Normative of Tone Burst ABR for Site of Lesion Testing

Register No. 10DNA001

Independent Project as a fulfillment of the Post Graduation Diploma in Neuro Audiology, Submitted to University of Mysore, Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI

MYSORE 570 006

JUNE 2011

Dedicated

To

Parents & Ratul

CERTIFICATE

This is to certify that this independent project entitled **"Normative of Tone-Burst ABR for Site of Lesion Testing"** is a bonafide work in part fulfillment of degree of Post Graduate Diploma in Neuroaudiology of the student registration no: 10DNA001. This has been carried under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore

June, 2011

Savithri. S.R.

Dr.S.R.Savithri

Director

All India Institute of Speech and Hearing

Manasagangothri, Mysore, 570 006.

CERTIFICATE

This is to certify that this independent project entitled **"Normative of Tone-Burst ABR for Site of Lesion Testing"** has been prepared under my supervision and guidance. It is also certified that this independent project has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore

June 2011

Dr. Sandeep M

Lecturer in Audiology,

All India Institute of Speech & Hearing,

Manasagangothri, Mysore, 570 006.

DECLARATION

This independent project entitled **'Normative of Tone-Burst ABR for Site of Lesion Testing'** is the result of my own study and has not been submitted earlier at any university for any other diploma or degree.

Mysore **Register No. 10DNA001**

June, 2011

Acknowledgements

Behind every successful project there stand a myriad of people whose help and contribution make it a success. I hereby, extend heartfelt thanks to all those, who, directly or indirectly, helped me sail through the tough times and encouraged me in their own ways to undertake and complete this Independent Project.

It would be extremely unfair to start the note of thanks without mentioning my guide Dr. Sandeep Maruthy, whose timely guidance not only helped me to accomplish my Independent Project in a better way but also in my personal life it was elderly brother blessings which helped me to overcome all the hurdles, was coming in my way.

My sincere gratitude towards Late Dr. Vijayalaxmi Basavraj Ex. Director to permitting me to conduct the study. Mam your absence will always be felt in our hearts. May your soul RIP.

My sincere thanks to Dr. S.R. Savithri, Director, to allowing me to carry out this study.

I would also like to thank Prof. P. Manjula, HOD of audiology, All India Institute of Speech and Hearing, for her endless support during the course of my education.

Dear Papa, without your constant support, I would never been able to come this long. You gave me the values of life which enlightened my soul. Without you, I cannot think of any of my dream come true. Thanking you will not be sufficient at all. I love you always.

Dear Maa, I have learned to love from you. I remember from time to time, how you have supported me and gave me courage to move further.

Dear Dii, from my childhood to present you supported me in each and every stage, you always shown confidence on me that I can do anything. Your guidance, help and support makes me to do things in a better way. You are an angel in my life, Love you lots.

Hey Purvi (my lovely niece), I missed you throughout these days. I will miss you afterwards, as I will not be able to stay with you. But your smile will refresh in my heart.

Sujeet Sir, Thank you very much for reminding me always about my job, it helped me a lot. Thanks for helping me throughout.

Animesh Sir, Thank you very much for your support and guidance.

Ganpathy Sir, Thank you very much sir, from your busy schedule you've always got time for us to finish off our work and always asking "do you want more subjects?"

Dhanya Mam, Thanks a lot mam for helping us during our RP and in completion of this project.

Rals, without you it was not at all possible to finish off any thing till now and here I cannot express what you mean to me, you always being an elder bro taking care of mine, and inspiring me to do the things in a better way.

He is being always Very Important Person (VIP) to me, from our childhood, he has shown me the right path for the life, how to face the "LIFE" I learnt from you.

In every story there are mostly three stars but my story is bit different because another star is also shining in my life VJ, who always shown faith on me and was more confident about me that I can complete the tasks in easy way.

S.K. always keeps on motivating me, supporting me and was behind me to finish the things quickly thanks a billion for being with me.

Thanks to all my seniors who always guide me for my studies and about this project; especially Akshay, Navdeep, Akash, Mukesh and Nike.

Mini, The way you helped me in AIISH no- one had ever. I will be thankful to you. Have a great life ahead.

Ghazala, Saresh , Sony , Ameen and, Shamin we had nice time together going to miss you all, all the best for your future.

At last it is not complete until I thank all my classmates, Ist MSc friends, and beloved juniors who have taken out their valuable time to contribute as subjects of the study. Thank you all.

Table of Contents

Chapter 1

INTRODUCTION

The Auditory evoked potentials (AEPs) are the electrical potentials of the nervous system to the auditory stimuli (Stapells, Picton, Perez-Abalo, Read & Smith, 1985). AEPs have assumed an essential role in the clinical practice of Audiology and Auditory Brainstem Response (ABR) in particular is most widely used. This is due to its ability for objective threshold estimation without active participation of the subjects. It is also used for detection, localization and monitoring of auditory and neurological deficits, involving lower auditory brainstem (Mahajan, 2007).

The auditory brain stem response (ABR) was originally introduced by Jewett, Romano, and Williston (1970) and subsequently used in detection of cerebellopontine angle tumors as described by Selters and Brackmann (1977).

The auditory brainstem response (ABR) is a useful electrophysiological technique for assessing hearing sensitivity in patients whose age or handicaps rule out the use of conventional behavioral audiometric techniques (Jacobson & Hyde, 1985; Hood & Berlin, 1986; Kileny & Magathan, 1987; Hall, 1992; Weber, 1994; Oates & Stapells, 1998; Gorga, 1999).

Utilizing ABR to its maximum potential is primarily an exercise in identifying response patterns and knowing which value falls within the range of normal variation and which values have diagnostic significance for peripheral or brainstem dysfunctions (Thronton, 1975; Stockard, & Sharbrough, 1977; cited in Gerling & Fintzo-Hieber, 1983).

ABR is a well established method for acoustic tumor screening to discern cochlear from retro cochlear lesions. The use of ABR testing in the screening of retro cochlear pathology is widespread. Multiple studies have shown that its sensitivity exceeds 90%, thus establishing it as the most sensitive audiologic test for the detection of space occupying lesions in the low brainstem. Currently, the standard criteria for tumor diagnosis using ABR are delayed wave V and prolonged inter peak intervals.

Bauch, Olson, and Pool (1996) reported that a combination of inter aural wave V latency differences and I-V inter peak latency (IPL) data improved the sensitivity of standard ABR protocol to detect tumors of less than 1.0 cm. Bauch, Olson, and Pool (1996) found 92% sensitivity to all tumors with 88% specificity.

1.1 Justification for the Study

Click evoked ABR gives information about integrity auditory nerve fibers upto lower brainstem. However, its utility is limited in the presence of high frequency sensori-neural hearing loss as click-ABR is primarily contributed by high frequency nerve fibers (2000 Hz to 4000 Hz) which also is not frequency specific. In such instances, tone-burst evoked ABR may play a role to detect the presence and site of the space occupying lesion in the lower frequency regions of auditory nerve.

To use tone-burst ABRs for site of lesion testing, it is necessary to have separate normative of absolute latency, inter-wave intervals, and amplitude ratio. Considering that travelling wave excitation is different for clicks and frequency specific tone bursts, these measures are expected to be different. Hence, the present study was taken up.

1.2 Objective of the Study

The sole objective of the study was to develop normative of tone-burst evoked ABR, to be useful in the site of lesion testing.

Chapter 2

REVIEW OF LITERATURE

Auditory Brainstem Response (ABR) is one of the most useful clinical procedures for the examination of the auditory sensitivity and integrity of the auditory system. ABR as a measure has been used successfully in site of lesion testing (Selters & Brackmann, 1977; Chandrasekhar, Brackmann & Devgan, 1995; Selesnick & Jackler, 1992; Welling, Glasscock, Woods & Jackson, 1990; Bauch, Olsen & Harner, 1983; Barrs, Blackmann & Olsen & House, 1985; Jerger, Oliver, Chmiel & Rivera, 1986). It has been reported that the sensitivity of ABR in detection of tumors is 95% or greater (Josey, Glasscock & Jackson, 1988). However the sensitivity of ABR in detection of acoustic neuroma depends on its size and location. In one of the earliest report of advocating ABR as a useful tool for detecting acoustic tumors, Selters and Brackmann (1977) stated that ABR can be used successfully in detecting acoustic tumors. But in these studies, the size of the tumors was fairly large. Numerous studies have led to the assumption that ABR cannot be used for tumor diagnosis because of lack of adequate sensitivity to small acoustic tumors despite their excellent sensitivity to medium and large tumors (Levine, Antonelli, Le & Haines, 1991; Chandrasekhar, Brackmann & Devgan, 1995; Eggermont, Don & Brackmann 1980).

Wilson, Hodgson, Gustafson, Hogue and Mills (1992) found that sensitivity of ABR in tumor detection was 96% in patients with extracanalicular tumors. However the sensitivity dropped to 67% with intracanalicular tumors. Gordon and Cohen (1995) reviewed data of 105 patients who proved to have acoustic neuromas confirmed by ABR and enhanced MRI scans. ABR testing was positive for all tumors larger than 2cm in 18 patients. However as total tumor size decreased ABR sensitivity also decreased dropping to 69% for tumors less than 1cm in total diameter, where as these tumors were detected by high resolution MRI (gadolinium enhance MRI).

Contrary to these findings, Elkashlan, Eisenmann and Kileny (2000) reported that ABR was abnormal in 92% of 25 patients with tumor size less than 1cm. They concluded that with strict adherence to optimal technique and evaluation criteria, the conventional ABR is a viable option for acoustic neuroma screening. However, in 58 patients studied by Schmidt, Satallof, Newmann, Spiegel and Myers (2001) the ABR sensitivity rate was around 100% in detecting acoustic tumors sized > 1.5cm but the sensitivity gradually decreased to 58% for the acoustic tumor with size < lcm. They concluded that ABR testing cannot be relied on for the detection of small tumors and should not be used as a criterion determining whether MRI should be performed when an acoustic tumor is suspected clinically. Similar findings have been reported by other investigators.

The standard criteria for tumor diagnosis using ABR are delayed wave V and prolonged inter-peak latencies. The notion of using a rapid stimulus repetition rate as a diagnostic feature was proposed in the late 1970s (Don, Allen, & Starr, 1977; Stockard, Stockard & Sharbrough, 1978), given the rationale that the minimal neural recovery time imposed by this technique significantly delays wave V latency when the auditory nerve is compromised. Burkard (1994) made the same observation when presenting very rapid stimulus rates. Nonetheless, the use of rapid stimulus rate was never adopted as standard diagnostic protocol in neuro-diagnostic assessment.

The ABR test is reported to have as high as 98% sensitivity in identifying large tumors of the auditory nerve and brainstem (Barrs, Brackmann, Olson, & House, 1985; Zappia, O'Connor, Wiet, & Dinces, 1997). Wilson (1992) retrospectively reviewed 40 patients with acoustic neuromas and found the overall sensitivity of ABR in detecting tumors in this group to be 85%. When tumors were divided by size, the sensitivity was 96% for extracanalicular tumors measuring greater than 1cm but was only 67% for intracanalicular tumors measuring 1 cm or less.

Chandrashekhar, Brackmann and Devgan (1995) reported on 197 patients who had both ABR and MRI. The overall sensitivity of ABR in their study was 92.3% when using an ILD for wave V of more than 0.2 ms, and was 81.6 % using waveform morphology, for smaller tumors measuring 1cm or less the ABR ILD sensitivity was 83.1% and waveform morphology was abnormal in only 76.5%. Gordon and Cohen (1995) reported an overall sensitivity of 87.6%. They found that the ABR sensitivity decreased with tumor size; with 100% sensitivity in tumors 2cm or larger but only 69% in tumor less than 1 cm. Auditory brain stem electric responses evoked with suprathreshold tone bursts. Jewett V latencies were considerably prolonged in patients with retrocochlear or central pathology.

Bauch, Olson, and Pool (1996) reported that a combination of interaural wave V latency differences and I-V inter-peak latency (IPL) data improved the sensitivity of standard ABR protocol to detect tumors of less than 1.0 cm. Bauch, Olson, and Pool (1996) found 92% sensitivity to all tumors with 88% specificity. However, greatest sensitivity to small (<1.0 cm) tumors was reported by the same authors with absolute wave V latency data, which indicated a positive finding in 82% of cases.

There are very few reports of ABR sensitivity of better than 80% to 1.0 cm size tumor or smaller. Perhaps more common is a reported by Schmidt, Sataloff, Newman, Spiegel and Mysers (2001), who found in a dozen patients with tumors of less than 1.0 cm where 58% of cases were detected by ABR. The methods in each of the previous studies were conservative in defining I-V IPLs and wave V absolute latencies as abnormal when they varied by 0.2 ms from the norms.

The Interaural Latency Difference (ILD) is an auditory brainstem response measurement that has gained wide clinical acceptance and popularity. This ABR measures determines the latency of wave V or wave III for each ear for interaural latency comparison (Moller & Moller, 1983; Selters & Brackmann, 1977).

The ILD has been most useful as an index for the determination of acoustic tumors; with a number of studies reporting sensitivity exceeding 90% (Bauch, Rose, & Harner, 1982; Clemis & McGee, 1979; Selters & Brackmann, 1977, 1979). Because the ILD does not require the presence of a wave I, this measure has become popular for site of lesion determination (Musiek, Josey & Glasscock, 1986).

There is general agreement among investigators that stimulus rates of less than 10 to 20/s have little effect on the latencies or amplitudes of ABR waves I, III, or V (Don, Allen & Starr, 1977; Yagi & Kaga, 1979; Beattie, 1988). Repetition rates greater than about 20/s tend to increase latencies (Fowler & Noffsinger, 1983; Campbell & Abbas, 1987) and reduce amplitudes, particularly for the earlier waves (waves I and III); these increased rates have less effect on the amplitude of wave V and little effect on the threshold of wave V (Sininger & Don, 1989; Beattie & Torre, 1997; Oates & Stapells, 1998).

2.1 Type of stimuli

The Stimuli used for tone-ABR can be tone burst in quiet or tone burst in noise. The tone bursts are operationally defined as gated sinusoids having duration of less than one second (Gorga, Karninski, Beauchaine & Jesteadt 1988). Acoustics of these stimuli have concentration of energy at the nominal frequency of the tone and side bands of higher or lower frequency (Gorga & Thornton, 1989). This spread of energy to frequency other than nominal frequency of the tone is termed as "spectral splatter" (Durant, 1983). The spectrum of these stimuli is defined by two parameters, duration of the stimuli and rise time. In the spectra first few milliseconds of the stimulus which is defined as critical duration is important in eliciting onset response. This critical duration is approximately 2ms for 2000 Hz and 4ms for 500 Hz tones (Kodera, Marsh, Suzuki & