensory neural hearing loss.

Dau et al. (2000) have also reported that the ABR involved by chirp's stimulus involve cochlear processing and evokes larger wave V ABR response at low sensation levels with good morphology it will be interesting to see the effects of cochlear processing in individuals with cochlear hearing loss. Also there is dearth of studies in literature comparing clicks and chirp evoked ABR in individuals with cochlear hearing loss. Thus, the study aimed at studying chirp evoked ABR in individuals with normal hearing and sensory neural hearing loss.

Dau et al. (2000) have also reported that at equal sensation levels (SL's) the amplitude of chirp evoked ABR wave V was greater than click evoked ABR in individuals with normal hearing loss. But there is dearth of information in comparing click and chirp evoked ABR thresholds in individuals with normal hearing and cochlear hearing loss and also in correlating pure tone averages with chirp evoked ABR. So there is a need to compare the amplitude at equal sensation levels obtained in individuals with normal hearing and sensory neural hearing loss. Also there is need to compare click and chirp evoked ABR thresholds with pure tone averages in individuals with normal hearing and sensory neural hearing loss.

It has also been reported that the chirp stimuli evoked synchronous neural activity in auditory nerve, compared to click stimuli (Dau et al, 2000). Thus, there is a need to assess whether chirps can evoke a detectable ABR in individuals with auditory neuropathies where outer hair cells were preserved. It is also necessary to observe whether the chirp stimuli can help us to estimate threshold in individuals with auditory dysnchrony.

Aims of the study were:

- To establish ABR data using chirp stimuli in large number of individuals with normal hearing.
- Obtain latency intensity functions for chirp evoked ABR wave V in individuals with normal and hearing impaired.

- To compare the wave parameters (amplitude, latency and morphology) of click and chirp evoked ABR in individuals with normal hearing and cochlear impaired at 80 dBnHL and 40 dB SL and at repetition rates of 11.1/ sec and 30.1/ sec.
- To compare behavioral thresholds and ABR thresholds obtained by click and chirp in normal hearing and cochlear impaired individuals at 30.1/ sec repetition rate.
- To analyze whether chirps can evoke any significant neural synchrony in individual with auditory dysynchrony at 11.1/ sec repetition rate.

II. REVIEW OF LITERATURE

Evoked responses represent the summation of responses from many neurons, recorded from electrodes placed on the surface of the head (Jewett, 1970), i.e., remote to the individual neurons. Auditory evoked potentials can be recorded from all levels of the auditory system. They are usually grouped by the time of occurrence after the onset of the stimulus, and this grouping corresponds roughly to the site of generation. The click-evoked auditory brainstem response (ABR) waveform generally consists of seven peaks, all occurring within the first 10 msec after the signal onset. Of the seven peaks, waves I, III, and V are sufficiently robust for clinical use. The most robust peak is wave V which can be elicited at near-threshold levels. It is generally assumed that ABR are best evoked by transient stimulus like clicks. Clicks are commonly used in electrophysiological tests of the human auditory system to elicit synchronized auditory brainstem responses (ABR). Because of its abrupt onset, the acoustic click is often thought to be an ideal stimulus for eliciting a detectable ABR. Clicks or impulsive stimuli are usually used under the assumption that their wide spectral spread, inherent in transient signals, elicits synchronous discharges from a large proportion of cochlear fibers (Kodera et al. 1977; Gorga & Thornton, 1989). But there are some limitations of click evoked ABR.

Limitations of click stimuli:

In cochlea the response of a click is not entirely synchronous, that is the peak of the response occurs several milliseconds later in the low frequency channels than it does

in high frequency channels (Bekesy, 1960). As a consequence ABR responses are largely generated by synchronized activity of high frequency region. Also strong synchronization is seen in high frequency regions due to the high travelling wave velocity in basal region of cochlea (Dau et al. 2000)

Although the click responses are synchronous at the basal region, depending on the relative timing of activation between low frequency and high frequency some neural elements can phase cancel the activity of others (Don, Msuda & Brackmann, 1997). As a result of phase cancellation with broad band stimuli like clicks, phase cancellation of field activity from more apical regions of cochlea occur, so that the resulting peaks in the response largely reflect activity from more basal regions. This leads to more amount of variability and decrease in amplitude of click evoked ABR (Don & Elberling, 1994)

Studies supporting the above limitations of click ABR:

Forward masking or derived masking experiments have been support to these limitations of Click ABR they are as follows.

Near field recording:

Dolan, Teas, and Walton (1983) have recorded Whole-nerve action potentials evoked for click stimuli from a gross electrode on the cats and the discharges of auditory nerve fibers to the same standard click were recorded from micropipette electrodes in the auditory nerve. The effect of a preceding tone burst (2, 4, or 8 kHz} upon the responses

was measured for forward-masker intensities from 20 to 80 dB SPL. All forward maskers reduced the discharges of auditory nerve fibers to the standard click with the greatest reduction occurring for fibers with characteristic frequencies {CFs} near the masker frequency. The 4 and 8 kHz forward maskers produced similar effects on N1, P1, and N2 of the cat's response. However, the 2 kHz reward masker produced enhancement at P1 and N2 in the auditory nerve response to the standard click**.** Thus he reported that when auditory nerve is stimulated with a click, only auditory-nerve units tuned above 2–3 kHz contribute to synchronous activity in the N1-P1 complex.

Far field recording:

- Don and Eggermont (1978) recorded click ABR at 60 dB SL in noise high passed at various cutoff frequencies separated by l/2-octave steps in normal-hearing adult subjects. By applying a derived response technique, narrow-band contributions to the ABR from specific portions of the basilar membrane were revealed. Latencies and amplitudes of the various waves in the derived ABR were recorded. Results indicated that nearly the whole cochlear partition can contribute to the brainstem response. But when they looked the contribution to the ABR of various regions along the cochlear partition, using derived band method they found that that for high cutoff frequencies, a normal response pattern is generated by those high-frequency regions along the cochlear partition. As the central frequency (CF) became lower, there appears to be in the derived response less contribution to the earlier peaks, but good

contributions to wave V. From their results they made a division that above 2 kHz, the wave V behavior was the same as for the earlier waves; below 2 kHz, however, wave V amplitude remains nearly constant for the whole range of CF's while waves I and III show a rapid drop in amplitude with decreasing CF. It could be inferred from the above study that click ABR contribution is more above 2 kHz than at low frequencies.

- Gorga, Worthington, Reilamd, Beauchine and Goldgar (1985) compared auditory brain stem responses (ABR) and pure-tone behavioral audiograms in patients with cochlear hearing loss. He found that Click-evoked ABR thresholds appeared to be related most closely to the audiometric thresholds at 2000 and 4000 Hz, with relatively poor agreement at either 1000 or 8000 Hz.

Thus, from the masking and threshold estimation studies it could be concluded that click evoked ABR have more synchrony in high frequency region rather than being throughout the basilar membrane. So overcome this phase cancellation effects different types of stimuli were generated to optimize the basilar membrane dispersion and increase neural synchrony. One of such stimuli used in the generation of neural synchrony along the basilar membrane is chirps.

Chirps stimuli:

Auditory brainstem responses (ABR) were recorded by Shore and Nuttall (1985), and Dau et al. (2000) using chirp-stimuli that are designed to compensate for the cochlear traveling wave delay. The traveling wave in the cochlea in response to a brief stimulus

like click takes a considerable amount of time to reach from the base of the cochlea to the apex, i.e., from the highest to the lowest frequency responding area. Thus individual areas along the cochlear partition and the corresponding hair cells and nerve fibers of the auditory nerve will not be stimulated at the same time. Thus, the compound neural response will be temporally smeared. This temporal dispersion can be counteracted by delaying the higher frequencies relative to the lower frequencies of the stimulus. Such a scheme has to be based on an appropriate model of the traveling wave delay.

A chirp stimulus attempts to compensate for the dispersion by aligning the arrival time of each frequency component in the stimulus to its place of maximum excitation along the basilar membrane. Such compensation will make the stimulus more efficient by achieving higher temporal synchronization between the evoked activities from the different neural elements that contribute to the formation of not only the auditory compound action potentials but also the ABR and Auditory steady state responses Elberling, Don, Cebulla and Stürzebecher (2007).

Types of chirp stimuli:

Chirp is a short duration frequency sweep stimuli to compensate basilar membrane travelling wave. Dau et al. (2000) have reported 2 different ways the chirp stimuli can be generated

1) *Rising chirp* stimuli starts with low frequencies and sweeps nonlinearly in time toward high frequencies.

2) *Falling chirp stimuli/ reversed chirp* starts with high frequencies and sweeps nonlinearly in time toward low frequencies.

Comparison of rising and falling chirp stimuli:

Comparison of wave V amplitude of ABR using rising vs. falling chirps stimuli were compared in humans by Dau et al. (2000). The average Wave-V amplitude was significantly smaller ($p < 0.05$; n=10) for the reversed chirp than for the rising chirp for all stimulation levels of 10–40 dB SL. The reversed-chirp amplitude was also significantly smaller than the click response for the levels 20–40 dB SL ($p < 0.05$; n=10), while the difference was not significant for 10 dB SL. This is due to the fact that using reversed chirp will decrease the neural synchrony instead of increasing it. Falling sweeps produce sequential activation of high-frequency fibers followed by low-frequency fibers (Dau et al. 2000). This may lead to a desynchronized neural activation at the brainstem level, as implied by the results of Shore and Nuttall (1985) at the level of VIIIth nerve and CN. Thus, rising chirp stimuli were used in all the studies to evoke synchronized neural responses.

Rising chirp stimuli:

Different studies done using rising chirp stimuli had used different models and formulas to generate rising chirp stimuli.

Different types of rising chirps used in these studies were:

1) *A- chirp:* A- chirp is ABR based chirp stimuli which was developed based on the tone-burst-evoked ABR data by Gorga, Kaminski, Beauchaine, and Jestead,

(1988). They used tone bursts at ten frequencies (0.25, 0.5, 0.75, 1, 1.5, 2, 3, 4, 6, and 8 kHz0 and nine intensities (20 to 100 dB SPL in 10-dB steps) and obtained this stimulus.

2) *O- chirp:* also called as OAE based chirp stimulus was developed based on the experimental SFOAE data by Shera and Guinan (2000). They did experiments for stimulus frequencies in the range from 0.5 to 10 kHz in humans, at a level of 40 dB SPL and from this data they formulated the chirp stimulus.
3) *Exact chirp stimuli:* This stimulus was generated by Dau et al (2000) using de Boer's cochlear model. In this stimulus spectral weightage to higher frequencies was not given thus the spectrum of the chirp stimuli was not flat.
4) *M- chirp*: Also called as modified chirp which was used in the study was developed by Dau et al (2000). They developed chirp with a flat magnitude spectrum and he denoted it as the ''flat-spectrum chirp.'' Since this chirp is based on de Boer's model (1980), it is also referred to as the ''M-chirp''. The time course of the chirp developed and used in the study by Dau et al (2000) was determined by the traveling-wave velocity along the partition as derived by de Boer (1980), and the functional relationship between stimulus frequency and place of maximum displacement (Greenwood, 1990). de Boer (1980) developed linear cochlear model in which he assumed that the fluids of the canals around the basilar membrane would be incompressible and that all viscosity effects were negligible. All movements were assumed to be so small that the fluid as well as the BM operates linearly.

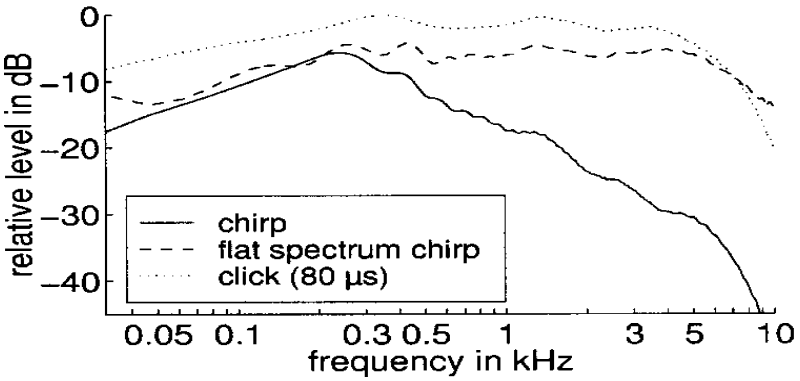

Figure 1: Spectral representation of click, exact chirp and flat spectrum chirp developed by Dau et al. (2000).

