Comparison of Click and Chirp Evoked ABR in Normal Hearing and Hearing Impaired Individuals

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Abstract

Auditory brainstem responses (ABR) evoked by click stimuli are most commonly evoked potentials used for threshold estimation. It has been reported that the click stimuli doesn't evoked a synchronous neural firing along the basilar membrane and thus resulting in reduced amplitude of ABR wave V. To overcome the reduction in amplitude, chirp stimuli have been developed to compensate the group delays in basilar membrane traveling wave. Thus the present study aimed at Comparing the ABR wave (amplitude, latency and morphology) elicited by click and chirp stimuli in 30 ears with normal hearing and 20 ears with cochlear hearing loss at 80 dBnHL and 40 dB SL at the repetition rates of 11.1/ sec and 30.1/ sec. ABR thresholds obtained by click and chirp in normal hearing and cochlear impaired individuals elicited at 30.1/ sec repetition rate were compared with behavioral thresholds. Also to know whether chirps can evoke any significant neural synchrony in individual with auditory dysynchrony chirp evoked ABR were recorded at 11.1/ sec repetition rate in 10 ears with auditory dysnchrony. The results revealed that there was a significant difference in latencies within and across groups for click and chirp stimuli but there was no significant differences observed in terms of amplitude except for wave I at 11.1/sec repetition rate at 80 dBnHL revealing cochlear processing differences across the groups. There were high correlations between click and chirp evoked with their behavioral thresholds in both normal hearing and hearing impaired subjects suggesting the application of chirp evoked ABR in threshold estimation. Chirp stimuli can evoke better synchrony then click stimuli suggesting the clinical use of chirp evoked ABR in individuals with auditory dysnchrony.

Introduction

The Auditory Evoked Potentials are the electrical responses of the auditory nervous system to auditory stimuli. 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

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proportion of cochlear fibers (Kodera, Yamane and Suzuki, 1977; Gorga and 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 and 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 (Gorga and Thornton, 1989). Thus, it suggests that the click may not be the optimal stimuli for ABR recording.

Recent studies have shown that a chirp rising in frequency, which is tailored to activate the entire cochlea concurrently, evokes a larger wave-V amplitude than a traditional click presented at the same sensation level (Dau et al., 2000; Wegner and Dau, 2002; Fobel and Dau, 2004). Rising chirp stimuli starts with low frequencies and sweeps nonlinearly in time toward high frequencies. The rising chirp theoretically produces simultaneous displacement maxima by cancelling traveling-time differences along the cochlear partition. The equations determining the temporal course of the chirp were derived on the basis of a linear cochlear model (de Boer, 1980), and were calculated to be the inverse of the delay-line characteristic of the human cochlear partition. The use of a broadband rising chirp was shown to reflect activity also from low-frequency regions.

Since studies done so far on comparison of click and chirp evoked ABR on a limited number of subjects with normal hearing it is necessary to study in large population of normal hearing and hearing impaired individuals using to elicit ABR threshold for generalization and clinical use. 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. Also there is a need to assess whether chirps can evoke a detectable ABR in individuals with auditory neuropathies where outer hair cells are preserved.

Thus, the purpose of the present study was to

- ✓ Establish ABR data using chirp stimuli in large number of individuals with normal hearing,
- ✓ 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.

- ✓ Compare behavioral thresholds and ABR thresholds obtained by click and chirp in normal hearing and cochlear impaired individuals at 30.1/ sec repetition rate and
- ✓ To know whether the chirp stimuli can evoke any significant neural synchrony in individual with auditory dysynchrony at 11.1/ sec repetition rate.

Method

A. Subjects

To accomplish the aims three groups of subjects were taken

Group I: consisted of 19 subjects (30 ears) with normal hearing, aged from 19-40 years. Air conduction and bone conduction thresholds were less than or equal to 15 dB HL in the octave frequencies. All the subjects had 'A' type tympanogram and acoustic reflexes were within normal limits indicating normal middle ear function. Click evoked ABR and Transient Otoacoustic emissions were present in all the subjects. 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: consisted of 15 subjects (20 ears) with mild to moderate cochlear hearing loss, aged from 25 to 70 years with flat or sloping configuration. 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 all the 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: consisted of 5 subjects (10 ears) with auditory neuropathies, aged from 11 to 22 years. Both air conduction and bone conduction thresholds showed mild to moderate neural hearing loss with pure tone average ranged between 26 dB HL to 55 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. All subjects in this group had 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 reflexes. These subjects had no history of middle ear infections or general weakness.

B. Instrumentation

A calibrated two channel diagnostic audiometer (AC40) with TDH-39 head phone and B-71 bone vibrator was used to obtain pure tone thresholds. A calibrated immittance meter (GSI- tympstar) was used to assess the middle ear function. TEOAE's were recorded using ILO292 DP Echoport instrument. ABR recordings were done using Intelligent Hearing Systems (IHS) smart Evoked potential systems (version 2.39) with TDH-49 P head phones.

C. Stimuli

Click and chirp stimuli were used to record ABR. Click stimulus with duration of 100 µs was used. Flat spectrum rising Chirp stimuli of 10.31 ms duration with a frequency range of 100 Hz to 6 kHz was generated to record ABR. 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 44100 Hz 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 1.

A B

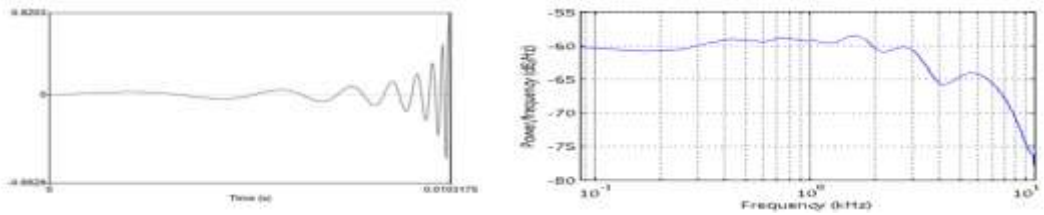

Figure 1*:* Temporal (A) and spectral representation (B) of flat rising chirp used in the present study.

D. Procedure

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. Click and chirp stimuli were presented with alternating polarity at 11.1/sec and 30.1/ sec repetition rates. The ABRs were recorded differentially between electrodes applied to the upper forehead (FpZ) and the ipsilateral mastoid (M1 or M2). The contralateral mastoid was used as ground. Intraelectrode impedance and interelectrode impedance were maintained within 5 KΩ and 3 KΩ respectively. Scalp activity was amplified by 1,00,000 times and filtered with a pass band of 0.1–3 kHz.

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. Once the response was 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 adopted 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.

For group III ABR recording were done using click and chirp at 80 dBnHL with repetition rate of 11.1/s. If any detectable wave V responses were observed at 80 dBnHL either for click or chirp stimuli, threshold estimation was carried out at 11.1/sec repetition rate. The step size used to estimate threshold were the same as mentioned earlier. 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

Absolute latencies and peak to peak amplitude were measured for each of the identified peaks. Descriptive statistics (mean and standard deviation) for wave latencies (I, III & V) and amplitude (I, III & V) parameters were computed for click and chirp evoked ABR 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 to see the significance level. Paired t - test were applied to compare the click and chirp evoked ABR wave I and III latency and amplitude(I & III) 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 - PTA 1 (averaged from 500 Hz, 1 kHz and 2 kHz thresholds) and PTA 2 (averaged from 1 kHz, 2 kHz and 4 kHz thresholds). The behavioral thresholds (PTA1 and PTA2) and ABR thresholds obtained at 30.1/ sec repetition rate using click and chirp were correlated using Karl Pearson's correlation test. 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 behavioral thresholds. No statistical analysis was carried out. Morphology of ABR recorded using click and chirp ABR were discussed.

Results and Discussion

Individuals with normal hearing

Morphology of click and chirp evoked ABR varied with the type of the stimulus, repetition rates and level. From Figure 2 it can be observed that major peaks wave I, III and wave V were observed at higher intensity levels. 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.

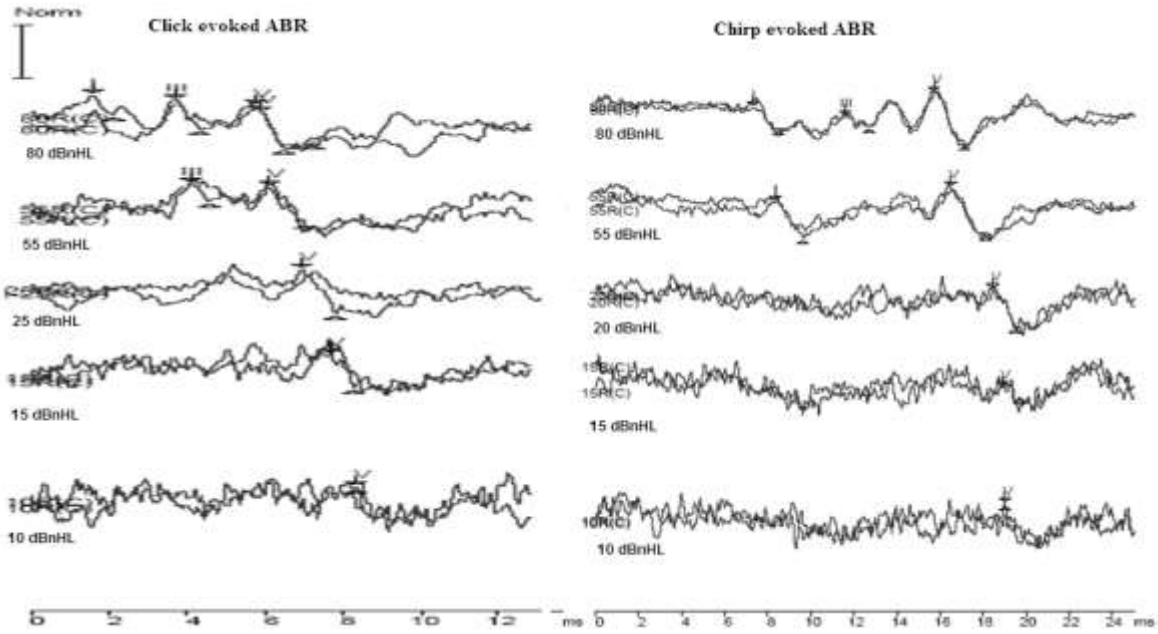

Figure 2*:* Shows click evoked ABR waveforms (left panel) and chirp evoked ABR waveforms (right panel) observed for different intensity levels at 30.1/sec repetition rate in one subject with normal hearing.

Latency and amplitude measures

The mean absolute latency values for click and chirp evoked ABR 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 1. The absolute latency of wave V was significantly different between the stimuli, intensity and repetition rate ($p<0.05$). 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.

Table 1: 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	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	1.67 (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

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 Figure 3 that as the intensity decreased the latency of chirp evoked ABR wave V increased.

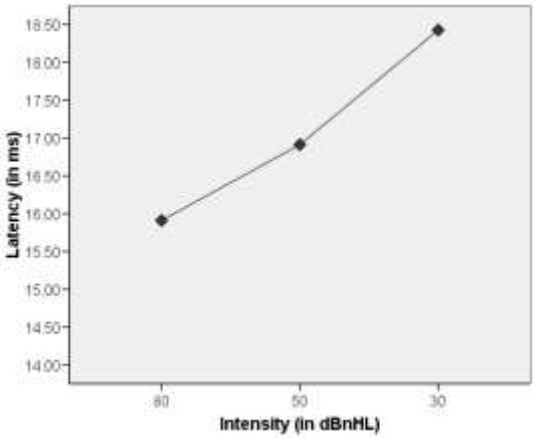

Figure 3*:* Latency intensity function of chirp evoked ABR wave V.

From Table 2 it can be observed that there was a significant difference between 11.1/sec and 30.1/sec wave III and wave I 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.

Table 2: t – Values, degrees of freedom and significance level for wave (III & I) latency and amplitude in normal hearing individuals at 80 dBnHL

Pairs compared (wave III)	*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
Pairs compared (wave I)						
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

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.

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	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	0.41 (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

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. 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 ($p > 0.05$).

Results of paired t - test (Table 2) showed that there was no significant difference between 11.1/sec and 30.1/sec for wave III amplitude obtained either by chirp stimulus or click stimulus. But wave I amplitude were significantly different for click stimuli but not

for chirp stimuli between 11.1/sec and 30.1/sec repetition rates (Table 2). When wave III and wave I 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 except wave I click and chirp ABR amplitude at 30.1/ sec repetition rate. Also wave I was consistently observed at and near 40 dB SL for normal hearing subjects.

Individuals with 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). 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:

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. 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 4 shows the latency intensity functions for wave V in individuals with mild and moderate sensory neural hearing loss. It can be observed from Figure 4 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 and were significantly different from individuals with normal hearing ($p < 0.05$). 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 absolute latency values for click and chirp evoked ABR for all the peaks increased as the rate and intensity increased.

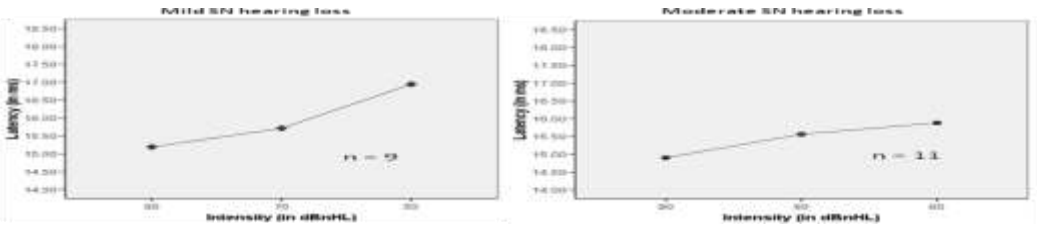

Figure 4**:** Latency intensity functions for mild sensory neural hearing loss and moderate sensory neural hearing loss subjects for chirp evoked ABR wave V.

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, III & I amplitude values reduced with increase in repetition rates and decrease in intensity for individuals with mild and moderate sensory neural hearing loss. 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. It was also observed that the wave I amplitude in individuals with mild and moderate sensory neural hearing loss were consistently higher for chirp evoked ABR than click evoked ABR at all intensities and repetition rates.

Between group comparisons

The repeated measure ANOVA was done for click and chirp evoked ABR wave V latency and amplitude 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 4 it can be observed that there was a significant difference between the groups.

Table 4: *Duncan's post hoc test results for wave V latency 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. 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.

The absolute latency of click and chirp evoked ABR differed significantly between groups. 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 for chirp evoked ABR, 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). 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.

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). 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. 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.

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 that 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. 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 does not take the advantage of cochlear processing at higher intensity levels. 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 and also due to some disadvantages of chirp evoked ABR which may lead to variation in chirp evoked ABR amplitude. Disadvantage is that there is significant variation from subject to subject in the cochlear response time between frequency regions. Thus this may cause 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. 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 comparison.

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.

Table 5: 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
Click - thresholds	19.00	5.47	10- 30	38.33	15.20	15- 60	51.81	4.62	45- 60

The pure tone averages (PTA 1 and PTA 2) were correlated with click and chirp evoked ABR threshold. From Table 5 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.

Table 6: 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**

** $p < 0.01$

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 6 that both click and chirp ABR were significantly correlating with behavioral threshold (PTA1 & PTA2) with having high positive correlation between them. 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 7: 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

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. From the Table 7 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.

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:

Out of 10 ears tested 3 ears showed click ABR responses at 80 dBnHL, whereas, 4 ears out of 10 ears had chirp evoked ABR responses 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 8 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 ABR wave was absent when click intensity was reduced by 10 dB.

Table 8: 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

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. 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.

Conclusions

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.

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