EFFECT OF INTENSITY, REPETITION RATE AND STIMULUS TYPE ON SPECTRUM OF AUDITORY BRAIN STEM RESPONSE

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May, 2017

CERTIFICATE

This is to certify that this dissertation entitled "**Effect of Intensity, Repetition Rate and Stimulus Type on Spectrum of Auditory Brain Stem Response"** is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number: 15AUD020. 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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May, 2017

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CERTIFICATE

This is to certify that this dissertation entitled "**Effect of Intensity, Repetition Rate and Stimulus Type on Spectrum of Auditory Brain Stem Response"** has been prepared under my supervision and guidance. It is also been certified that this dissertation 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 "**Effect of Intensity, Repetition Rate and Stimulus Type on Spectrum of Auditory Brain Stem Response"** is the result of my own study under the guidance of Prof. Animesh Barman, Professor in Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru, **Registration No. 15AUD020**

May, 2017

ABSTRACT

Malinoff et al., (1990) performed the spectral analysis of ABR with respect to change in intensity, rate and polarity and found that low frequency components below 500 Hz were significantly more regardless of intensity, rate and polarity. Thus the current study have taken up to see effect of repetition rate, intensity and type of stimulus on ABR spectral components Auditory brainstem response (ABR) were recorded from 24 individuals by varying stimulus parameters intensity (40dBnHL & 80dBnHL) repetition rate (30.1 &70.0/sec) and type of stimulus (click, tone burst 500Hz & 4000Hz). For the evoked response FFT was carried out, to know the effect of each parameter on spectral composition. The results in this study showed that, there is a corresponding decrease in the amplitude of all spectral components with the reducing in stimulus intensity. Peak at the lower frequency region persisted inspite of intensity reduction. There was a drastic reduction found above 500 Hz for both higher and lower intensities. Spectral amplitude was reduced with increase in the repetition. It is also observed that across stimulus (Click, 500 Hz & 4000 Hz) there was a significant difference in spectral amplitude. Difference in the spectrum magnitude was greater at an intensity of 80 dB nHL compare to 40 dB nHL. Thus, it can be concluded that spectrum of the ABR is sensitive to changes in the stimulus parameters. Also the findings suggests that the spectral analysis can be used as another way of interpreting ABR results similar to time based analysis and also appropriate filter setting should be used to record ABR depending upon the stimulus parameters selected to record ABR.

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INTRODUCTION

Spectrum is a concentration of energy of frequencies in an acoustic signal. Human auditory system capable of perceiving frequency range of 20Hz-20 kHz in an environment but it is not true when it is presented and perceived in controlled condition. Frequency of perception varies depending up on type of transducer and stimulus used.

Auditory brain stem response (ABR) is one of the widely used objective methods of recording the response from auditory system. ABR is a complex electrophysiological wave form typically recorded in the time domain. Regular analysis of ABR data usually involve determination of absolute latency and amplitude of major wave components and also relative latency or amplitude measure such as the wave I-V latency interval or the wave V/I amplitude ratio (Hood 1998).

Presence of good amplitude wave at a specified range of latency indicates the functioning of auditory system but it will not provide any information about frequency composition of the response. It is possible to calculate the frequency composition of a response waveform by means of spectral analysis technique for the determination of frequency composition of a human auditory evoked potential. This is helpful in selecting the appropriate band pass filters, which in turn helps in recording of ABR with minimal distortion maximum exclusion of both biologic and instrumental noise. They are useful in improving signal to noise ratio, permitting a reduction in the number of averages and thus, reducing the testing trial duration (Kevanishvili and Aphonchenko, 1979).

Investigation on spectral analysis of normal ABR by Kevanishvili and Aphonchenko (1979), Suzuki et al., (1982), Hall III (1986), indicated a greater energy of spectral composition at low frequencies region below 250Hz. Difference in recording parameter and stimulus parameter result in difference in location of spectral peaks and also limits the spectrum of ABR. Malinoff et al (1990) reported the effect of intensity, rate and polarity on ABR spectral composition the result revealed that effect of rate were concentrated on low frequency and while effect of polarity was concentrated in higher frequency. Effect of polarity and rate are related to, change in ABR latency and amplitude. Thus once can report corresponding change in frequency domain also.

Hall (1986), Spiva and Malinoff (1987) suggest that ABR spectral analysis is use full in differential diagnosis of auditory pathology. In order to use a spectral analysis as a tool of diagnosis effect of each parameter must be well understood.

Need of the study

There is dearth of studies investigating the spectral composition of ABR with respect to change in repetition rate, intensity and type of stimulus on the same sample of subjects. Suzuki et al., (1982) performed the spectral analysis on tone burst at frequency of 500 Hz to 4 kHz at an intensity of 40 dB and 80 dB and concluded that spectral peak around 100 Hz consistently appears regardless of stimulus intensity and frequency. Kevanishvili and Aphonchenko (1979) documented the spectral composition of ABR for tone bursts at 40 dB nHL and 80 dB nHL and found with decrease in stimulus intensity the energy of all spectral components dropped except for wave V(100-500 Hz). Malinoff et al., (1990) performed the spectral analysis with respect to change in intensity, rate and polarity and found that low frequency components below 500 Hz were more significant regardless of intensity, rate and polarity. Spivak and Malinoff (1990) and Spivak (1993) studied age effect on spectral composition of ABR and found significant low frequency energy of 150 Hz both in adult and younger subjects.

However none of the study have changed repetition rate, intensity and type of stimulus on the same subject and studied the effect on ABR spectral components. Thus this study has been taken up.

Aim of the study

To study the effect of type of stimulus, repetition rate and intensity level on spectrum of auditory brain stem responses.

Objectives of the study

Was to study the,

1. Effect of intensity on spectrum of auditory brain stem response.
2. Effect of stimulus type on spectrum of auditory brain stem response.
3. Effect of repetition rate on spectrum of auditory brain stem response.

CHAPTER II

REVIEW OF LITERATURE

Auditory brain stem response testing is an objective method of evaluating the function of auditory system from the level of cochlea up to lower brain stem.

ABR response wave consist of series of 5-7 peaks in a time period of 1.4ms - 8.0ms response waveform is characterized by absolute latency, response reproducibility, inter wave latency interval. . It is generally recorded for click, tone burst and speech stimulus. Via electrode placed on the scalp. It widely used clinical method to make inferences about hearing and for neural diagnosis and as a screening tool. (Hood, 1998).

Response of the ABR influence by several factors

- Stimulus factors: Type of stimulus, intensity, rate, polarity, montage, stimulation mode, masking effect, rise and fall time.
- Recording factors: Electrode montage, Analysis time, Filter settings, Number of sweeps.
- Subject Variables: age ,gender ear effect ,body temperature , Muscle/Movement artefact, drugs and pathological conditions related to auditory system
- Effect of each one is discussed below

Intensity

Increase in latency and decrease in amplitude as stimulus intensity decreases from 70 or 80 dB nHL to the threshold of detectability (Picton et al., 1974; Starr and Achor, 1975). Wave V is most visible at lower intensity levels, whereas the earlier components tend to become indistinguishable at intensities of 25 to 35 dBnHL (Hood, 1998). The wave V is generally not detected visually at intensity levels below

10-20 dBnHL for normal listeners. Near the threshold of the response, Wave I occurs at approximately 4.0 ms and Wave V at about 8.0 ms in adults (Hood, 1998). The wave V latency shift with changes in intensity is nonlinear, with shifts of approximately 0.2 to 0.3 ms per 10 dB at higher intensities and a steeper slope at lower intensities (Hood, 1998). As intensity is reduced from 70 to 30 dBnHL, the latency shift is the greatest for wave I and least for wave V (Stockard et al., 1979).

Rate

Rate of the stimulation affects both latency and amplitude components of the ABR wave (Hood, 1998). As the rate of the stimulus increase it was observed there is a prolongation of latency and decrease in amplitude of earlier peaks (Fowler and Noffsinger, 1983; Hyde, Stephens and Thornton, 1976; Paludetti,Maurizi, and Ottaviani, 1983; Pratt & Sohmer,1976). Faster rate of stimulation helps in diagnosis of neurological lesion (Don, 1977; Stockard, and Sharbrough, 1978)

Polarity

ABR can be recorded for various polarity, rarefaction condensation and alternating (Hood, 1998). For rarefactions polarity latency is shorter and amplitude is larger for earlier components compare to condensation (Borg and Lofqvist, 1982; Coats & Martin, 1977). Most often alternating polarity used to cut down the stimulus artifact especially for BC recording (Hood, 1998).

Stimulus Duration

The standard pulse duration (click) utilized in clinical ABR testing is 100 microseconds or 0.1 ms because the ABR is an onset response; the duration of the stimulus should not alter the response (Hecox, Squires and Galambos, 1976; Stapells and Picton, 1981).

Stimulus Frequency

ABR evoked by moderate intensity (60 dBnHL) click stimulus with conventional transducer reflects activity in the high frequency region (1-4 kHz) of the cochlea H Davis, 1976; Davis and Hirsh, 1979). More apical regions of the cochlea (LFs) are also activated by clicks, but they don't contribute for ABR, at least in normal listeners. The click evoked ABR is very useful and clinically practical for estimation at auditory functioning in the 1000-4000 Hz regions. For hearing screening purpose it is highly suitable.

The most obvious approach for generating an ABR reflecting hearing sensitivity at a specific frequency is to use brief tone stimulation, such as tone burst. The tone burst ideally has energy as a single pure tone frequency (.e.g. 500 Hz) under all presentation conditions, including high stimulus intensity levels, and it contains no energy at other frequencies.

The ABR can be obtained using tone bursts that have a rapid rise time while still maintaining some frequency specificity (Picton et al., 1979). There is a trade-off between frequency specificity and neural synchrony in that tone bursts with longer rise times will be more frequency specific, but will generate poorer neural synchrony, which will affect the quality of the response (Hood, 1998). Higher frequency stimuli elicit shorter latencies than lower frequency stimuli because high frequencies stimulate the more basal portions of the basilar membrane (Hood, 1998).

Filter settings

A high pass setting of 30 Hz or lower is essential in order to encompass the low frequency portion of the ABR spectrum, which is prominent for a low frequency stimulus. (Hyde 1975 and Picton et al, 1981).

Raising this cut-off frequency results in decreased wave V amplitude, response distortion, elevated response threshold and reduced response detectability

Monaural versus Binaural Recordings

Responses to binaural stimuli show an average of a 60% increase in amplitude over responses recorded using monaural stimuli (Blegvad, 1975).

Latencies of responses obtained with monaural or binaural stimuli should be similar.

Time window

Analysis window should be set appropriately to obtain all components of the ABR. it also depends on the population tested (Hood, 1998). Compare to adults more time window is required to infants. Over all 10 -15 ms time window is sufficient for recording click ABR (Hood, 1998).

Single and double channel recording

Compare to single channel recording two channel recording gives simultaneous information about ipsi and contra response. This helps in better definition of IV and V peaks in contra recording and wave I in ipsi lateral recording (Hood, 1998)

Number of sweeps

For the ABR recording usually 1000-2000 sweeps are sufficient to obtain good response at higher intensity level at lower intensity level sweeps required will be more to obtain adequate signal to noise ratio (Hood, 1998).

Age

ABR response changes as a function of age particularly in infants between 12-18 months due central auditory system continuous to mature (Hood, 1998). Adults greater than 55 year old demonstrated 0.1 to 0.2 ms longer latencies when compare to normal adults (Allison, Wood and Goff, 1983; Jerger and Hall, 1980)

Gender

Female tend to have longer latencies and greater amplitude than males (Allison et al., 1983)

Spectral analysis of ABR wave

Auditory evoked potential obtained for transient and brief stimulus are aperiodic electrical activity within the response is time locked to multiple discreet stimulus and averaged .Average response occur over time is analysed by calculating latency and amplitude of wave components . Only based on the visual inspection of the wave one can understand the effect of change in frequency example rounded peaks occurs due to low pass filter noise. By means of fast Fourier technique it is able separate the major frequencies contributing for response after it has been digitalized (Regan, 1966). FFT analysis helps in obtaining spectral amplitude across range of frequency. Digital filtering and FFT are important for response measurement. With the help of the FFT technique the frequency response can be analysed and manipulated mathematically (deleting energy at certain frequency) later manipulated response can be converted in to time domain which in turn helps in better representation and interpretation of wave form . FFT analysed waveform is usually displayed in a graph with frequency on horizontal axis and amplitude on vertical axis .smallest difference in frequency can be assessed using FFT which is not seen in time domain.

Previous investigation on spectral analysis by FFT revels. ABR consist of three major frequency region .greater amount of low frequency energy (below 150 Hz) and also energy at 500-600Hz , 900-1100Hz and very less energy above 2000Hz above mentioned findings are result of spectral analysis and offline digital filtering technology (Abdala and Folsom (1995) , Kevanishvili and Aphonchenko (1979); Wilson and Aghdasi (2001).

Malinoff and Spiva (1990) studied the effect of intensity, rate and polarity on the spectral content of ABRs. The study was performed on 15 normal- hearing individuals within the age range of 20 to 40 years. The study was performed by varying the three stimulus parameters systematically. Responses were elicited for intensities of 80, 60 and 40 dBnHL and were recorded at 11.1 and 33.3 clicks per seconds. Polarities used were rarefaction and condensation clicks. It was found that as stimulus intensity decrease, ABR waveforms decrease in amplitude and increase in latency. It was found that there was a corresponding decrease in the amplitude of all spectral components. The effect of rate and polarity were frequency specific unlike intensity. It was observed that the effects of rate were concentrated in low frequencies while polarity in the high frequencies. It was concluded that the effects of stimulus parameters must be considered in examining the ABR spectral analysis.

Suzuki et al (1982) have studied the power spectral analysis and digital filtration on tone burst ABR. They have recorded tone burst ABR in 3 normal hearing individuals at 2 different intensities. 1, 2 and 4 KHz at 80dBnHL, and 0.5, 1 and

2 KHz at 40dBnHL. Tone burst stimuli had raise, fall and plateau for every 2 periods for all the selected frequencies. ABR was recorded using standard parameters. The result revealed, the response obtained with the tone stimulus 1, 2 and 4 KHz at 80dB SL, had frequency spectrum response between 50-1300Hz. The frequency range for the 3 peaks observed were 50-150, 500-600 and 1000-1100 Hz. The amplitude of the response frequencies reduced as the frequency of the stimulus reduced at specific frequency. The amplitude of the higher frequency became almost not identifiable when the second set of stimulus was used 0.5, 1 and 2 KHz at 40dBnHL. Therefor each peak in the response is in correlation with the frequency of the stimulus. They have also studied the effect of digital low and high pass filtering on the spectral responses where they found that when the ABR recorded using 4 KHz with a low pass filter of 800Hz there was a complete absence of a high frequency peak that is V. The amplitude of wave II and IV were hardly identified and reduction in the amplitude of wave I and III was observed. They reported that there was a complete absence of all the ABR peaks except the slow deflection of the V Peak was found when the filter was reduced to 400Hz. In contrast all the ABR peaks would be observed except the slow deflection if the high pass filter kept as 400Hz. This study was in a good congruent with the previous studies where, the high frequency spectral response component declines rapidly with the reduction in the frequency as well as intensity.

Kevanishvili and Aphonchenko (1979) have done a study on the spectral analysis to see the effect of standard phase shift and zero phase shift on the amplitude of the ABR peaks. They have also compared the reduction in the muscular artifact using above mentioned techniques. They have recorded ABR in 12 normal hearing individuals, in the age range of 22-52 years. The auditory evoked potentials were recorder through pathfinder II (Nicolet corp.) using headphones. Click in rarefaction polarity was used as stimuli at 75, 55 and 35 dBnHL. The filter used was Butterworth with a band pass of 0.2- 8 KHz and 12db/ octave slop. The time base was 60msec and 1024 points were used for digitization.

In this study they have done a spectral analysis using a FORTRAN based program. It was used to derive the amplitude spectrum. The resolution of the spectral analysis used was 66Hz. Digital filtering was done through a program which uses “discrete Fourier transformation” which calculates the phase and power spectral component of the waveform which was baseline corrected. Fourier analysis assumes that the analyzed signal is periodic; therefore an ideal digital filtering model records many responses on a single time base.

Results revealed, energy of the major peaks reduced as the intensity reduced from 75-35dBnHL. This decrease was more observed towards the higher frequencies than compare to low frequencies and mean response shifted towards low frequencies. They also observed that using zero phase shift technique there was no significant decrease in the amplitude of IV/V peak. But the significant reduction in the amplitude was observed when standard phase shift was used at all intensity levels.

Authors have reported that the shifting of energy towards lower frequencies is not due to the reduction in the intensity, if it is because of that the wave would have become broadened. Hence they reported to be because of the progressive loss of high frequency component instead of reduction in the intensity.

Katbamna; Metz; Bennett and Dokler (1996), evaluated 16 infants to study the effect of montage on spectrum of ABR. Obtained response revealed the spectrum of ipsi lateral and noncephalic recordings are strongest irrespective stimulus intensity and rate. Spectrum energy of the infant was dominated by low frequency energy 200 Hz. Increase in intensity and rate enhances the amount of energy below 200 Hz.

Spivak and Malinoff (1990) analysed the effect of amplitude spectra of Auditory Brainstem Responses (ABR) on 40 young adults and 40 older adults to determine age related differences in ABR spectral composition. A spectral analysis was carried out on each person's ABR. The results showed a significant difference that the ABR obtained from older adults had greater amount of low frequency spectral energy composition with respect to young adults. This could be probably due to the low frequency background noise found in the ABR responses. In order to produce a clearer waveform a modification in the standard recording parameters while recording in older adults could be considered.

Spivak 1993 examined the spectral composition of ABR recorded from 20 full term neonates without any risk factor or hearing loss and compared them with the spectral composition of 10 normal hearing adults. The results indicated that the low frequency information were concentrated below 150 Hz in both the groups though there was a slightly greater percentage of low frequency information for neonates. Using a low high pass filter can preserve more of low frequency information that will enhance the presence of V peak in neonates at lower intensities. Hence band pass filter from 30-3000 Hz was recommended for neonate recordings.

CHAPTER III

METHOD

The current study aimed to find the effect of Intensity, repetition rate and stimulus type on spectrum of auditory brain stem response. To achieve the goal of the study 24 normal hearing participants were recruited.

Participants

- Twenty adult's participants with pure tone audiometric result indicating normal hearing sensitivity (PTA within 15dBnHL) were included in the study.
- Age ranges of the participants were 18-40 years.
- All the participants in the study had 'A' tympanogram with Ipsi and Contra lateral acoustic reflex present.
- Bilateral Transient Otoacoustic emissions (TOAEs) were present in all the participants indicating normal outer hair cell function.
- None of the participants had any history or presence of neurological, otological or any other associated problem.

Instrumentation

The following instruments were used for the present study.

- A calibrated two channel invents piano audiometer was used to obtain Pure tone threshold.
- Calibrated GSI TYMPSTAR (Garson – Stadler Incorporation, USA) clinical middle ear analyzer was used for tympanometry and reflexometrey.

- Transient evoked Otoacoustic emission was recorded and analyzed using ILO 292 DPEcho port system (Otodynamics ino, UK).
- Auditory Brain Stem Response was recorded using Intelligent Hearing System (IHS smart EP windows USB version 4.20) with AgCI electrodes and electrically shielded insert earphones.

Test environment

The entire test was carried out in an air conditioned, acoustically and electrically shielded room where the noise levels was within the permissible limits (ANSI S3.1; 1991).

Procedure

The following procedure used for subject selection.

- Using modified version of Hughson and Westlake procedure (Carhart & Jerger, 1959) behavioural air conduction and bone conduction threshold were obtained at octave frequency between 250Hz to 8000Hz to ensure the normal hearing sensitivity.
- Immittance audiometry was carried out by varying the pressure from +200 dapa to -400 dapa for probe tone frequency of 226 Hz, Ipsilateral and contralateral acoustic reflex thresholds were measured for 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz pure tones.
- Transient- evoked Otoacoustic emissions were obtained for 226 nonlinear click stimuli and SNR of + 6 dB in three consecutive frequencies were accepted as a response with reproducibility greater than 75% (Jessica,Sinnet and Dougls 2013).

Procedure to record Auditory Brain Stem Response

The subjects who satisfied the inclusion criteria were included for the study. Participants were seated on a reclining chair in a comfortable position and instructed to relax. The skin surface of right and left ear mastoid and vertex (Cz) were cleaned using skin preparation gel to achieve absolute electrode impedance ≤5 kΩ and inter electrode impedance ≤2 kΩ. Gold plated disc shaped electrodes were placed with conducting gel and adhesive tape for firm attachment. The recording of ABR was carried out using the protocol described in Table1. Stimulus was delivering using calibrated electrically shielded insert ear phone individually for right and left ear.

Table 3.1*: Stimulus and acquisition parameter used for recording of ABR*

Stimulus parameter	
Stimulus	Tone burst (500 Hz & 4000 Hz), Click
Duration	2-0-2 (Tone burst) 100µs(Click)
Polarity	Rarefaction
Repetition rate	30.1 and 70.0/sec (only for click stimulus)
Intensity	80 and 40 dB nHL
No of sweeps	2000
Transducer	ER-3A insert earphone

Acquisition parameter	
Band pass filters	30 Hz-3000 Hz
Analysis time	15 ms (500Hz) 10 ms (click & 4000Hz)
Gain	100000
Artifact rejection	31%
No of channels	1
Montage	Vertical , Cz – Mi (vertex and Ipsi lateral mastoid) Ground: Mc (contra lateral mastoid)
Notch	Off
Electrode impedance	Inter electrode impedance ≤2 kΩ Absolute electrode impedance ≤5 kΩ
No of recording	2 at each stimulus level and Repetition rate.

Response analysis

Click and tone burst evoked ABR was analysed both subjectively and objectively. In subjective analysis wave V was marked based on visual inspection. Later, to evaluate the spectral composition of evoked response, digital filtering and Fast Fourier transformation (FFT) analysis was carried out.

CHAPTER IV

RESULTS

The current study was carried out on 24 individuals and was aimed to find the effect of intensity, repetition rate and stimulus type on spectrum of auditory brain stem response.

Amplitude across frequency for each individual ABR was obtained. This was obtained for different types of stimulus, repetition rate and also for intensity level. The data was then tabulated and analysed using Statistical Package for the Social Sciences (SPSS, version 17.0).

Descriptive analysis was performed to obtain mean and standard deviation value for each of the following condition:

- Effect of intensity
- ✓ 40 dBnHL and 80 dBnHL
- Effect of repetition rate (RR)
- ✓ 30.1/sec and 70.0/sec(only for click stimulus)
- Effect of type of stimulus
- ✓ Click and tone bursts

Shapiro-Wilk's test for normality was administered to decide upon the use of parametric / non-parametric statistical procedures. Results revealed non-normal distribution of the data .Therefore non-parametric statistical analyses procedures were used. Wilcoxon sign rank test was performed to compare the data obtained between two repetition rates and also between intensity levels. As most of the data in the current study are not normally distributed Friedman test was done to see the significant main effect of type of stimulus on ABR spectrum followed by Wilcoxon Two related sample test for pairwise comparison.

Effect of intensity and rate on click and tone burst evoked ABR

Descriptive analysis was done for the spectral amplitude obtained across frequencies of ABR obtained at different repetition rates and intensities for different types of stimulus. The mean and standard deviation obtained for ABR spectrum amplitude at different intensities and rate for click stimulus is shown in figure 4.1.

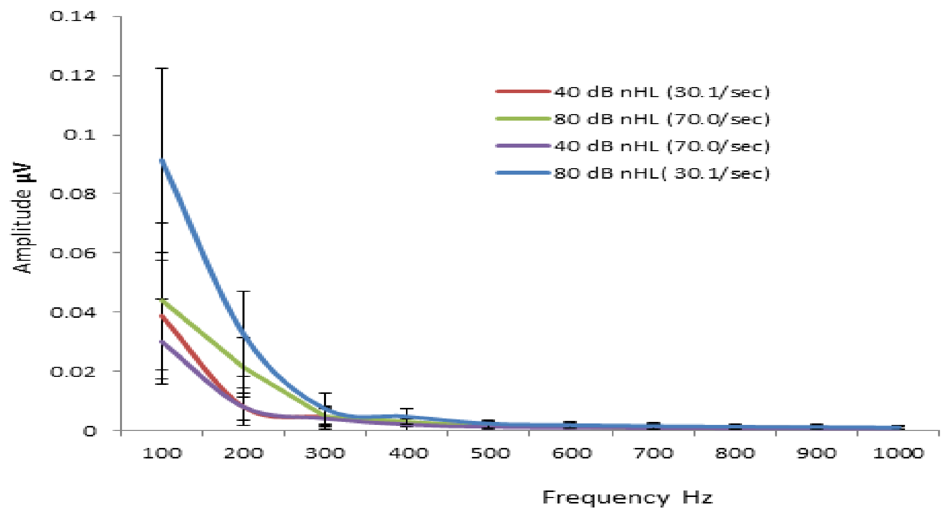

Fig.4.1.**Mean and Standard Deviation of ABR spectral amplitude for click obtained at two rates and two intensities**

It can be seen from the figure 4.1 that spectral amplitudes reduced with the increase in frequency at all repetition rates and intensities. Spectral energy seemed to have reduced drastically after 500 Hz. It can also be seen that maximum spectral energy is present for low repetition rate compare to high repetition rate. Also spectral energy is more for the ABR elicited by higher intensity clicks. However, since it is difficult to visualize the spectral energy at higher frequencies, a histogram was obtained for the same for better visualization. The figure 4.2 shows the mean spectral energy and standard deviation at high frequencies for different repetition rate and intensities elicited ABR waveforms.

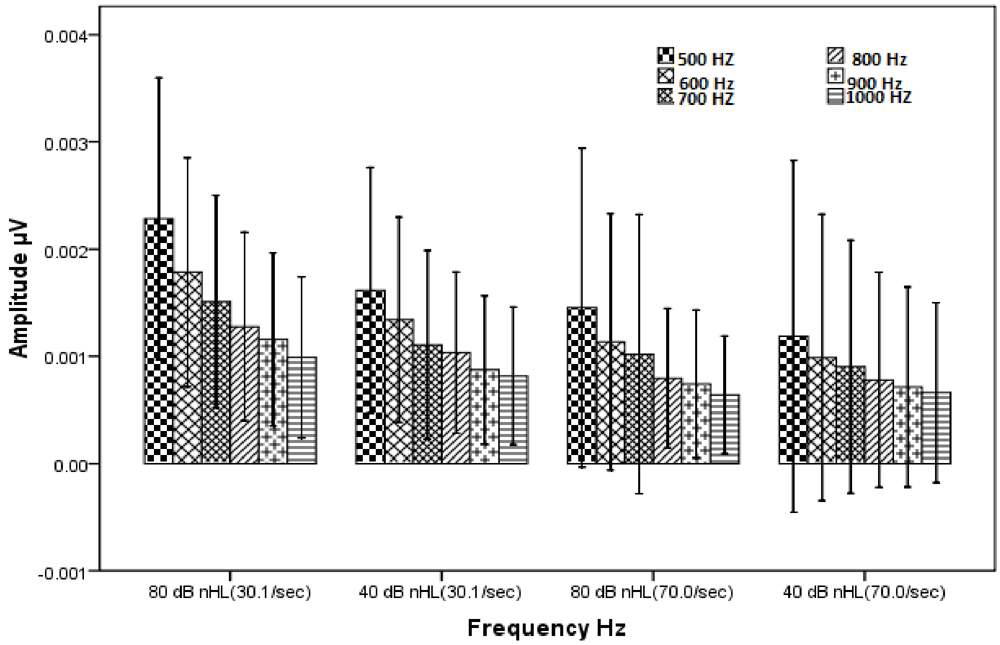

Fig.4.2. **Mean and SD of spectral amplitude of ABR obtained at higher frequencies component for click at two intensities and two rates.**

Figure 4.2 shows similar findings as that is seen in figure 4.1. Spectral amplitude reduced with a decrease in intensity and also with an increase in repetition rate. To see the significant effect of intensity and repetition rate on amplitude of the spectra, Wilcoxson signed ranked test was administered. The results indicated that as the intensity reduced spectral amplitude reduced significantly at 30.1 repetition rate but not at 70.1 repetition rate. Also as the repetition rate increased spectral amplitude reduced significantly at each intensity. The details are given in Table 4.1.

Table 4.1.*Z value along with significance level obtained of ABR spectrum 0f click obtained at two rates and two intensities.*

Stimulus condition	Frequency	Z- value	Significant level
Click at 80dBnHL between 30.1/sec and 70.0/sec rate	100Hz	-5.421	0.000
	200Hz	-4.302	0.000
	300Hz	-3.570	0.000
	400Hz	-3.940	0.000
	500Hz	-4.290	0.000
	600Hz	-4.250	0.000
	700Hz	-4.072	0.000
	800Hz	-3.702	0.000
	900Hz	-3.740	0.000
	1000Hz	-3.015	0.003
Click at 40dBnHL between 30.1/sec and 70.0/sec rate	100Hz	-2.440	0.15
	200Hz	-0.580	0.564
	300Hz	-5.501	1.33
	400Hz	-2.840	0.005
	500Hz	-2.790	0.005
	600Hz	-2.931	0.003
	700Hz	-1.822	0.68
	800Hz	-2.380	0.17
	900Hz	-2.445	0.15
	1000Hz	-1.930	0.054
Click at 30.1 rate between two intensities	100Hz	-5.300	0.000
	200Hz	-5.553	0.000
	300Hz	-3.690	0.000
	400Hz	-4.893	0.000
	500Hz	-3.861	0.000
	600Hz	-3.020	0.003
	700Hz	-3.160	0.002
	800Hz	2.171	0.30
	900Hz	2.976	0.003
	1000Hz	1.845	0.065
Click at 70.1 rate between two intensities.	100Hz	-2.689	0.07
	200Hz	-5.326	0.00
	300Hz	-1.251	0.211
	400Hz	-2.488	0.013
	500Hz	2.256	0.24
	600Hz	1.817	0.069
	700Hz	1.575	0.115
	800Hz	1.499	0.136
	900Hz	1.658	0.097
	1000Hz	0.890	0.373

Similar to click evoked ABR, spectral energy across frequencies for 500 Hz tone burst evoked ABR was obtained .The mean and SD were calculated using descriptive analysis. The details can be seen in figure 4. 3.

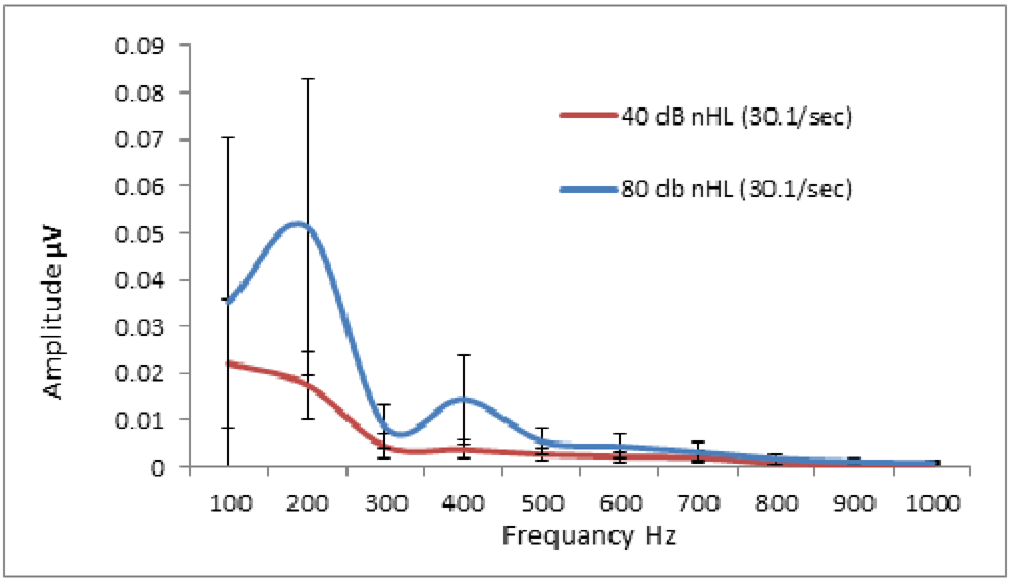

***Fig.4.3*. Mean and 1Standard Deviation of ABR spectrum for 500 Hz obtained at two and two intensities**

Tone burst ABR was obtained only for 30.1 RR. Hence the comparison is made only between the intensities. The results obtained for 500Hz tone burst elicited ABR showed a similar trend as seen for click evoked ABR with slight difference at

80 dBnHL. It is evident that 80 dBnHL elicited ABR had maximum energy at around 200 Hz and had a second peak at around 400 Hz. But spectral energy continued to reduce with increase in frequency for 40 dBnHL elicited ABR. As spectral energy at higher frequencies cannot be visualized clearly, a histogram was plotted for the same as seen in Fig 4.4.

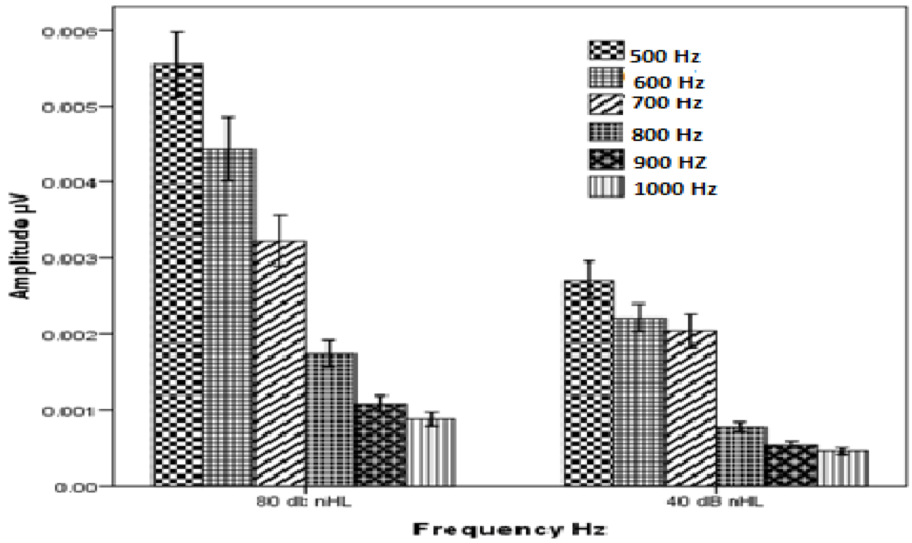

Fig.4.4. **Mean and SD of spectral amplitude of ABR obtained at higher frequencies component for 500 Hz tone burst at two intensities.**

From Figure 4.4 it can be observed that as the frequency increased spectral energy reduced and that spectral energy is less for 40 dBnHL. To see whether this variation in amplitude across frequency between the two intensities differ significantly or not Wilcoxson signed rank test was administered. The result can be seen in Table 4.2.

Table 4.2. ***Z value along with significance level obtained for ABR spectrum of 500 Hz tone burst obtained at 30.1 /sec rate between the intensities.***

Frequency	Z- value	Significant level
100Hz	-2.080	0.038
200Hz	-4.460	0.000
300Hz	-3.862	0.000
400Hz	-4.950	0.000
500Hz	-4.821	0.000
600Hz	-3.560	0.02
700Hz	-3.144	0.000
800Hz	-5.034	0.000
900Hz	-4.065	0.000

1000Hz	-4.092	0.000

Similarly mean and SD for spectral energy for 4000 Hz tone burst elicited ABR across frequencies was calculated. It can be seen in figure 4.5

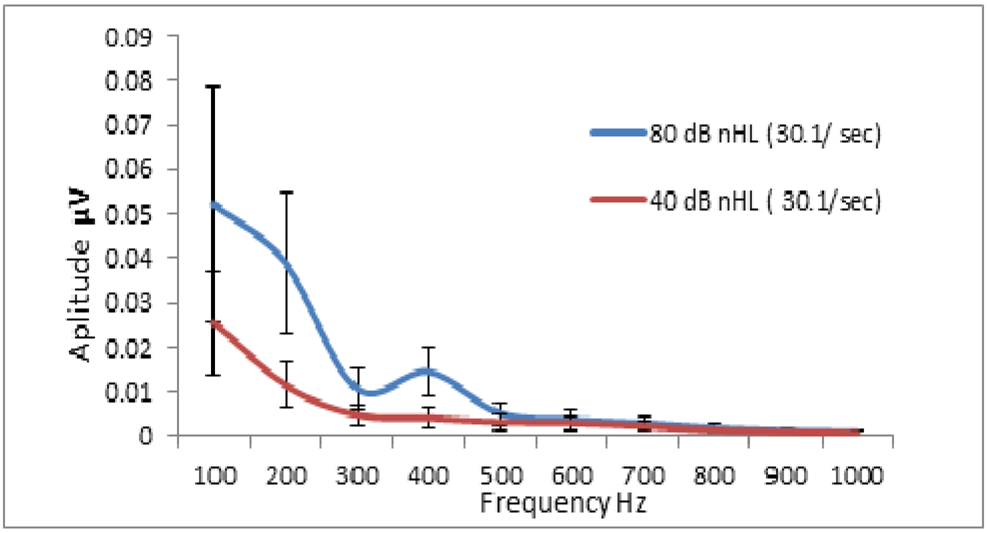

***Fig.4.5*. .Mean and Standard Deviation of ABR spectrum for 4000 Hz tone burst obtained at two intensities at 30.1 repetition rate**

The results obtained for 4000 Hz tone burst elicited ABR showed a similar trend as seen for click evoked ABR with slight variation at 80 dBnHL. It is evident that 80 dBnHL elicited ABR had maximum energy at lower frequencies and also had another peak at around 400 Hz. But, spectral energy continues to reduce with increase in frequency for 40 dBnHL elicited ABR. As spectral energy at higher frequencies cannot be visualized clearly, a histogram was plotted for the same as seen in figure 4.6.

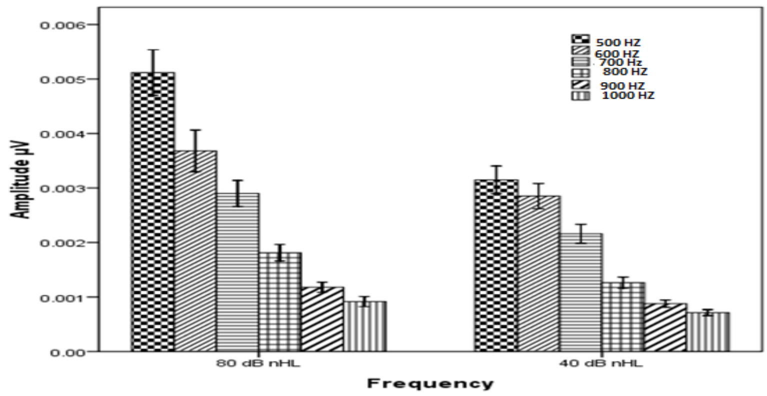

Fig.4.6. **Mean and SD of spectral amplitude of ABR obtained at higher frequencies component for 4000Hz tone burst at two intensities.**

In Figure 4.6 it can be observed that as the frequency increased spectral energy reduced and also spectral energy is less for 40 dBnHL. To see whether this variation in amplitude across frequency between the two intensities differ significantly or not Wilcoxson signed rank test was administered. The result can be seen in Table 4.3.

Table 4.3. ***Z value along with significance level obtained for ABR spectrum of 4000 Hz tone burst obtained at 30.1 /sec rate between intensities .***

Frequency	Z- value	Significant level
100Hz	4.970	0.000
200Hz	5.230	0.000
300Hz	4.903	0.000
400Hz	5.243	0.000
500Hz	3.822	0.000
600Hz	1.440	0.151
700Hz	2.075	0.38
800Hz	3.013	0.003
900Hz	2.260	0.24

1000Hz	1.690	0.92

- Effect of type of stimulus on spectral energy of ABR.

To obtain mean and SD of spectral energy across frequencies, descriptive analysis was done for the ABR obtained using three different types of stimulus at 80 dBnHL. The details can be seen in figure 4.7.

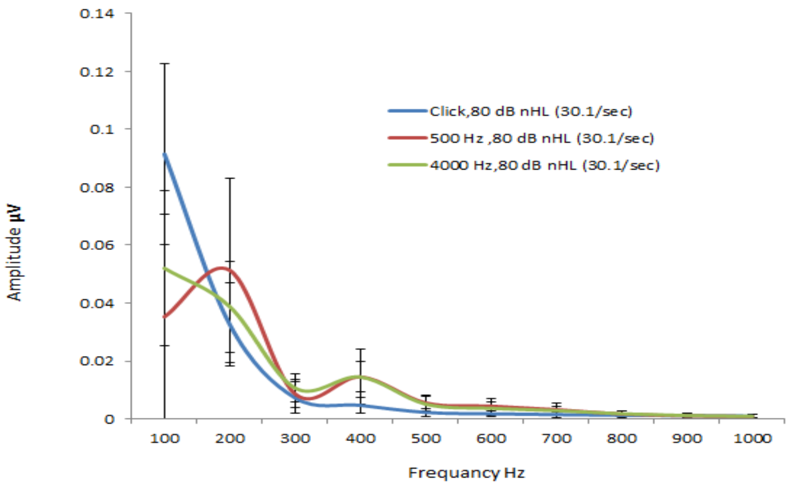

Fig.4.7**. .Mean and Standard Deviation of ABR spectrum of 80dBnHL click, 500Hz and 4000 Hz at 30.1/sec.**

It can be seen in figure 4.7 that clicks evoked ABR had maximum energy at around 100 Hz compared to ABR spectral energy elicited by two tone burst at 80 dBnHL. 500 Hz tone burst elicited ABR had maximum spectral energy at around 200 Hz. The spectral energy obtained at around 400 Hz was more than the neighbouring frequencies elicited click by 500 Hz and 4000Hz tone bust stimuli, and was more than the click evoked ABR energy. As the spectral energy at high frequencies for all the three stimuli elicited ABR is not clearly visible, a histogram was obtained. Spectral energy at higher frequencies can be seen in figure 4.8.

500 Hz
600 Hz
700 Hz
800 Hz
900 Hz
1000 Hz

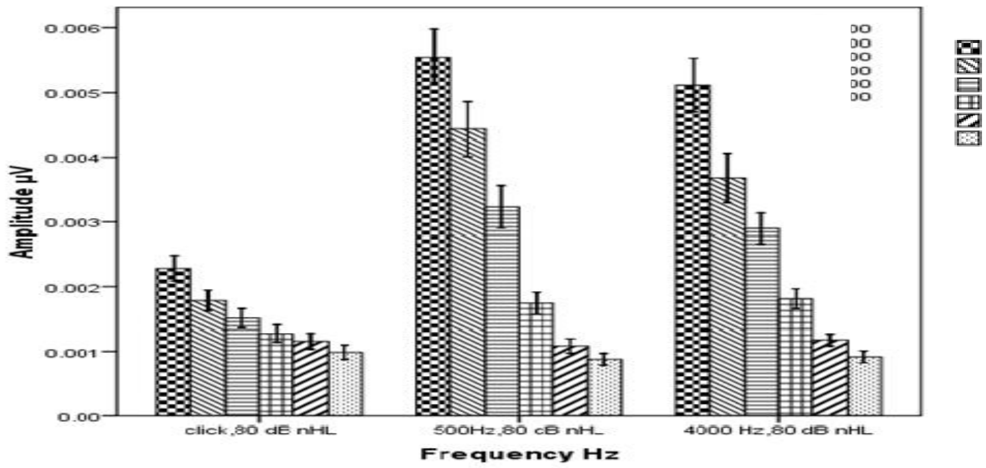

***Fig.4.8*. Mean and SD of spectral amplitude of ABR obtained at higher frequencies component of 80dBnHL click, 500 Hz and 4000Hz elicited ABR at 30.1/sec rate.**

Figure 4.8 indicates that the spectral energy at high frequency region is more for 500 Hz and 4000 Hz tone burst elicited ABR, compared to click evoked ABR at 80 dBnHL. 500 Hz tone burst elicited ABR had the maximum spectral energy at high frequencies. To check whether there is any significant main effect of type of stimulus on spectral energy of ABR Friedman test was done. The result indicated a significant main effect of type of stimulus. The details are given in Table 4.4. And also to see whether this variation in amplitude between stimuli reaches the significant level or not. Wilcoxson signed rank test was administered. The result can be seen in Table 4.5.

Table 4.4. ***Chi –square value along with degree of freedom and significance level obtained for ABR spectrum across type of stimulus at 30.1 /sec rate and 80dBnHL.***

Frequency	Chi-square	Df	Significance level
100Hz	46.160	2	0.000
200Hz	4.263	2	0.200
300Hz	5.421	2	0.070
400Hz	45.684	2	0.000
500Hz	27.253	2	0.000
600Hz	29.280	2	0.000
700Hz	25.316	2	0.000
800Hz	7.000	2	0.30
900Hz	o.980	2	0.613
1000Hz	0.870	2	0.650

Table4.5. ***[Z]-value along with significance level obtained for ABR spectrum for 3 different combination of stimulus (click,500Hzand 4000Hz) at 30.1 /sec rate and 80dBnHL***.

Frequency	**Click and 500Hz**		**Click and 4000Hz**		**500 and 4000Hz**	
	Z- value	**Significant level**	**Z- value**	**Significant level**	**Z- value**	**Significant level**
100Hz	-4.675	0.000	-4.420	0.000	-3.771	0.000
200Hz	-2.400	0.16	-1.508	0.31	-1.951	0.51
300Hz	-0.712	0.480	-2.183	0.30	-2.030	0.043
400Hz	-5.140	0.000	-5.112	0.000	-0.703	0.482
500Hz	-4.560	0.000	-4.700	0.000	-0.660	0.509
600Hz	1.352	0.000	-4.316	0.000	-1.073	0.283
700Hz	1.352	1.80	-4.090	0.000	-0.341	0.733
800Hz	1.730	0.84	-1.962	0.050	-0.200	0.844
900Hz	4.520	0.000	-0.102	0.920	-0.530	0.600
1000Hz	1.230	0.220	-0.540	0.592	1.060	0.952

It can be seen in the above table 4.5 that spectral energy at around 400 to 700 Hz for the TB evoked ABR was significantly higher than the click evoked ABR. Click evoked ABR had a significantly higher spectral energy at low frequencies compared to TB ABR. However spectral amplitude between two TB elicited ABR did not differ significantly at any frequencies.

To obtain mean and SD of spectral energy across frequency, descriptive analysis was done for the ABR obtained using three different types of stimulus at 40 dBnHL. The details can be seen in figure 4.9.

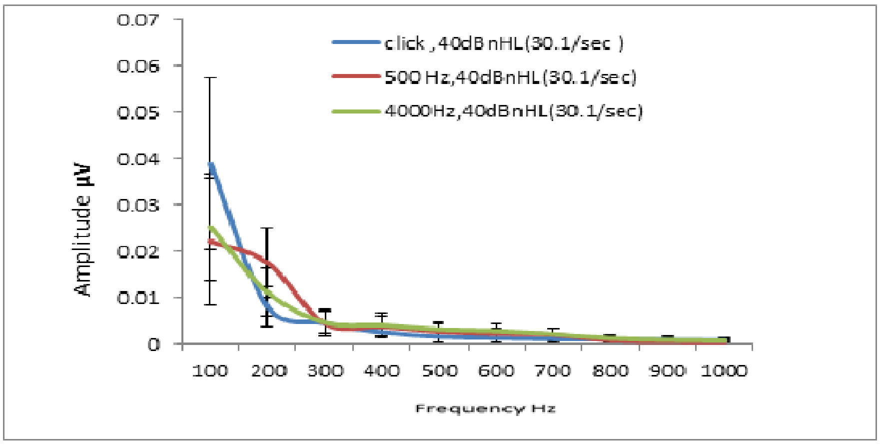

***Fig.4.9* .Mean and Standard Deviation of ABR spectrum for click, 500Hz and 4000 Hz obtained at 30.1/sec. and at 40 dBnHL.**

It can be seen in figure 4.9 that clicks evoked ABR had maximum energy at around 100 Hz compared to ABR spectral energy elicited by two tone bursts at 40 dBnHL. However at around 200 Hz spectral energy was more for TB evoked ABR compared to click evoked ABR. As the spectral energy at high frequencies for all the three stimuli elicited ABR is not clearly distinguishable, a histogram was obtained. Spectral energy at higher frequencies can be seen in figure 4.10.

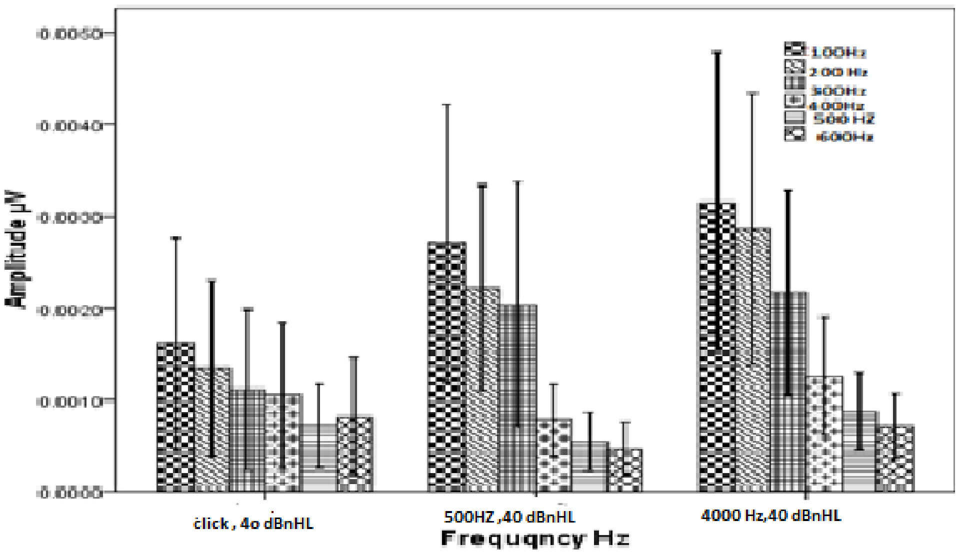

***Fig.4.10*. Mean and SD of spectral amplitude of ABR obtained at higher frequencies component for click, 500 Hz and 4000Hz at intensity of 40 dBnHL for 30.1/sec rate.**

Above figure indicates that the spectral energy at high frequency region is more for 500 Hz and 4000 Hz tone burst elicited ABR, compared to click evoked ABR at 40 dBnHL. 4000 Hz tone burst elicited ABR had the maximum spectral energy at high frequencies. To check whether there is any significant main effect of type of stimulus on spectral energy of ABR Friedman test was done. The result indicated a significant main effect of type of stimulus. The details are given in Table 4.6. And also to see whether this variation in amplitude between types of the stimulus reaches the significant level or not across frequency at 40 dBnHL .Wilcoxson signed rank test was administered. The result can be seen in Table 4.7

Table 4.6. ***Chi –square value along with degree of freedom and significance level obtained for ABR spectrum across type of stimulus at 30.1 /sec rate and 40dBnHL.***

Frequency	Chi-square	df	Significance level
100Hz	6.973	2	0.031
200Hz	28.760	2	0.000
300Hz	2.0753	2	0.252
400Hz	8.400	2	0.015
500Hz	20.162	2	0.000
600Hz	26.193	2	0.000
700Hz	17.434	2	0.000
800Hz	12.340	2	0.002
900Hz	10.060	2	0.007
1000Hz	9.650	2	0.008

Table4.7. ***Z value along with significance level obtained for ABR spectrum between types of stimulus combination at 30.1 /sec rate and 80dBnHL.***

Frequency	**Click and 500Hz**		**Click and 4000Hz**		**500 and 4000Hz**	
	Z- value	**Significant level**	**Z- value**	**Significant level**	**Z- value**	**Significant level**
100Hz	-3.462	0.001	-3.071	0.002	-1.360	0.175
200Hz	-4.715	0.000	-2.870	0.004	-3.270	0.001
300Hz	-0.291	0.771	-0.40	0.969	- 0.990	0.322
400Hz	-2.624	0.009	-3.150	0.002	-0.392	0.700
500Hz	-3.185	0.001	-4.450	0.000	-1.509	0.131
600Hz	-3.450	0.001	-3.872	0.000	-2.332	0.020
700Hz	-3.245	0.001	-1.870	0.000	-0.740	0.460
800Hz	-1.430	1.530	-1.870	0.016	-3.520	0.000
900Hz	-2.503	0.012	-0.890	0.375	-3.572	0.000
1000Hz	-2.830	0.05	-0.806	0.420	-3.060	0.002

It can be seen in above table that spectral energy of ABR obtained using two TB did not differ significantly at most of the frequencies. However spectral energy for click evoked ABR at low frequencies were significantly higher compare to TB evoked ABR. Whereas at high frequencies TB evoked ABR spectral energy was significantly higher than click evoked ABR except at few frequencies.

CHAPTER V

DISCUSSION

The present study was carried out on 24 normal hearing individuals to study the effect of intensity, repetition rate and stimulus type on the spectrum of auditory brain stem response. The results obtained in the study are discussed below.

- **Effect of intensity on spectrum of ABR**

Results of this study indicated that changing stimulus parameters resulted in changes in ABR wave form and significantly affected the ABR spectrum. Changes occurring in the time domain corresponded to change occur in frequency domain also. The amplitude of spectral components was found to be directly related to stimulus intensity. The results in this study showed that, there is a corresponding decrease in the amplitude of all spectral components with the reducing in stimulus intensity. Peak at the lower frequency region continuously present even at lower stimulus intensity. In additional spectral energy reduced drastically after 500 Hz for both higher and lower intensities.

The results of the current study are in congruence with the existing literature. Suzuki et al., (2009), Kevanishvili and Aphonchenko (1979) and Malinoff and spiva (1990) found that spectrum of the ABR components decreases as intensity decreases and peak at low frequency energy appears consistently irrespective of changes in stimulus parameter.

Result of the present study shows there is a decrease in spectral energy even at higher intensity as increase in frequency. It was also observed from a histogram result there is a very minimal energy observed at higher frequencies region .This findings contradict the results obtained by Susuki et al.(1990) they observed three dominant peaks (A:50-150Hz, B: 500-600Hz & C:1000-1100 Hz) across low to higher frequencies at higher intensity level . The difference in results at higher frequency region possibly due to Difference in the units of conversion while performing FFT to mean averaged waveform also influence of subject and measurement parameters.

Reduction in spectral energy with reduced intensity can be attributed to the number of neuron activated during the stimulation. It is well established that with the increase in intensity number of neurons gets activated is more. Increase number of active neurons increases the compound action potential, thus increasing the spectral amplitude with the increase in intensity and vice versa.

- **Effect of stimulation rate.**

Results from the current study reveal that as stimulation rate increased there is a corresponding decrease in the spectral amplitude. It can also be seen that maximum spectral energy is present for low repetition rate compared to high repetition rate. Overall rate effect was significant at lower frequency region. And this effect observed to be reducing after 500 Hz with the increase in click rate current study findings supports the findings by Malinoff and Spiva (1990), they compared the compare the spectral energy of ABR obtained with higher RR and lower RR result shows there is a decreases in higher frequency energy with increasing RR .

However this could be to current study findings, they found that lower frequency energy increased with increase in RR. This could have been attributed to the fact that, as the repetition rate increase, stress on auditory neurons also increases. This resulted in lack of synchronized firing as some neurons start firing even during relative refractory period. This would results in broadening of ABR peak and reduction in amplitude. Thus this might have resulted in reduction in spectral peaks at certain frequencies.

- **Effect of stimulus on ABR spectrum**

In the present findings across stimulus (Click, 500 Hz & 4000 Hz) a significant difference in spectral amplitude was obtained. Difference in the spectrum magnitude was greater at an intensity of 80 dBnHL compare to 40 dBnHL. These results were agreed with previous investigation by Suzuki et al., (2009) , they compared the spectral response of 500Hz to 4000 Hz evoked ABR result showed that 500Hz had larger spectral amplitude when compare to 1 kHz & 2 kHz. They also observed that 1 kHz and 2 kHz had almost similar spectral amplitude compared to 4kHz. Tone burst ABR Overall they found that there is a significant difference among the type of stimulus used and difference in spectral energy was greater at higher intensity (80 dBnHL) compare to lower intensity (40 dBnHL) .

Increased spectral energy for 500 Hz tone burst elicited ABR could be due to the increased no of neuron got activated. It is well know that travelling wave for 500 Hz cover larger area of basilar membrane compare to higher frequencies. This would result in stimulating more no of neuron, this resulting in increased compound action potential.

CHAPTER VI

SUMMARY AND CONCLUSION

Auditory brain stem response is a widely used objective method of assessing the functioning of the auditory system up to lower brain stem. It is an early evokes potential response. Latency of response peak ranges up to 8msec in adults. ABR response is highly influence by stimulus, acquisition and subject related factors. Over all influence of this factor results in reduction of amplitude, prolong latency of the peaks or absence of earlier peaks, Poor wave morphology can also be observed in time domain. But there is limited information about Influence of all these stimulus related parameter on spectral domain .thus this study was taken up with the purpose of to study the

- Study the effect of intensity on spectrum of auditory brain stem response.
- Study the effect of stimulus type on spectrum of auditory brain stem response.
- Study the effect of repetitions rate on spectrum of auditory brain stem response.

To study the above mentioned objectives 24 adult participants (18-40 years) with normal hearing sensitive were taken. ABR recorded for participants by varying stimulus parameters (intensity, rate, & stimulus) individually from both the ears. Obtained response is averaged separately for each condition, obtained mean amplitude data and then tabulated and analysed statistically using SPSS software. Descriptive analysis was performed to obtain mean and standard deviation value for each condition with respect to change in rate, intensity and stimulus type. Since data was not distributed normally non- parametric statistical analysis was carried out.

Wilcoxon sign rank test was done to compare between two related samples and also Friedman test was carried out across the type of stimulus condition to see main effect or significance.

Analysed data revealed following results.

Effect of intensity and rate on click and tone burst stimulus

Results revealed decrease in spectral amplitude with increase in frequency at all rate and intensities .It was also observed that maximum spectral energy was present at lower rate and higher intensity. Similar trend of result found for click

500 Hz and 4000 Hz tone burst ABR. Spectrum Wherein slight variation for 4000 Hz, 500 Hz tone burst ABR spectrum was observed it had maximum energy at lower frequency and had another peak around 400 Hz.

Click evoked ABR had maximum spectral energy at lower frequency region when compared to tone burst. At higher frequency region more energy was observed tone burst evoked ABR compare to click stimulus at 80 dBnHL. Similar trend was observed for all three stimuli at 40 dBnHL and results were statistically significant.

Conclusion of the study

From the above results it can be concluded that spectrum of the ABR is sensitive to changes in the stimulus parameters. It is also observed that there is a decrease in spectral amplitude with increase in frequency at all rate and intensities. At higher intensity click response are dominated at lower frequencies and at lower intensity 500 Hz and 4000Hz tone burst has more spectral energy at higher frequency region . These findings suggest spectral analysis can be used as another way of interpreting ABR results similar to time based analysis also it suggest that appropriate filter setting should be used to record ABR.

Implication of the study

- ✓ The result of the study led to better understand of ABR response especially in spectral domain.
- ✓ Spectral analysis helped us to understand the effect of intensity, repetition rate and stimulus type on spectral characteristic of ABR.
- ✓ Result of the study showed greater spectral energy at certain frequency region with respect to change in intensity, rate and stimulus type used. Knowledge about this aspects in useful to select the appropriate band pass filter for better recording and interpreting of ABR result. Time domain based response can be cross checked with spectral responses for confirmation and interpreting results.

REFERENCES

Abdala, C., & Folsom, R. C. (1995). Frequency contribution to the click-evoked auditory brain-stem response in human adults and infants. *The Journal of the Acoustical Society of America*, *97*(4), 2394-2404.

Carhart, R., & Jerger, J. (1959). Preferred method for clinical determination of pure-tone thresholds. *Journal of Speech & Hearing Disorders*.

Fowler, C. G., & Noffsinger, D. (1983). Effects of stimulus repetition rate and frequency on the auditory brainstem response in normal, cochlear-impaired, and VIII nerve/brainstem-impaired subjects. *Journal of Speech, Language, and Hearing Research*, *26*(4), 560-567.

Frank, T., & Williams, D. L. (1993). Ambient noise levels in audiometric test rooms used for clinical audiometry. *Ear and hearing*, *14*(6), 414-422.

Hall III, J. W. (1986). Auditory brain stem response spectral content in comatose head-injured patients. *Ear and hearing*, *7*(6), 383-389.

Hood, L. J. (1998). *Clinical applications of the auditory brainstem response*. Singular.

Hyde, M. L., Stephens, S. D. G., & Thornton, A. R. D. (1976). Stimulus repetition rate and the early brainstem responses. *British Journal of Audiology*, *10*(2), 41-46.

Katbamna, B., Metz, D. A., Bennett, S. L., & Dokler, P. A. (1996). Effects of electrode montage on the spectral composition of the infant auditory brainstem response. *JOURNAL-AMERICAN ACADEMY OF AUDIOLOGY*, *7*, 269-273.

Kevanishvili, Z., & Aphonchenko, V. T. (1979). Frequency Composition of Brain-stem Auditory Evoked Potentials: A Comment On: Terkildsen, Osterhammel & Huis In't Veld. *Scandinavian audiology*, *8*(1), 51-55.

Malinoff, R. L., & Spivak, L. G. (1990). Effect of stimulus parameters on auditory brainstem response spectral analysis. *Audiology*, *29*(1), 21-27.

Paludetti, G., Maurizi, M., & Ottaviani, F. (1983). Effects of stimulus repetition rate on the auditory brain stem responses (ABR). *Otology & Neurotology*, *4*(3), 226-234.

Spivak, L. G. (1993). Spectral composition of infant auditory brainstem responses: implications for filtering. *Audiology*, *32*(3), 185-194.

Stockard, J. E., Stockard, J. J., Westmoreland, B. F., & Corfits, J. L. (1979). Brainstem auditory-evoked responses: normal variation as a function of stimulus and subject characteristics. *Archives of Neurology*, *36*(13), 823-831.

Suzuki, T., Sakabe, N., & Miyashita, Y. (1982). Power spectral analysis of auditory brain stem responses to pure tone stimuli. *Scandinavian audiology*, *11*(1), 25-30.

Tyler, R. S., & Wood, E. J. (1980). A comparison of manual methods for measuring hearing levels. *Audiology*, *19*(4), 316-329.

Wilson, W. J., & Aghdasi, F. (2001). The importance of pre-analysis windowing on auditory brainstem response fast Fourier transform analysis. *Scandinavian audiology*, *30*(1),