Out of all these chirp reported in literature most commonly used chirp was M-chirp (Dau et al, 2000; Wegner & Dau ,2002; Feobel & Dau, 2004; Agung, Purdy, Patuzzi, O'Beirne, & Newall, 2005).

Comparison of click evoked ABR and chirp evoked ABR (M- chirp) in individuals with normal hearing:

Dau et al. (2000) have done a series of experiments comparing various parameters (amplitude, latency and threshold) of click and chirp evoked ABR responses in 10 normal hearing individuals evoked at 20/ sec repetition rate. The stimulus level was varied and they were compared in equal SL levels from 10 dB SL to 60dB SL in 10 dB steps. They measured the response to the click stimulus, in terms of latencies relative to click onset. But in the case of the chirp stimulus, a dual abscissa is used representing recording time relative to stimulus onset and offset so that the stimuli could be response latency could be compared relative to onset and offset of the stimuli. They noted that the wave-V latencies for the

two stimuli, relative to stimulus onset, are shifted by the duration of the chirp stimulus which equals to 10.5 ms. Thus the latency values relative to stimulus offset are the same in both conditions.

The results were discussed in terms of their peak to peak amplitude, latency using click and chirp stimuli:

- ✓ The wave-V amplitude was larger for chirp stimulation than for click stimulation. Wave-V amplitude was significantly larger ($p < 0.05$; $n=10$) for the chirp than for the click, for the levels of 20–40 dB SL. For 50 and 60 dB SL, the average wave-V amplitude was still larger for the chirp than for the click, but the difference was not significant ($p > 0.05$). This attributed that the increase in amplitude in with chirp stimuli is due to the temporal organization and temporal integration (longer duration), as it increases neural synchrony thus amplitude.
- ✓ At the two highest stimulation levels, earlier activity in response to the chirp becomes visible with a first response peak at about 8–9 msec after chirp onset. At the highest levels (50 and 60 dB SL), the early low-frequency energy of the chirp probably stimulates basal regions of the BM due to upward spread of excitation, producing a response at about 8–9 ms after stimulus onset.
- ✓ For the lowest stimulation level, 10 dB SL, four of the subjects showed no clear wave-V peak in either the chirp or in the click condition. The number of the remaining subjects was too small to reveal a significant difference in the ABR.
- ✓ It was observed that not only temporal organization of the stimulus, but also its spectral shape, influences the ABR pattern. The phase characteristic of the chirp,

combined with a flat spectral distribution (as in case of the click), led to a large wave-V amplitude, but also to a more pronounced pattern of the earlier waves (at high stimulation levels), which is comparable to that evoked by the click. In contrast, responses evoked by the rising chirp without specific spectral weighting did not show clear earlier peaks I–III. This may be due to cancellation of overlapping responses at high stimulation levels where the early low-frequency energy in the chirp stimulates basal regions of the BM due to upward spread of excitation. Alternatively, or in addition, this may also be due to biased frequency representations at the level of the neural generators for wave's I–III, while the generator for wave V probably has a flatter frequency response.

Thus, the authors have concluded that the use of the rising frequency chirp enables the inclusion of activity from lower-frequency regions, whereas with a click or a falling chirp synchrony is decreased in accordance with decreasing traveling velocity in the apical region. The rising frequency chirp may therefore be of clinical use in assessing the integrity of the entire peripheral organ, and not just its basal end.

Frequency specificity of M- chirp stimuli:

Wegner & Dau (2002) compared ABR responses evoked by click and broad band M- chirp stimuli in the presence of high pass masking noise, with cut off frequencies of 0.5, 1, 2, 4 and 8 KHz for 9 normal hearing subjects. Results revealed larger wave-V amplitude for chirp than for click stimulation in all masking conditions. Wave-V amplitude for the chirp increased continuously with increasing high-pass cutoff frequency

while it remains nearly constant for the click for cutoff frequencies greater than 1 kHz. Their results demonstrated that the increased synchrony obtained with the chirp stretches over the entire frequency region. Thus, they reported that chirp may be particularly interesting for clinical use in the low-frequency region below about 0.5–1 kHz.

Wegner & Dau (2002) have tested both the stimuli in the presence of a notched-noise masker with one-octave wide spectral notches corresponding to the cutoff frequencies used in the first experiment. The recordings were compared with derived responses, calculated offline, from the high-pass masking conditions. No significant differences in response amplitude between click and chirp stimulation was found for the notched-noise responses as well as for the derived responses. The derived responses obtained with high-pass noise masking as well as the responses using notched-noise maskers indicate that the gain in synchrony within frequency regions of about one octave is not sufficient for the chirp to produce significantly larger response amplitude than the click.

In their second experiment Wegner and Dau (2002) compared a narrow band low-frequency chirp (100 – 480Hz) and a 250-Hz tone pulse with comparable duration and magnitude spectrum were used as stimuli. The narrow-band chirp elicited larger response amplitude than the tone pulse at low and medium stimulation levels. Overall, the results of the study further demonstrated the importance of considering peripheral processing for the formation of ABR. Thus, they reported that the chirp might be of particular interest for assessing low-frequency information. Since synchrony is present evoked at low

frequency region it was hypothesized that chirp stimuli may evoked synchrony in auditory neuropathy subjects.

Optimum stimuli to evoke ABR:

Foebel and Dau (2004) compared different stimuli to find the optimum stimuli for eliciting ABR in 9 normal hearing individuals. Auditory brainstem responses (ABR) were elicited by clicks and rising frequency chirps (O-chirp, A- chirp and M- chirp).

The results of the study are as follows:

- ✓ All chirps evoked larger wave-V amplitude than the click stimulus indicating that for the chirps a broader range of spectral components contributes effectively to the ABR.

- ✓ Only small differences were found between the O-chirp and M-chirp responses at low and medium levels. This indicates that SFOAE may not provide a robust estimate of BM group delay, particularly at low frequencies, or that frequency-dependent neural delays exist which are not reflected in the design of these chirps. No significant differences between the response amplitudes obtained with the O-chirp and the M-chirp were found, not even at low stimulation levels where an advantage of the O-chirp was expected. One possible explanation might be that SFOAE group delays do not allow a reliable estimate of BM group delays, particularly at low frequencies (1 kHz). Another explanation might be that level

and frequency dependent neural delays are involved in ABR (wave-V) latency which is not reflected in the design of these two chirps.

- ✓ The A-chirp caused the largest responses and is particularly effective at very low levels where wave-V amplitude is about three times as large as for the click. This level dependent chirp intrinsically includes both mechanical and neural delays since it was derived from wave-V latency data.

- ✓ For the O-chirp, no earlier waves are present, even at the highest stimulation levels. In contrast, for the M-chirp, A-chirp, and the click, waves I and III become visible at the highest levels. Interestingly, for the A-chirp, wave I is visible even down to a level of 20 dB SL.

Thus, they reported A-chirp might be very useful for clinical applications, in connection with objective tests of hearing threshold and specifically, this chirp might be valuable in all applications where the standard click stimulus has been used so far.

Agung et al. (2005) used the chirp generated by Dau et al. (2000) in an experiment to investigate the post-auricular-muscle response (PAMR) in 12 normal-hearing young adults. The Chirp stimuli was compared to a standard click and a /t/ stimulus using both a standard clinical earphone (EAR-3A) and one with extended high-frequency response (ER-2). The chirp was found to generate larger PAMRs than the click and the /t/ stimulus, and the PAMR was further augmented when the extended high-frequency response earphone was used. The results support previous ABR studies that have demonstrated a significant advantage of chirps over clicks for evoked response

audiometry, and indicate that the PAMR is enhanced by inclusion of high-frequency stimulus energy that is by using ER – 2 ear phones.

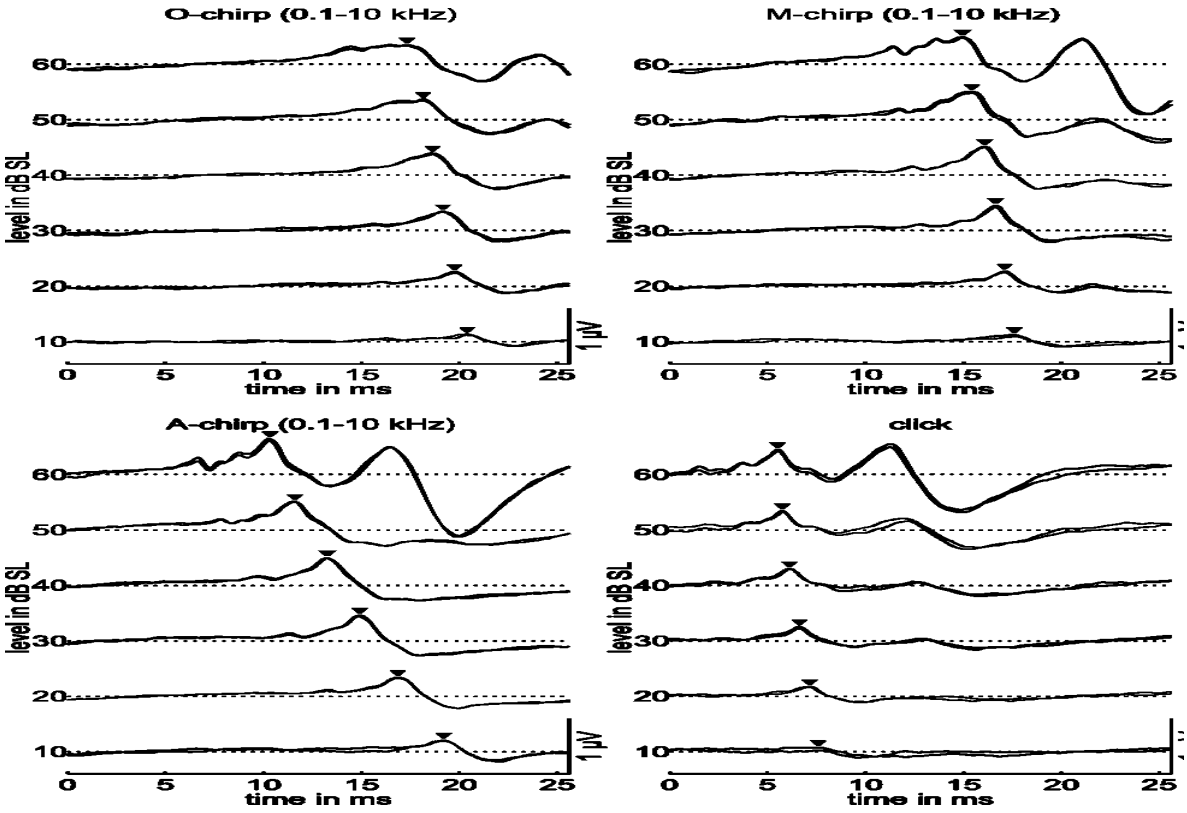

Figure 2: ABR evoked by click, O-chirp, M-chirp and A- chirp by (Feobel and Dau, 2004).

Effect of stimulation rate and neural adaptation on click and chirp evoked ABR:

Junius and Dau (2005) investigated the effect of within-train rate on wave-V response on five normal hearing individuals using the chirp developed by Dau et al (2000) and click stimulus. The within train rates used in this study were 47.6 Hz, 95.2 Hz, and 250 Hz and they were presented as chain stimuli. Wave V latency and amplitude

parameters were measured and compared for both click and chirp stimulus across different within train rates of 47.6 Hz, 95.2 Hz, and 250Hz.

- The mean amplitude of the single-chirp response was about twice as large as the corresponding click response. The results of within train rate experiment revealed that the presentation within train rate of 100Hz did not have any change in wave-V amplitude. For the within-train rate of 250 Hz, wave-V amplitude was reduced both for the chirp and the click evoked ABR.
- Wave-V latency increased as the number of chirps/clicks increased within the stimulus train. Also Wave-V latency increased with temporal position in the train for all within-train rates (47.6, 95.2, and 250Hz). The effect was strongest for the highest rate. Wave-V amplitude, however, was only affected at the highest within-train rate tested (250 Hz), and behaved linearly at the lower rates. So they reported that Wave-V latency reflects a more sensitive indicator of neural synchronization than wave-V amplitude.
- Thus this study suggests that while investigating wave-V amplitude, the stimulus train paradigm allows higher mean stimulus rates (using chain stimuli) than the traditional single-stimulus paradigm.

Thus, literature suggests that the chirp stimulus might be useful objective indicator of hearing threshold since it enables the inclusion of contributions from the lower frequencies. So the present study aimed at comparing the ABR thresholds obtained using both click and chirp stimuli. Most of the studies done in this area have compared the

amplitude of click and chirp evoked ABR responses at equal sensation levels and near threshold levels rather than comparing them at presentation levels in dBnHL. All these studies done with chirp stimuli were focused on normal cochlear processing and neural synchrony and there are no reports of literature regarding chirp evoked ABR in cochlear pathology. Thus, the present study aimed at comparing click and chirp evoked ABR amplitude and latency at equal sensation levels and threshold levels. Since chirp stimuli excite basilar membrane at same time thus producing greater synchrony than click it will be interesting to see whether chirp stimuli can evoke any detectable ABR in auditory dyssynchrony subjects. So the present study further aimed at analyzing chirp evoked ABR in auditory dyssynchrony subjects.

III. METHOD

Subjects

To accomplish the aims three groups of subjects were taken for the present study:

- Group I: consisted of 19 subjects (30 ears) with normal hearing. The mean age was 21.5 years with the age range of 19-40 years.
- Group II: consisted of 15 subjects (20 ears) with cochlear hearing loss. The mean age was 53.8 years with the age range of 25 to 70 years.
- Group III: consisted of 5 subjects (10 ears) with auditory neuropathies. The mean age of the subjects was 17 years and the age range was between 11 to 22 years.

The subjects were selected on the basis of following criteria:

Group I: Individuals with normal hearing

- Air conduction thresholds were less than or equal to 15 dB HL in the octave frequency range of 250 Hz to 8000 Hz and bone conduction thresholds less than or equal to 15 dB HL in the octave frequency range of 250 Hz to 4000 Hz.
- All the subjects had 'A' type tympanogram and acoustic reflexes were within normal limits indicating normal middle ear function.
- Speech identification scores (SIS) were greater than or equal to 90%.

- Transient otoacoustic emissions were present in all the subjects.
- Click evoked auditory brainstem response did not show any abnormality.
- None of them had any history of otological symptoms (ear ache, ear discharge, and tinnitus or hearing loss) or neurological problems or any other general weakness.

Group II: individuals with cochlear hearing loss

- Individuals with mild to moderate degree of cochlear hearing loss with flat or sloping configuration of air conduction thresholds from 26 dB HL to 55 dB HL were considered for the study.
- The air-bone gap was less than or equal to 10dB.
- All of them had 'A' type tympanogram with present, elevated or absent of acoustic reflexes, indicative of no middle ear pathology.
- Latencies of click evoked ABR waves were appropriate to their hearing loss and did not indicate retrocochlear pathology.
- Transient otoacoustic emissions were absent in these subjects, indicated cochlear involvement.
- Speech identification scores were proportionate to their degree of hearing loss.

- None of them had any history of acute or chronic ear infections (ear pain or ear discharge) or neurological problems or any other general weakness.

Group III: individuals with auditory neuropathy/ dysynchrony

- Both air conduction and bone conduction thresholds showed mild to moderate sensorineural hearing loss with pure tone average ranged between 26 dB HL to 55 dB HL). The air- bone gap was within 10 dB HL.
- Transient otoacoustic emissions were present in all the subjects.
- Absent or poor click evoked ABR morphology at 90 dBnHL which was disproportionate to the degree of hearing loss.
- Poor Speech identification in quiet or speech in noise scores and difficulty in understanding speech in noisy condition.
- All of them had 'A' type tympanogram with absent ipsilateral and contralateral reflexes.
- These subjects had no history of middle ear infections or general weakness.

Instrumentation

The following instruments were used for the study:

a) A calibrated two channel diagnostic audiometer (AC40) with TDH-39 head phone and B-71 bone vibrator was used to obtain pure tone thresholds.

b) A calibrated immittance meter (GSI- tympstar) was used to assess the middle ear function.

c) TEOAE's were recorded using ILO292 DP Echoport instrument.

d) ABR recordings were done using Intelligent Hearing Systems (IHS) smart Evoked potential systems (version 2.39) with TDH-49 P head phones.

Stimuli

To record ABR, click and chirp stimuli were used. Click stimulus with duration of 100 µs and wide spectral range below 10 KHz was used. Flat spectrum rising Chirp stimuli of 10.31 ms duration with frequency range of 100 Hz to 6 KHz was generated to record chirp ABR.

Generation of chirp stimuli:

A chirp stimulus was generated using a program written in MATLAB using the method as described by Dau et al. (2000). The stimuli were generated with the sampling rate of 44100Hz and 8 bit resolution. This stimulus was further loaded in IHS system and was converted to the IHS software acceptable format. No windowing were applied to the chirp stimuli presented. The temporal and spectral representation of chirp stimuli used to record chirp evoked ABR is shown in the Figure 3 and Figure 4.

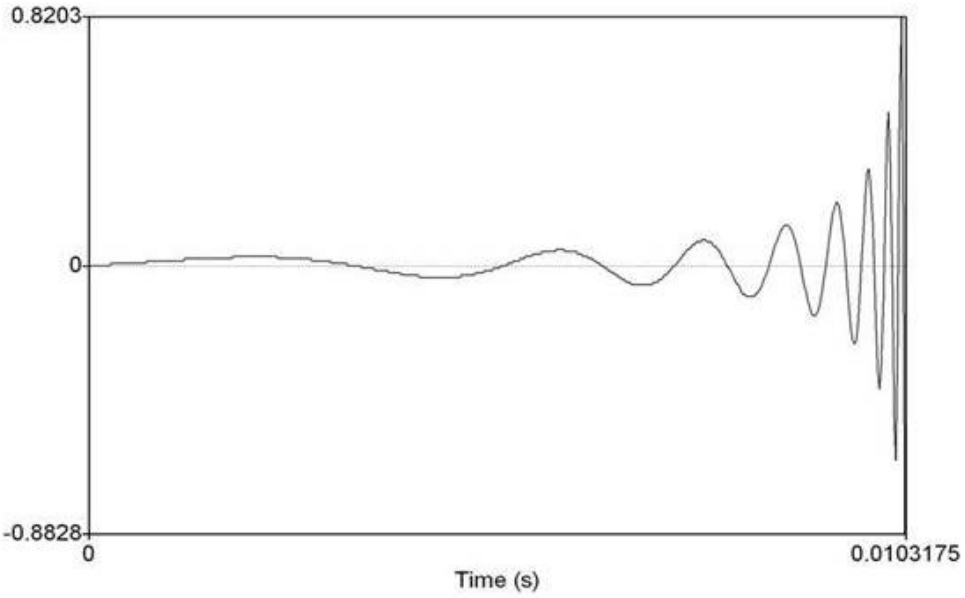

Figure 3: Temporal representation of flat rising chirp (M-chirp) used in the present study.

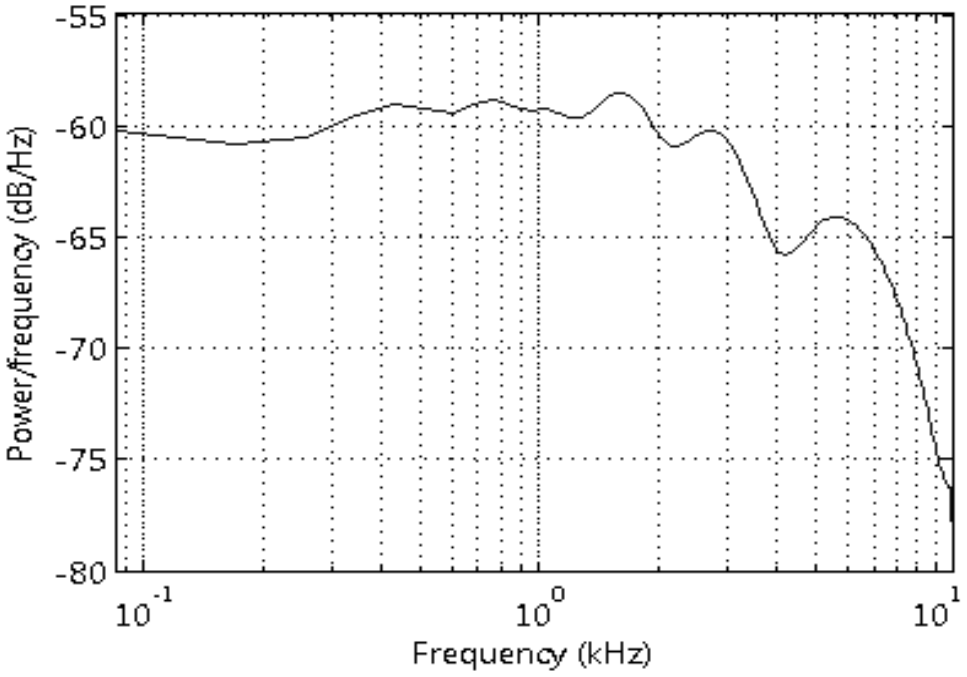

Figure 4: spectral representation of flat spectrum rising chirp (M- chirp) used in the present study.

Test environment

All the tests were carried out in a well illuminated air conditioned rooms which were acoustically treated. The noise levels were within permissible levels as recommended by ANSI (1996).

Test procedure

Pure tone audiometry:

Pure tone air conduction thresholds for each individual were established in octaves frequencies from 250Hz to 8 KHz using modified Hughson - Westlake method (Carhart & Jerger, 1959). Bone conduction thresholds were also established in octaves frequencies from 250Hz to 4 KHz using the same.

Immittance:

The tympanometric measurements were done using 226 Hz probe tone at 85 dB SPL. For reflex measurements the reflex eliciting tone of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were presented ipsilaterally and contralaterally to find out the presence or absence of reflexes. A significant change of admittance value of 0.03ml was considered as a presence of reflex.

Transient otoacoustic emissions (TEOAEs):

The transient Otoacoustic emissions were recorded for nonlinear clicks presented at 85 dBpeSPL. The responses of 256 sweeps were averaged to obtain the TEOAE

responses. The amplitude of TEOAE and noise levels was measured and the amplitude to noise ratio of 6 dB SPL or more was considered as the presence of TEOAE with the reproducibility of greater than or equal to 50% as described by Glattke, Pafitis, Cummiskey, and Herrer (1995). The absence of TEOAEs in the presence of hearing loss was considered as an indication of cochlear damage.

ABR recording:

The subjects were instructed to sit comfortably and relax on a reclining chair facing away from the instrument. They were instructed to avoid movement of head, eyes, neck and limbs during testing to avoid artifacts.

Electrode placement:

Initially the electrode sites were cleaned using skin preparation paste (neoprupe). The silver chloride disc type of electrode was placed on the scalp at electrode placement site with adequate amount of conduction paste material. Then the electrodes were taped along with skin to prevent any dislocation of electrodes by means of surgical plaster. TDH – 49 P head phone were placed on the ears to present the stimuli. The parameters used to record ABR can be seen in Table 1.

Table 1:

Protocol used to record ABR

Stimulus parameters	
Stimuli	Click / chirp
Duration of stimuli	Click: 100 µs, chirp: 10.31 ms
Polarity	Alternating polarity
Stimuli level	80 dBnHL/ 40 dB SL and variable for threshold estimation
Repetition rate	11.1/sec and 30.1/sec
Acquisition parameters	
Filter settings	High pass filter: 100Hz, Low pass filter : 3KHz
Number of averaging	1500 times
Notch filter	On
Artifact rejection level	40%
Gain	1,00,000 times
Time window	12 msec for click stimuli and 25 msec for chirp stimuli
Impedance	Intraelectrode impedance within 5 KΩ Interelectrode impedance within 3 KΩ
Electrode montage	A1/A2 – inverting FpZ – Noninverting A2/A1 - common

Both the stimuli were presented through TDH – 49 P headphones and they were calibrated in dBnHL subjectively. The instrument was calibrated for both the stimuli behaviorally considering 10 normal hearing subjects and the average/ mean threshold for both click and chirp stimuli were calculated. The average values were then considered as 0 dBnHL values for each stimulus respectively. ABR was recorded in 2 phases. In Phase I click evoked ABR was recorded while in Phase II chirp evoked ABR was recorded for the same subject.

Phase I: Click evoked ABR was initially recorded for 11.1/ sec repetition rate at 80 dBnHL and then at 40 dB SL levels. Later the responses were recorded at the same intensity levels (80 dBnHL and 40 dB SL) at 30.1/ sec repetition rate. For threshold estimation the intensity level were then set at 30 dB SL values above pure tone averages and ABR recordings were carried out. When there was a response obtained at 30 dBnHL the intensity level of the click stimuli was reduced in 10 dB steps until no response was observed. Once no response was observed, the intensity was then increased in 5 dB steps till a detectable ABR could be obtained. The minimum intensity level at which a detectable ABR could be identified was considered as click ABR threshold. All recording for threshold estimation were carried out at the repetition rate of 30.1/ sec.

Phase II: Chirp evoked ABR were also recorded at 11.1/ sec and then at 30.1/ sec repetition rates for the intensity levels of 80 dBnHL and 40 dB SL. The procedure

adopted to estimate ABR thresholds using click stimulus was also used to establish chirp evoked ABR thresholds.

Both Phase I and Phase II were carried out for both the individuals with normal hearing and cochlear hearing impaired. At each level ABR was recorded twice to see the reproducibility of waveforms.

For group III ABR recording were done using click and chirp at 80dBnHL with repetition rate of 11.1/s. If any detectable wave V responses were observed at 80dBnHL level either for click or chirp stimuli, threshold estimation was carried out at 11.1/ sec repetition rate. The intensity levels were decreased in 10 dB steps until no response could be obtained. Once a no response was obtained then intensity was increased in 5dB steps until a detectable ABR response could be obtained. The minimum level where a detectable ABR could be obtained was considered as click or chirp evoked ABR threshold in individuals with auditory neuropathy. ABR recordings for all the groups were repeated near or at threshold for replicability for the evoking stimuli.

Analysis:

All the waveforms recorded were given to two qualified audiologist to mark wave I, III and V peaks. If there was an agreement between the audiologists, the waveforms were then taken for further analysis. Absolute latencies and peak to peak amplitude were measured for each of the identified peaks.

- Descriptive statistics (mean and standard deviation) for latency and amplitude parameters were computed for click and chirp evoked ABR wave I, III and V obtained at two repetition rates (11.1/sec & 30.1/sec) and two intensity levels (80 dBnHL and 40 dB SL).

- Repeated measures ANOVA were applied to the above click and chirp evoked ABR wave V latency or amplitude across different intensity, repetition rate conditions and groups.

- Paired t - test were applied to compare the click and chirp evoked ABR wave I and III latency and amplitude between 11.1/sec and 30.1/sec repetition rates recorded at 80 dBnHL.

- Since chirp ABR frequency specificity lies in the region of 0.5 – 1 KHz and click ABR frequency specificity between 2 – 4 KHz two pure tone averages were calculated for correlation analysis. Pure tone averages calculated were PTA 1 (averaged from 500Hz, 1 KHz and 2 KHz thresholds) and PTA 2 (averaged from 1 KHz, 2 KHz and 4 KHz thresholds). Then the behavioral thresholds (PTA1 and PTA2) and ABR thresholds obtained at 30.1/ sec repetition rate using click and chirp were correlated.

- Latency intensity functions were computed for chirp evoked ABR wave V latency values elicited at 80 dBnHL, 50 dBnHL and 30 dBnHL in individuals with normal hearing. For hearing impaired individuals the subjects were sub grouped into mild and moderate hearing loss and latency intensity functions were computed for wave V

latency elicited 80 dBnHL, 70 dBnHL and 50 dBnHL for individuals with mild hearing loss and at 90 dBnHL, 80 dBnHL and 60 dBnHL for individuals with moderate hearing loss.

- For group III chirps evoked ABR obtained at 80 dBnHL at 11.1/s RR were discussed in terms of presence or absence of response. The chirp ABR thresholds were correlated with their individual behavioral thresholds. No statistical analysis was carried our. Morphology of ABR recorded using click and chirp ABR were discussed.

IV. RESULTS AND DISCUSSION

The present study was designed to compare click and chirp evoked ABR wave parameters in individuals with normal hearing and hearing impaired individuals across different repetition rates (11.1 & 30.1) and different intensity levels (80 dBnHL, 40 dB SL) and also to compare click and chirp evoked ABR thresholds. The latency, amplitude and threshold values from 19 normal hearing subjects (30 ears), 15 hearing impaired subjects (20 ears) and 5 auditory neuropathy subjects (10 ears) were analyzed using statistical package for social sciences (SPSS) software version 14.

Variables used in this present study were:

- Independent variables (stimulus type, intensity and repetition rate)
- Dependent variables (latency and amplitude values)

The following analysis was carried out within and between groups:

- Descriptive statistics for all the ABR parameters.
- Repeated measures ANOVA to see the significant main effect across the stimulus type, intensities and rates between the groups and also within groups for ABR wave V latency and amplitude obtained using click and chirp.
- Duncan post hoc analysis was performed to test pair wise differences when the repeated measure ANOVA results indicated a significant effect.
- Since heterogeneity was present in peaks observed for Wave I and Wave III mixed ANOVA could not be performed. To compare main effect and interaction

effect using ANOVA ‘n’ number of peaks should be constant across rates, intensity, stimuli between the groups and within the groups. Thus, Paired t - test was performed to find out the significant difference between the stimuli and rates for wave I and III.

- Karl pearsons correlation analysis was done between pure tone averages (PTA1 & PTA2) with click and chirp evoked ABR thresholds. Paired t – test was also performed to find out the difference between click and chirp evoked ABR thresholds.

The mean, Standard deviation (SD) and range were calculated for click and chirp evoked ABR (latency and amplitude parameters) obtained at 2 intensity levels (80 dBnHL and 40 dB SL) and 2 repetition rates (11.1/ sec and 30.1/sec) in individuals with normal hearing, mild and moderate sensory neural hearing loss.

Individuals with normal hearing

Morphology

Morphology of click and chirp evoked ABR varied with the type of the stimulus, repetition rates and level. From Figure 5 it can be observed that major peaks wave I, III and wave V were observed at higher intensity levels.

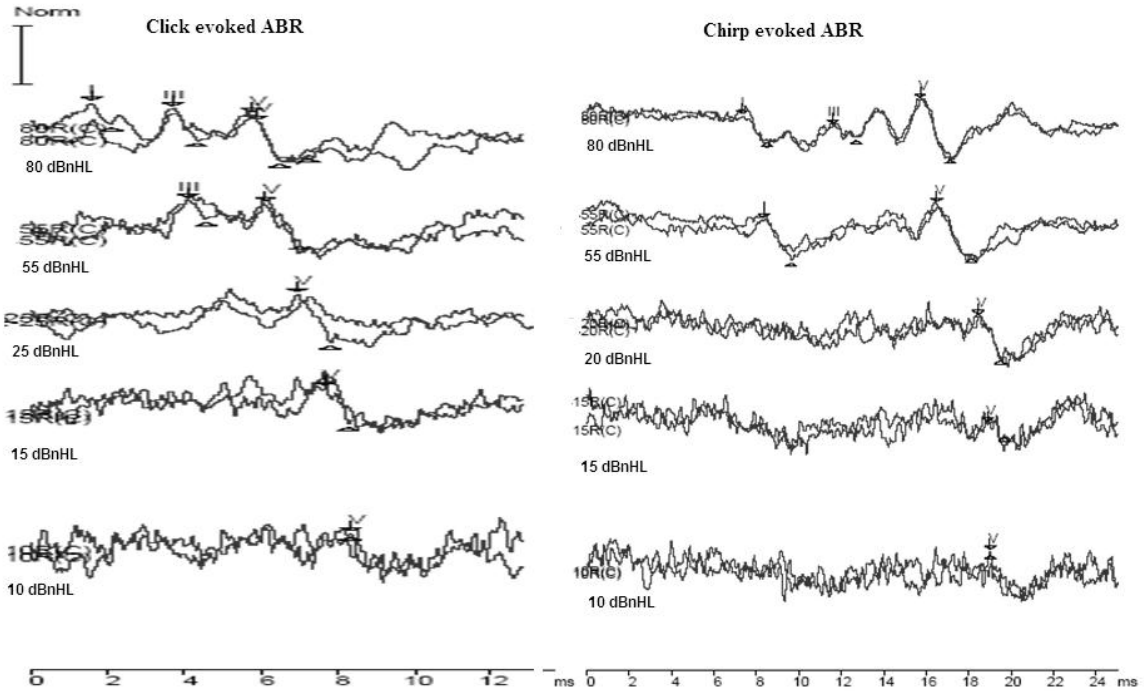

Figure 5: shows click evoked ABR waveforms (left panel) and chirp evoked ABR waveforms (right panel) observed for different intensity levels at 30.1/sec repetition rate in one subject with normal hearing.

When the intensity of both the click and chirp stimuli were changed to 40 dB SL the frequency of occurrence of earlier peaks wave I and III reduced. It was observed that for click stimuli at 40 dB SL wave III and wave V were the most frequently occurring peaks but for chirp stimuli at the same intensity level wave I and wave V were the most frequently occurring peaks. Near threshold levels for both click and chirp evoked ABR only wave V was observed.

Latency and amplitude measures

The mean absolute latency values for click and chirp evoked ABR parameters differed in individuals with normal hearing. Latency of the click and chirp evoked ABR wave I, III and V increased with decrease in intensity of the stimuli. Wave latencies also increased with increase in repetition rate for both the stimuli which can be seen in Table 2.

The mean Peak to peak amplitude values for click and chirp evoked ABR responses did not vary between both the stimuli at higher intensity levels and higher repetition rates in individuals with normal hearing. But for 40 dB SL at 11.1/sec repetition rate the mean amplitude values of wave I and V for chirp stimuli was higher than the mean click amplitude values. From Table 3 it can be observed that as the intensity of the stimuli was varied from 80 dBnHL to 40 dB SL the mean amplitude of click and chirp ABR also decreased. The amplitude of click and chirp evoked ABR wave decreased with the increase in repetition rate.

Table 2:

Mean, SD and range for wave I, III and V latencies (in ms) of click and chirp evoked ABR at different intensities and repetition rates in individuals with normal hearing

Repetition rate			Click evoked ABR			Chirp evoked ABR		
	Intensities		Wave I	Wave III	Wave V	Wave I	Wave III	Wave V
11.1/sec	80 dBnHL	Mean	1.67 (n=29)	3.71 (n=30)	5.53 (n= 30)	6.65 (n=30)	11.22 (n=23)	15.43 (n= 30)
		SD	0.09	0.13	0.16	0.22	0.49	0.55
		Range	1.55-1.90	3.45-1.55	5.15-5.90	6.15-7.00	10.00-11.80	13.45-16.30
	40 dB SL	Mean	2.01 (n=3)	4.47 (n=10)	6.15 (n=30)	8.04 (n=27)	12.52 (n=16)	16.46 (n= 30)
		SD	0.02	0.58	0.28	0.58	1.23	0.75
		Range	2.00-2.05	4.10-6.03	5.80-6.90	7.25-9.45	10.65-16.25	14.35-17.80
30.1/sec	80 dBnHL	Mean	1.72 (n=28)	3.84 (n=30)	5.67 (n= 30)	7.43 (n=30)	11.73 (n=25)	15.89 (n= 30)
		SD	0.10	0.20	0.13	0.28	0.94	0.28
		Range	1.50-2.00	3.55-4.65	5.45-5.95	6.80-7.90	9.70-15.75	15.45-16.40
	40 dB SL	Mean	2.43 (n=2)	4.49 (n=10)	6.33 (n= 30)	8.50 (n=24)	12.20 (n=7)	16.87 (n= 30)
		SD	0.04	0.27	0.27	0.58	0.88	0.54
		Range	2.40-2.47	4.10 – 4.95	5.93-7.00	7.35-9.45	10.45-12.95	16.10-18.35

Table 3:

Mean, SD and range for wave I, III and V amplitude (in µv) of click and chirp evoked ABR at different intensities and repetition rates in individuals with normal hearing

Repetition rate			Click evoked ABR			Chirp evoked ABR		
	Intensities		Wave I	Wave III	Wave V	Wave I	Wave III	Wave V
11.1/sec	80 dBnHL	Mean	0.41 (n= 29)	0.40 (n=30)	0.60 (n=30)	0.52 (n=30)	0.23 (n=23)	0.67 (n=30)
		SD	0.16	0.21	0.22	0.14	0.17	0.29
		Range	.13 -.74	.13-1.03	.29-1.15	.30-.85	.04-.80	.24-1.33
	40 dB SL	Mean	0.15 (n=3)	0.15 (n=10)	0.42 (n=30)	0.63 (n=27)	0.17 (n=16)	0.70 (n=30)
		SD	0.05	0.07	0.17	1.02	.08	1.38
		Range	.10-.21	.03-.25	.16-.85	.08-.63	.05-.35	.17-8.00
30.1/sec	80 dBnHL	Mean	0.30 (n=28)	0.33 (n=30)	0.66 (n=30)	0.31 (n =30)	0.21 (n= 30)	0.61 (n=30)
		SD	0.14	0.10	0.22	0.14	0.10	0.24
		Range	.05-.65	.13-.57	.32-1.11	.23-6.00	.06-.39	.25-1.16
	40 dB SL	Mean	0.10 (n=2)	0.23 (n=10)	0.40 (n=30)	0.32 (n=24)	0.20 (n=7)	0.44 (n=30)
		SD	0.03	0.25	0.13	0.22	0.08	0.15
		Range	.08-.13	.09-.90	.16-.62	.14-1.00	.07-.30	.16-.76

Individuals with mild sensory neural hearing loss

In individuals with mild hearing loss the morphology of click and chirp evoked ABR varied. There was inter-subject variability observed in the presence or absence of earlier peaks (wave I and III). However, Wave V was consistently observed in all individuals with mild cochlear hearing loss even at low sensation levels.

Latency and amplitude measures:

The mean absolute latency values for click and chirp evoked ABR for all the peaks differed. As the rate increased the absolute latency values also increased for all the waves (Table 4). It can also be observed from the Table 4 that the latency of all the three peaks increased with decrease in intensity of the eliciting stimuli.

The mean peak to peak amplitude for chirp evoked ABR showed higher amplitude for wave I and wave V than click evoked ABR at 11.1/ sec repetition rate. But these differences were less pronounced at 30.1/ sec repetition rates. From Table 5 it can be observed that as the repetition rate increased the amplitude of all the peaks were reduced. It can also be observed from the table that as the intensity of the click and chirp stimuli reduced the amplitude of auditory brainstem responses also reduced.

Table 4:

Mean, SD and range for wave I, III and V latencies (in ms) of click and chirp evoked ABR at different intensities and repetition rates in individuals with mild sensory neural hearing loss

Repetition rate	Intensities		Click evoked ABR			Chirp evoked ABR		
			Wave I	Wave III	Wave V	Wave I	Wave III	Wave V
11.1/sec	80 dBnHL	Mean	1.72 (n= 6)	3.82 (n=8)	5.78 (n= 9)	7.36 (n=8)	11.4 (n=5)	14.89 (n=9)
		SD	0.06	0.15	0.35	0.70	0.68	0.81
		Range	1.63-1.80	3.55-4.05	5.30-6.53	6.45-8.60	10.70-12.45	13.40-15.70
	40 dB SL	Mean	1.77 (n=4)	3.96 (n=7)	6.03 (n=9)	7.89 (n=7)	11.70 (n=1)	15.67 (n=9)
		SD	0.06	0.12	0.34	0.67	-	0.50
		Range	1.70-1.85	3.80-4.15	5.72-6.90	6.95-9.05	11.70-11.70	14.60-16.35
30.1/sec	80 dBnHL	Mean	1.80 (n=4)	3.92 (n=6)	5.92 (n=9)	8.08 (n=7)	11.20 (n=1)	16.15 (n=9)
		SD	0.08	0.15	0.36	0.42	-	0.87
		Range	1.70-1.90	3.65-4.10	5.32-6.67	7.35-8.50	11.20-11.20	13.55-16.10
	40 dB SL	Mean	1.75 (n=1)	4.20 (n=4)	6.18 (n=9)	9.36 (n=3)	-	15.38 (n=9)
		SD	-	0.05	0.35	0.48	-	0.74
		Range	1.75-1.75	4.13-4.25	5.82-7.03	8.85-9.80	-	15.00-17.60

Table 5:

Mean, SD and range for wave I, III and V amplitude (in µv) of click and chirp evoked ABR at different intensities and repetition rates in individuals with mild sensory neural hearing loss

Repetition rate	Intensities		Click evoked ABR			Chirp evoked ABR		
			Wave I	Wave III	Wave V	Wave I	Wave III	Wave V
11.1/sec	80 dBnHL	Mean	0.14 (n= 6)	0.23 (n=8)	0.41 (n= 9)	0.35 (n=8)	0.20 (n =5)	0.53 (n=9)
		SD	0.09	0.10	0.08	0.12	0.07	0.40
		Range	.09-.33	.08-.35	.30-.55	.18-.55	.16-.36	.22-1.53
	40 dB SL	Mean	0.17 (n=4)	0.21 (n=7)	0.39 (n=9)	0.37 (n=7)	0.09 (n=1)	0.47 (n=9)
		SD	0.13	0.05	0.15	0.14	-	0.40
		Range	.06-.37	.11-.30	.25-.66	.15-.53	.09-.09	.12-1.48
30.1/sec	80 dBnHL	Mean	0.16 (n=4)	0.53 (n=6)	0.46 (n=9)	0.26 (n=7)	0.27 (n=1)	0.37 (n=9)
		SD	0.03	0.72	0.17	0.10	-	0.14
		Range	.13-.21	.10-2.00	.24-.75	.13-.41	.27-.27	.19-.59
	40 dB SL	Mean	0.14 (n=1)	0.24 (n=4)	0.36 (n=9)	0.28 (n=3)	-	0.37 (n=9)
		SD	-	0.08	0.19	0.04	-	0.15
		Range	.14-.14	.13-.35	.14-.79	.23-.32	-	.16-.62

Individuals with moderate sensory neural hearing loss

Morphology

Morphology for both click and chirp evoked ABR in individuals with moderate hearing loss was poorer than individuals with mild haring loss and normal hearing. The frequency of occurrence of earlier wave I and III were reduced with increase in degree of hearing loss. Wave V was the prominent peak observed even near the threshold levels.

Latency and amplitude measures

The absolute latencies for click and chirp evoked ABR were different. From Table 6 it can be observed that the mean wave latencies also varied with repetition rates and intensities in a similar fashion that observed in individuals with mild hearing loss and normal hearing.

The peak to peak amplitude values for click and chirp evoked ABR waves also varied within the type of the stimulus, rate and intensities. It can be observed from the Table 7 that the mean peak to peak amplitude of chirp evoked ABR wave V was lesser than click evoked ABR at all intensity levels and repetition rates. But for wave I the amplitude of chirp ABR was higher than click ABR at all intensities and repetition rates.

Table 6:

Mean, SD and range for wave I, III and V latencies (in ms) of click and chirp evoked ABR at different intensities and repetition rates in individuals with moderate sensory neural hearing loss

Repetition rate	Intensities		Click evoked ABR			Chirp evoked ABR		
			Wave I	Wave III	Wave V	Wave I	Wave III	Wave V
11.1/sec	80 dBnHL	Mean	1.78 (n=5)	4.04 (n=9)	5.91 (n= 11)	7.54 (n=5)	11.05 (n=1)	14.90 (n= 11)
		SD	0.21	0.14	0.18	0.61	-	1.11
		Range	1.55-2.05	3.85-4.28	5.65-6.25	6.70-8.25	11.05-11.05	12.35-16.05
	40 dB SL	Mean	1.72 (n=5)	3.95 (n=9)	5.91 (n= 11)	7.09 (n=5)	11.47 (n=2)	14.34 (n= 11)
		SD	0.26	0.17	0.26	0.78	-	0.97
		Range	1.38-2.05	3.78-4.32	5.57-6.45	6.20-8.25	11.05-11.90	12.35-15.90
30.1/sec	80 dBnHL	Mean	2.15 (n=1)	4.13 (n=6)	6.07 (n= 11)	-	-	15.37 (n= 11)
		SD	-	0.17	0.25	-	-	0.78
		Range	2.15-2.15	3.95-4.45	5.75-6.55	-	-	13.85-16.30
	40 dB SL	Mean	2.02 (n=2)	4.13 (n=7)	6.09 (n= 11)	-	-	14.75 (n= 11)
		SD	0.17	0.24	0.28	-	-	0.80
		Range	1.90-2.15	3.88-4.55	5.65-6.60	6.90-6.90	-	13.85-16.10

Table 7:

Mean, SD and range for wave I, III and V amplitude (in µv) of click and chirp evoked ABR at different intensities and repetition rates in individuals with moderate sensory neural hearing loss

Repetition rate			Click evoked ABR			Chirp evoked ABR		
	Intensities		Wave I	Wave III	Wave V	Wave I	Wave III	Wave V
11.1/sec	80 dBnHL	Mean	0.19 (n=5)	0.24 (n=9)	0.46 (n= 110	0.52 (n=5)	0.21 (n=1)	0.38 (n= 11)
		SD	0.12	0.13	0.26	0.27	-	0.18
		Range	.06-.39	.10-.47	.17-1.09	.22-.89	.21-.21	.19-.82
	40 dB SL	Mean	0.19 (n=5)	0.27 (n=9)	0.50 (n= 11)	0.38 (n=5)	0.35 (n=2)	0.39 (n= 11)
		SD	0.10	0.14	0.26	0.20	-	0.17
		Range	.06-.33	.08-.56	.18-1.09	.17-.72	.21-.50	.10-.64
30.1/sec	80 dBnHL	Mean	0.16 (n=1)	0.19 (n=6)	0.45 (n= 11)	0.38 (n=3)	-	0.41 (n= 11)
		SD	-	0.11	0.22	0.07	-	0.22
		Range	.16-.16	.05-.39	.22-.95	.31-.46	-	.21-.92
	40 dB SL	Mean	0.16 (n=2)	0.19 (n=7)	0.49 (n= 11)	0.37 (n=1)	-	0.41 (n= 11)
		SD	0.00	0.09	0.22	-	-	0.21
		Range	.16-.16	.08-.31	.23-.95	.37-.37	-	.21-.92

Between group comparisons

The repeated measure ANOVA was done for click and chirp evoked ABR wave V at different intensities and repetition rate within and across groups. Since the wave V was the most prominent peak observed in all the subjects at 80 dBnHL and at 40 dB SL intensities and at 11.1/sec and 30.1/sec repetition rate for both click and chirp stimuli a repeated measure mixed ANOVA [stimuli (2) X intensity (2) X repetition rate (2) X groups (3)] was applied to see the significant main effect. This analysis was carried out for both latency and amplitude of wave V separately.

Latency

Repeated measure mixed ANOVA results for latency values revealed a highly significant main effect for type of stimuli [$F(1, 47) = 8664.677$, $p < 0.01$)], intensities [$F(1, 47) = 55.624$, $p < 0.01$] and repetition rates [$F(1, 47) = 73.97$, $p < 0.01$]. Also latency values showed significant main effect [$F(2, 47) = 17.317$, $p < 0.01$].

A significant interactions between stimulus type and groups [$F(2, 47) = 20.446$, $p < 0.01$], stimulus type and repetition rate [$F(1, 47) = 15.597$, $p < 0.01$) and stimulus intensity and groups [$F(2, 47) = 59.674$, $p < 0.01$] was also observed. However, significant interactions were not observed between stimulus type and intensities [$F(1, 47) = 1.377$, $p > 0.01$], repetition rates and groups [$F(2, 47) = 0.015$, $p > 0.01$], intensities and repetition rates [$F(1, 47) = 0.031$ $p > 0.01$].

Significant interaction for latency values were observed only for stimulus type, intensities and groups [F (2, 47) = 16.744, p < 0.01]. No significant interactions were observed between stimulus type, repetition rates and groups [F (2, 47) = 0.084, p > 0.01], intensities, repetition rates and groups [F (2, 47) =0.022, p > 0.01] and stimulus types intensities and repetition rates [F (1, 47) =0.412, p > 0.01]. Interaction between stimulus types, intensities, repetition rates and groups were also statistically insignificant [F (2, 47) =0.059, p > 0.01].

Duncan's post Hoc test was carried out between groups. From Table 8 it can be observed that there was a significant difference between the groups.

Table 8:

Duncan's post hoc test results for wave V across the group

Groups	1	2	3
Moderate hearing loss	10.4217		
Mild hearing loss		10.7532	
Normal hearing			11.0462

Amplitude

Repeated measures mixed ANOVA results for amplitude values revealed no significant main effect for the types of stimuli, intensities and repetition rates. The F values along with significant levels for wave V amplitude are given in Table 9.

Table 9:

F – values along with significance level for wave V amplitude

Interaction	F values	Significance
Stimulus Type	F (1, 47) = .054	0.816
Intensities	F(1, 47) = 1.242	0.271
Repetition rates	F (1, 47) = .763	0.387
Stimulus type and groups	F (2, 47) = .977	0.384
Intensities and groups	F(2, 47) = 1.262	0.293
Repetition rates and groups	F (2, 47) = .279	0.758
Stimulus type and intensities	F (1, 47) = .271	0.605
Stimulus type and repetition rate	F (1, 47) = .945	0.336
Intensities and repetition rates	F (1, 47) = .358	0.553
Stimulus type, intensities and group	F (2, 47) = .401	0.672
Stimulus type, repetition rates and groups	F (2, 47) = .562	0.574
Intensities, repetition rates and groups	F (2, 47) = .336	0.716
Stimulus type, intensities and repetition rates	F (1, 47) = .00	0.985
Stimulus type, intensities, repetition rates and groups	F (2, 47) = .166	0.848

Wave V amplitude for normal hearing group was consistently greater than mild and moderate sensory neural hearing loss group in all the conditions tested but the difference were not statistically significant ($p > 0.05$). For click and chirp stimuli as the repetition rate increased the amplitude of wave V decreased for both normal and hearing impaired group.

Within group comparisons

Individuals with normal hearing

Chirp evoked ABR latency and amplitude of wave I, III, V obtained at different intensity were calculated. They were compared with the presentation level between and the rate used to elicit ABR. The details are discussed separately for each group.

Latency

The mean latency for chirp evoked ABR wave V obtained at 80 dBnHL, 50 dBnHL and 30 dBnHL were computed at 30.1/sec repetition rate. The mean latency values were plotted as a function of intensities. It could be observed from the Table 10 and Figure 6 that as the intensity decreased the latency of chirp evoked ABR wave V increased.

Table 10:

Mean and SD for chirp evoked ABR wave I, III, V latency (in ms) and amplitude (in µv) at different intensity levels

Intensities		Latency			Amplitude		
		I	III	V	I	III	V
80 dBnHL	Mean	7.43 (n=30)	11.73 (n=25)	15.89 (n= 30)	0.31 (n =30)	0.21 (n= 30)	0.61 (n=30)
	SD	0.28	0.94	0.28	0.14	0.10	0.24
50 dBnHL	Mean	8.50 (n=24)	12.20 (n=7)	16.87 (n= 30)	0.32 (n=24)	0.20 (n=7)	0.44 (n=30)
	SD	0.58	0.88	0.54	0.22	0.08	0.15
50 dBnHL	Mean	-	-	18.42 (n= 30)	-	-	0.28 (n=30)
	SD	-	-	0.88	-	-	0.11

Since wave III and I were not present in all the condition and groups, main and interaction effects using ANOVA could not be carried out. Instead paired t - test was carried out to compare the significant difference between the rates for wave III and I latency and amplitude.

From Table 11 it can be observed that there was a significant difference between 11.1/sec and 30.1/sec wave III latency for click stimulus and chirp stimulus. When stimulus latency values were compared between the type of stimuli at either 11.1/sec or

30.1/sec RR, significant difference was also observed at both the repetition rates between the stimuli.

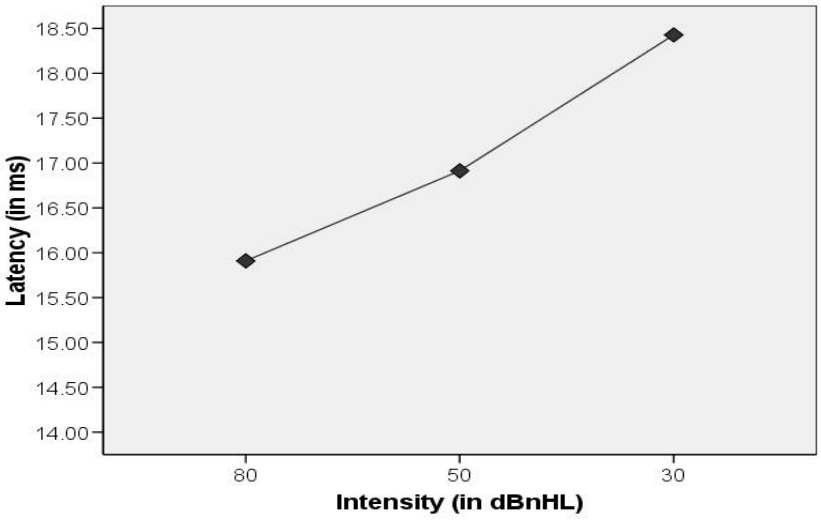

Figure 6: Latency intensity function of chirp evoked ABR wave V.

Table 11:

t – values, degrees of freedom and significance level for wave III latency and amplitude in normal hearing individuals at 80 dBnHL

Pairs compared	*latency*			*Amplitude*		
	t	df	Sig.	t	df	Sig.
CL at 11.1/sec - CL at 30.1/ sec	4.225	29	0.00	1.999	29	0.05
CP at 11.1/sec - CP at 30.1/sec	2.221	21	0.03	0.933	20	0.362
CL at 11.1/sec – CP at 11.1/sec	67.229	22	0.00	3.272	22	0.003
CL at 30.1/sec – CP at 30.1/sec	41.050	24	0.00	5.393	22	0.000

Note: CL – click and CP – chirp

The latency of Wave I of chirp ABR was greater at all intensities and repetition rates when compared to click evoked ABR. It can be observed from the Table 12 that paired t - test results indicated a significant difference between rates and stimuli for wave I latency.

Amplitude

Wave V amplitude of click and chirp evoked ABR varied in normal hearing individuals. The repeated measures mixed ANOVA results did show no significant difference in amplitude between repetition rates and intensities in individuals with normal hearing.

Results of paired t - test (Table 11) showed that there was no significant difference between 11.1/sec and 30.1/sec for wave III amplitude obtained either by click stimulus or chirp stimulus. When amplitude values were compared between the type of stimuli at either 11.1/sec or 30.1/sec RR there was significant difference observed at both the repetition rates between the stimuli.

Wave I amplitude for chirp evoked ABR was consistently higher than click evoked ABR at all repetition rates and intensities. Also wave I was consistently observed at and near 40 dB SL for normal hearing subjects. Table 12 shows paired t - test results for wave I amplitude values in normal hearing group for click and chirp ABR amplitude values obtained at 80 dBnHL for two different repetition rates. The results show that there was a significant difference between wave I amplitude elicited at 11.1/sec and

30.1/sec for click stimulus and but no significant difference was observed with chirp stimulus. The results also showed a significant difference between click and chirp evoked ABR wave I amplitude at 11.1/sec RR but no significant difference at 30.1/sec RR.

Table 12:

t - values, degrees of freedom and significance level for wave I latency and amplitude in normal hearing individuals at 80 dBnHL

Pairs compared	*latency*			*Amplitude*		
	t	df	Sig.	t	df	Sig.
CL at 11.1/sec - CL at 30.1/ sec	3.973	27	0.00	4.002	27	0.000
CP at 11.1/sec - CP at 30.1/sec	15.334	29	0.00	0.605	29	0.550
CL at 11.1/sec – CP at 11.1/sec	131.267	28	0.00	3.031	28	0.005
CL at 30.1/sec – CP at 30.1/sec	118.707	27	0.00	1.725	27	0.096

Note: CL – click and CP – chirp

Individuals with sensory neural hearing loss

Chirp evoked ABR latency and amplitude of wave I, III, V obtained at different intensities were calculated in individuals with mild and moderate sensory neural hearing loss. They were compared with the presentation level and the rate used to elicit ABR.

Latency

The mean latency values for chirp evoked wave V obtained at 80 dBnHL, 70 dBnHL and 50 dBnHL were computed for individuals with mild sensory neural hearing loss. For individuals with moderate sensory neural hearing loss the mean latency values were calculated at 90 dBnHL, 80 dBnHL and 60 dBnHL.

Figure 7 shows the latency intensity functions for wave V in individuals with mild and moderate sensory neural hearing loss. It can be observed from Table 13 and Figure 7 that the latency increased with decrease in intensity for both the groups but the increase in latency was more for mild hearing loss group than normal hearing individuals and moderate hearing loss group.

Wave V absolute latency was shorter in moderate than mild sensory neural hearing loss and the latencies varied with repetition rates and intensities within mild and moderate hearing loss. Since individuals with mild and moderate sensory haring loss had lesser frequency of occurrence of wave I and wave III paired t - test was not administered to compare the date for both click and chirp evoked ABR. The mean latency values of Wave I and III increased with reduced intensity such increase were observed for all the peaks recorded for click and chirp stimuli (Table 13).

Table 13:

Mean and SD for wave I, III, V latency(ms) and amplitude (µv) at different intensity levels in individuals with mild and moderate sensory neural hearing loss

Groups	Intensities		Latency			Amplitude		
			I	III	V	I	III	V
Mild sensory neural hearing loss	80 dBnHL	Mean	8.08 (n=7)	11.20 (n=1)	16.15 (n=9)	.26 (n=7)	.27 (n=1)	.37 (n=9)
		SD	0.42	-	0.87	0.10	-	0.14
	70 dBnHL	Mean	9.36 (n=3)	-	15.38 (n=9)	0.28 (n=3)	-	0.37 (n=9)
		SD	0.48	-	0.74	0.04	-	0.15
	50 dBnHL	Mean	-	-	16.94 (n= 9)	-	-	0.32 (n= 9)
		SD	-	-	1.31	-	-	0.15
Moderate sensory neural hearing loss	90 dBnHL	Mean	-	-	14.75 (n= 11)	0.37 (n=1)	-	0.41 (n= 11)
		SD	-	-	0.80	-	-	0.21
	80 dBnHL	Mean	-	-	15.37 (n= 11)	-	-	0.38 (n=3)
		SD		-	0.78	-	-	0. 07
	60 dBnHL	Mean	-	-	15.88 (n= 11)	-	-	0.31 (n= 11)
		SD	-	-	0.70	-	-	0.14

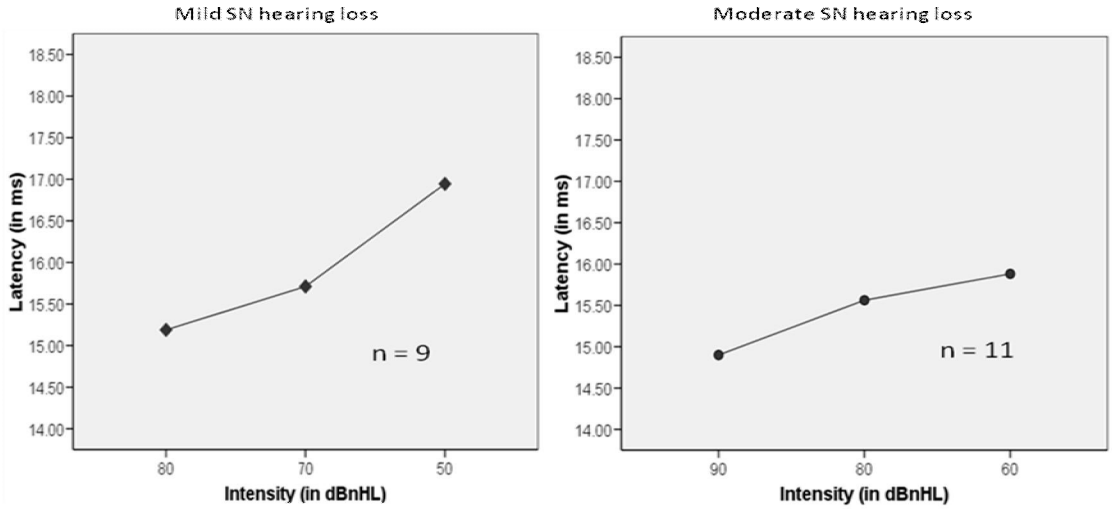

*Figure 7***:** Latency intensity functions for mild sensory neural hearing loss and moderate sensory neural hearing loss subjects for chirp evoked ABR wave V.

Amplitude:

Wave V amplitude was higher in individuals with mild hearing loss at 11.1/ sec than 30.1/sec repetition rates and also more for chirp evoked ABR. But in individuals with moderate hearing loss such differences between stimuli were not observed. However, the wave V amplitude values reduced with increase in repetition rates in individuals with moderate sensory neural hearing loss (Table 13).

Wave III amplitude values were lower for individuals with mild and moderate sensory neural hearing loss for chirp stimuli than click stimuli. The amplitude differences between stimuli were almost similar but high variability was observed in amplitude within individuals with mild or moderate sensory neural hearing loss as seen in Table 13.

It can also be observed from the Table 13 wave I amplitude in individuals with mild and moderate sensory neural hearing loss were consistently higher for chirp evoked ABR than click evoked ABR. The variability in amplitude across the stimulus type and repetition rates varied within the individuals with mild and moderate sensory neural hearing loss.

The absolute latency of click and chirp evoked ABR differed significantly between groups. The absolute latencies for click evoked ABR increased as the degree of hearing loss increased but for chirp stimuli this type of pattern was not seen. Interestingly the wave V latency decreased with increase in hearing loss and was shortest for moderate hearing loss than for mild hearing loss and normal hearing group. This can be due to shorter cochlear response times in cochlear hearing loss subjects as reported by Don, Ponten, Eggermont and Kwong (1998). Don et al.(1998) using derived band techniques has reported that cochlear response times appeared to shorten significantly with hearing loss, especially when the average pure tone (1 to 8 kHz) hearing loss exceeded 30 dB HL.

Click ABR in individuals with normal hearing is usually dominated by the latency from high frequency regions and this activity phase cancels activity from apical, low frequency regions. But in individuals with cochlear hearing loss the activity from high frequency regions no longer phase cancels low frequency activity due to greater degree of loss in high frequency regions. Thus, the latency of click ABR will be reflecting the shift in domination of low frequency regions. As the hearing loss increases more activity is represented from low frequency regions thus the latency also increases with the increase

in degree of hearing loss (Don and Kwong, 2005). But chirp evoked ABR is dominated by the lower frequency regions and thus increase of hearing loss in high frequencies doesn't cause much shift in latency,

Don et al. (1998) reported that the latencies of ABR depend on cochlear filter buildup time and it is dependent on degree of hearing loss. Cochlear filter buildup time is the time required to build up impulse response at the site of activation and depends on characteristic frequency, stimulus level and amount of hearing loss, but independent of gender. In cochlear hearing loss individuals the auditory filter becomes broadened thus the time required to build up an impulse response also decreases (Don et al. 1998). Since the response time is required to build up and impulse is reduced the time required for neural activation also decreases thereby decreasing the latency of response. So this can be reason another reason for getting earlier responses in chirp ABR with increase in degree of hearing loss. Thus chirp evoked ABR can be used as a useful indicator to reflect impaired cochlear processing in individual with sensory neural hearing loss.

Amplitude

The *peak to peak amplitude* values for click and chirp evoked ABR were not significantly different between the groups. But from the mean values individuals with normal hearing showed higher amplitude values than individuals with mild or moderate hearing loss. This could be due to differences in cochlear processing for different types of stimuli and differences in individuals itself.

There are no studies available in the literature in which they have compared amplitude for chirp stimuli between individuals with normal hearing and individuals with hearing impairment. Don et al (1994) have reported that there are larger variations of amplitude in individuals with normal hearing using click evoked ABR. Thus, it concluded that larger variation in amplitude can be expected.

Within group comparisons

Individuals with normal hearing

Wave I, III and V was obtained for both click and chirp evoked ABR at 80 dBnHL levels. The results were in correlation with the study done Feobel and Dau (2004) where they have reported the presence of earlier peaks with chirp evoked ABR at higher intensity levels in 9 individuals with normal hearing. But they have not reported the latencies and amplitude of wave I and III quantitatively. This can be due to cancellation of overlapping responses at high stimulation levels where by the early low frequency region of chirps stimuli stimulates basal regions of the basilar membrane due to upward spread of excitation (Dau et al, 2000).

As the intensity was reduced wave III and wave V were the most prominent peak in click evoked ABR but for chirp evoked ABR wave I and V were the most prominent peaks. The results were similar with the study done on comparison of click and chirp evoked ABR in individuals with normal hearing by Dau et al. (2000) , Feobel and Dau.,

(2004). As reported by Don et al. (1998 there are four processes affecting latencies of ABR. They are:

1. The cochlear transport time – it is the delay in the cochlea to the site of activation – depend on gender and independent of hearing loss and stimulus level.

2. Cochlear filter buildup time – it is the time required to build up impulse response at the site of activation (depends on characteristic frequency, stimulus level and amount of hearing loss, but independent of gender).

3. Synaptic delay between inner hair cells and auditory nerve fibers.

4. Neural conduction time and any intervening synaptic delay from cochlear nerve up to the point of brainstem pathway responsible for the peak activity (independent of hearing loss, stimulus level and characteristic frequency).

Thus, these factors lead to increase in latency with decrease in intensity for click and chirp evoked ABR latencies in individuals with normal hearing as it increase the cochlear transport time as well as cochlear filter build up time.

This could also be due to their differences in frequency specificity of the stimuli (Wegner & Dau, 2002). Don and Eggermont (1978) have reported that for characteristic frequencies below 2 KHz, the amplitude for wave I and III rapidly decreases as the characteristic frequency was decreased, whereas the amplitude of wave V increased in amplitude. Thus for chirp ABR initial peaks should have be absent / lesser in amplitude due to its frequency specificity more in lower frequency regions (500 Hz – 1 KHz). But Dau et al (2000) have justified the presence of wave I at higher levels by upward spread

of excitation where the basal region of the cochlea is excited by the low frequency energy of chirp when they are swept from low frequency to high frequency. Thus, from the present study it can be concluded that for chirp evoked ABR wave I and V are prominent peaks and wave III is less prominent with lesser amplitude.

The absolute latencies of click evoked ABR was shorter than chirp evoked ABR. This results were similar to the study done by Dau et al. (2000) where they has reported wave I latency of 8-9msec and wave V latency corresponding to the stimulus duration and offset of the stimuli at 60 dB SL for 20 /sec repetition rate. These differences in absolute latencies are due to the differences in the duration of the stimuli. Generally latency of ABR is calculated from the onset of the stimuli thus if they are measured from the onset of the stimulus it is prolonged. When they are considered relative to the offset of the stimuli the latencies/ brainstem conduction time would remain same. In the present study the latency was measured from the onset of the stimuli hence the latency of chirp evoked ABR was longer than click evoked ABR.

Peak to peak amplitude of click and chirp evoked ABR remained same at higher 80 dBnHL. As reported in literature higher amplitudes were expected for chirp stimuli than click stimuli but the results showed no significant difference between click and chirp stimuli. The results were similar to the study done by Dau et al. (2000) and Wegner and Dau (2004). They have reported that chirp evoked ABR doesnot take the advantage of cochlear processing at higher intensity levels. Also it is possible that neural saturation could have been reached at higher intensity levels thus there is no difference between clcik and chirp ABR amplitudes at higher intensity levels.

Peak to peak amplitude for chirp evoked ABR reduced with reduction in intensity of the stimuli. The results of present study were compatible with the study done by Dau et al. (2000) who have reported reduction in amplitude of chirp ABR with reduction in intensity from 60 dB SL to 20 dB SL. There were no significant amplitude differences obtained between click and chirp ABR at equal at lower intensity levels which is contrary to the studies done by Dau et al, (2000); Wegner and Dau (2002) Feobel and Dau, (2004). This could be due to the transducers used in these studies were different and large number of subjects taken for the study. Since 30 ears were taken for the study larger variability between the subjects could have lead to the non significance. Wegner & Dau (2002) have give some disadvantages of chirp evoked ABR which may lead to variation in chirp evoked ABR amplitude. For any given individual subject, the chirp designed from published functions regarding distance, frequency, and temporal maps in the cochlea is not necessarily optimal for that individual. That is, there is significant variation from subject to subject in the cochlear response time between frequency regions. Thus, the chirp may represent a compensation that is optimized for some mean delay of a group of individuals. Amplitude differences between individuals or between cochlear regions within a given individual may reflect how well the chirp represents the true cochlear response times across and within individuals and not solely the amount of activation.

Individuals with sensory neural hearing loss

At 80 dBnHL the wave V was the prominent peak observed in all sensory neural hearing loss subjects. The frequency of occurrence of wave I and III were reduced

and varied in individuals with mild and moderate sensory neural hearing loss. There is no information available in the literature where they have compared click and chirp evoked ABR in individuals with sensory neural hearing loss. Don and Kwong (2005) have reported that mid to high frequency cochlear hearing loss often results in poor or absent ABR wave I. Thus, due to hearing loss more in higher frequencies chirp evoked ABR earlier peaks could have been absent in the subjects with mild to moderate sensory neural hearing loss.

At 80 dBnHL wave V *absolute latency* of chirp evoked ABR were lesser in individuals with mild to moderate sensory neural hearing loss than normal hearing individuals. As the intensity of the chirp stimuli was reduced the latency of chirp ABR also increased, but the increase in latency was much lesser in cochlear hearing loss than in individuals with normal hearing. These latency differences could be due to impaired shorter cochlear response time which leads to decrease in latency in individuals with cochlear hearing loss (Don et al. 1998) which has been discussed earlier in group comparision.

The absolute latency of chirp evoked ABR were longer than the click evoked ABR in individuals with sensory neural hearing loss. The latencies varied with stimulus duration as seen in normal hearing individuals. The variability and trend seen in chirp ABR were same as those seen in normal hearing individuals.

Peak to peak amplitude of click ABR and chirp evoked ABR did not differ significantly in individuals with sensory neural hearing loss at 80 dBnHL. This can be due to neural saturation at higher amplitude levels as in normal hearing subjects.

As the intensity of chirp stimuli was reduced the amplitude of chirp evoked ABR was also reduced as seen in individuals with normal hearing. The amplitude variations were higher in both the groups with hearing impairment. There were no significant amplitude differences between the stimuli. The amplitude variations within cochlear hearing impaired individuals can be due to impaired cochlear processing and variability in degree of phase cancellation taking place between higher frequency and low frequency regions. Also Wegner and Dau (2002) have reported that issue of cochlear response time varies from individual to individual. Thus the chirp might not match with cochlear response time with all the individuals. Thus this issue becomes problematic when impaired cochlear are assessed in which case cochlear filter characteristics vary as a function of the degree of damage.

Comparison of click and chirp evoked ABR thresholds with behavioral thresholds

To observe the relationship between the ABR threshold and behavioral threshold, click and chirp evoked ABR thresholds were obtained at 30.1/ sec repetition rate. The pure tone averages (PTA 1 and PTA 2) were correlated with click and chirp evoked ABR threshold. From Table 14 it can be observed that the click and chirp evoked ABR thresholds were obtained 15 – 20 dB above the behavioral thresholds in individuals with normal hearing. Whereas in individuals with mild and moderate hearing loss the click and chirp ABR thresholds were closer to their pure tone averages.

To find out the correlation between PTA 1, PTA 2 with click and chirp evoked ABR thresholds Karl – Pearson correlation was applied. It can be observed from the Table 15 that both click and chirp ABR were significantly correlating with behavioral threshold (PTA1 & PTA2) with having high positive correlation between them.

Table 14:

Mean, S.D and range for PTA 1, PTA 2, click and chirp evoked ABR thresholds obtained in different groups

	Normal hearing			Mild sensory neural hearing loss			Moderate sensory neural hearing loss		
	Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.	Range
PTA 1	7.25	3.94	0- 15	30.15	5.50	21.6-38.3	45.88	4.31	36.6-50
PTA 2	6.64	4.02	0- 15	38.31	9.12	23.3-48.3	56.03	5.00	50- 65
Click - thresholds	19.83	5.79	10-35	37.77	7.12	25- 50	59.54	6.10	50 -70
Chirp - thresholds	19.00	5.47	10- 30	38.33	15.20	15- 60	51.81	4.62	45- 60

It is evident from the Table 15 that both click evoked ABR threshold and chirp evoked ABR threshold significantly correlate with both PTA 1 and PTA 2. Since there was good correlation between click and chirp evoked ABR with the behavioral pure tone

averages the study further compared the difference between click and chirp evoked ABR in individuals with normal hearing, mild and moderate sensory neural hearing loss.

Table 15:

Karl pearson's correlation coefficient results observed between PTA 1, PTA 2, Click and chirp evoked ABR thresholds

	PTA 2	Click thresholds	Chirp thresholds
PTA 1	.982**	.923**	.879**
PTA 2		.916**	.864**
Click dBnHL			.912**

** $p < 0.01$

Paired t - test was applied to the data to see whether there is any significant difference between the both the click and chirp evoked ABR thresholds in individuals with normal hearing, mild and moderate sensory neural hearing loss. There were little differences observed between click and chirp evoked ABR threshold in individuals with normal hearing and mild sensory neural hearing loss.

From the Table 16 it can be observed that significant difference between click evoked ABR thresholds and chirp evoked ABR thresholds were obtained only in individuals with moderate sensory neural hearing loss and chirp evoked ABR thresholds being better in moderate sensory neural hearing loss. Thus the chirp evoked ABR was better than click evoked ABR thresholds at higher degree of hearing loss.

Table 16:

t - test values with significance level between of click and chirp ABR thresholds for different groups

Groups	t - values	df	Significance level
Normal hearing	.841	29	.407
Mild sensory neural hearing loss	.170	8	.870
Moderate sensory neural hearing loss	3.963	10	.003

Since there was a significant difference in individuals with moderate sensory neural hearing loss the mean differences between ABR thresholds and pure tone averages were compared. It can be observed that there were less difference between PTA 1 and PTA 2 in individuals with normal haring and mild sensory neural hearing loss.

There are hardly any studies to state that chirp evoked ABR thresholds are better than click evoked ABR thresholds in individuals with normal hearing and sensory neural hearing loss. Most of the studies done with chirp evoked ABR have compared the amplitude of chirp evoked ABR with click evoked ABR at equal sensation levels. The differences obtained between click and chirp evoked ABR thresholds could be due to the configuration of hearing loss. Most of the subjects considered in the study had almost flat type of configuration and the differences between PTA 1 and PTA 2 were within 10 dB for individuals with mild hearing loss and within 15 dB for individuals for moderate hearing loss individuals. Since the difference between pure tone averages were greater for moderate hearing loss this differences could have lead to the differences seen in click and chirp evoked ABR threshold. Thus, from the correlation analysis it can be concluded

that like click evoked ABR, chirp evoked ABR could be also used in threshold estimation and can estimate thresholds closely to behavioral thresholds in individuals with higher degree of hearing loss. However, further research in this line is required to confirm this finding.

Comparison of click and chirp evoked ABR in individuals with auditory neuropathy:

A total of 10 ears with auditory neuropathy participated in this study and click and chirp evoked ABR was recorded at 11.1/sec repetition rate. Out of 10 ears tested 3 ears showed click ABR responses at 80 dBnHL. Seven ears did not show click evoked ABR responses even at 80 dBnHL. Whereas, 4 ears out of 10 ears had chirp evoked ABR responses and 6 ears didn't show chirp evoked ABR responses even at 80 dBnHL. Subjects who had click ABR also had chirp evoked ABR. However, those who did not have click evoked ABR also did not have ABR for chirp except one ear. Those who had ABR for click and chirp, morphology was poor for both the stimuli. Only wave V could be identified irrespective of severity of hearing loss. However, wave V latency for chirp evoked wave V was much longer in auditory neuropathy than that was observed with individuals with normal hearing and sensory neural hearing loss.

Table 17 shows the mean absolute latency and mean peak to peak amplitude for click and chirp evoked ABR responses wave V obtained at 11.1/sec repetition rate. When peak to peak amplitude was compared across the stimuli the chirp ABR had higher amplitudes compared to click evoked ABR. So paired t - test was administered to the see

the significant differences between them. Paired t - test result showed no significant peak to peak amplitude difference between click and chirp evoked ABR [t, (2) = 3.024, p > 0.05].

Since, 4 ears of auditory neuropathy subjects had identifiable wave V at 80 dBnHL, chirp evoked ABR was recorded at lower intensity levels for threshold estimation. When intensity of chirp stimuli was reduced to 70 dBnHL detectable chirp ABR wave V was observed for 3 ears out of 4 ears. However, when the intensity was further reduced to 60dBnHL there were no responses for any of these subjects. But for click evoked ABR when click intensity was reduced by 10 dB detectable wave V for click stimuli was not present any of those 3 ears who had click evoked ABR at 80 dBnHL.

It can be concluded from the above results that the chirp and click evoked ABR latency values for chirp ABR were prolonged compared to normal hearing ears. There are no studies available in literature using chirp evoked ABR in individuals with auditory dysnchrony.

Since chirp ABR evokes synchronous firing along the cochlea it was expected to obtain better ABR responses with chirp stimuli. Even though cochlear outer hair cells are normal in auditory neuropathy they are not able to evoke significant synchronous activity in the auditory nerve with the compensation of basilar membrane delay differences between high and low frequencies. Also chirp stimuli evokes synchronous activity by the entire basilar membrane at the same time by compensating these basilar membrane group

delay it could not evoked synchronous activity in auditory nerve for individuals with auditory dyssynchrony which could be due to demylination of auditory nerve.

Table 17:

Mean and S.D for click and chirp evoked ABR wave V latency (ms) and amplitude (µv) obtained from individuals with auditory neuropathy

Intensities		Auditory neuropathy			
		Latency		amplitude	
		Click ABR	Chirp ABR	Click ABR	Chirp ABR
80 dBnHL	Mean	6.68 (n=3)	16.03 (n=4)	0.27 (n=3)	0.39 (n=4)
	SD	1.05	0.82	0.07	0.15
70 dBnHL	Mean	No response	17.11 (n=3)	No response	0.24 (n=3)
	SD		0.22		0.10

From chirp evoked threshold comparisons it can be concluded that since 3 ears have got chirp evoked ABR thresholds at lower intensities than the click evoked ABR thresholds and 1 ear have got chirp evoked ABR in the absence of click evoked ABR chirp evoked ABR could be used for threshold estimation in auditory neuropathy. This would in turn give a better approximation to the behavioral threshold in individuals with auditory neuropathy.

V. SUMMARY AND CONCLUSION

Click evoked auditory brainstem responses are the most commonly used electrophysiological measure in the assessment of threshold. It was assumed that click evokes synchronous firing due to its abrupt nature of onset and they are ideal for evoking synchronous activity (Gorga and Thornton, 1989). But Bekesy (1960) by his invasive studies observed that the peak of basilar membrane travelling wave occurred several millisecond later in low frequency channels than at high frequency channels. Gorga et al. (1985) had also reported that Click-evoked ABR thresholds appeared to be related most closely to the audiometric thresholds at 2000 and 4000 Hz. These studies showed the high frequency activation of cochlea with click stimuli.

To overcome these disadvantages with the click stimuli Dau et al. (2000) have developed an optimum chirp stimulus to compensate human basilar membrane travelling wave delay. The chirp is a short duration stimuli which starts with low frequencies and sweeps nonlinearly in time toward high frequencies. It was reported in literature that by compensating the basilar membrane travelling wave this stimuli can evoke synchronous activity throughout the basilar membrane at the same time and thus increasing the neural synchronous activity.

Dau et al. (2000), Wegner & Dau (2002), Foebel & Dau (2004) and Agung et al. (2005) have used the modified chirp stimuli developed by Dau et al. (2000) in evoking auditory brainstem response and they have reported that the amplitude of chirp evoked wave V is significantly higher than click evoked ABR wave V responses at equal sensation level for individual with normal hearing. Hence, they have reported that chirp

ABR can be used clinically where click evoked ABR has been used so far. Since, these studies have been done on limited number of subjects and only in individuals with normal hearing there is dearth of studies on chirp evoked ABR normatives and their effects with other clinical populations such as cochlear hearing loss and auditory neuropathy.

Hence the present study aimed to

- establish data from large number of normal hearing individuals for chirp evoked ABR,
- obtain latency intensity functions for chirp stimuli for individuals with normal and hearing impaired,
- compare the wave parameters (amplitude, latency and morphology) of click and chirp evoked ABR in normal hearing and cochlear impaired individuals across intensity levels of 80dBnHL and 40 dB SL and at two repetition rates (11.1/sec and 30.1/sec),
- correlate behavioral thresholds and ABR thresholds obtained by click and chirp in normal hearing and cochlear impaired individuals and
- analyze whether chirps can evoke any significant neural synchrony in individual with auditory dysynchrony.

Subject taken were 30 ears with normal hearing and 20 ears with cochlear hearing loss and 10 ears with auditory neuropathy. Chirp stimuli were generated using a program

written in MATLAB using the method as described by Dau et al. (2000). Both click and chirp stimuli were presented through TDH 49P earphone and ABR wave forms were recorded using IHS smart evoked potential systems (version 2.39). Both click and chirp evoked waveforms were recorded for two repetition rate (11.1/sec & 30.1/sec) at 80 dBnHL, 40 dB SL and till threshold levels. Both click evoked and chirp evoked ABR were analyzed for wave I, III and V latency, amplitude and morphology.

The data obtained were statistically analyzed using SPSS software (version 14). The analysis of the data revealed the following results:

- The latency of chirp evoked ABR was prolonged when compared to click ABR due to their differences in stimulus duration.

- There was a significant difference in latency with increase in degree of hearing loss. The latencies reduced for chirp ABR with the increase in degree of hearing loss whereas for click ABR latency increased with increase in degree of hearing loss. This effect was observed for all the peaks, indicating altered neurophysiological processing in individuals with cochlear hearing loss.

- There was no significant difference in amplitude between and within groups indicating variability within and across groups.

- The chirp evoked ABR thresholds correlated significantly with pure tone averages (PTA1 & PTA 2) in individuals with sensory neural hearing loss, could be due to pattern of threshold they had.

- Better agreement between behavioral thresholds and chirp evoked ABR thresholds obtained in moderate sensory neural hearing loss group. Thus, suggests that it could be used to predict thresholds better in subjects with higher degree of hearing loss.

- The chirp evoked ABR could not evoked synchronous ABR response in auditory neuropathy individuals, but it can predicts thresholds better as it had lower ABR thresholds than click evoked ABR thresholds in auditory dyssynchrony.

It can be concluded from the study that the chirp evoked ABR can be used clinically for threshold estimation in individuals with normal hearing and cochlear hearing loss and auditory neuropathy. It can estimate more precise behavioral thresholds in individuals with higher degree of hearing loss and up to certain extent in individuals with auditory dysnchrony. It can also be used to study the cochlear processing such as cochlear transport time and cochlear filter responses. The chirp evoked ABR cannot be used for neurodiagnosis due to less frequency of occurrence of wave III. ABR wave I present till lower level could be of particular interest for future studies.

Implications of the study

1) Data obtained from the group of individuals with normal hearing can be used for clinical purpose.

2) It can be used to assess neurophysiological processing in individuals with hearing impairment.

3) Chirp evoked ABR can be used for threshold estimation in difficult to test population.

4) This study adds information to the literature.

Future research directions

1) Chirp evoked ABR can be recorded in steeply sloping hearing loss subjects to verify the frequency specificity of chirp ABR

2) Needs to be evaluated in infants to know whether it can be an useful tool to estimate threshold.

3) Effect of cochlear processing can be further studied using chirp stimuli with derived band and masking techniques.

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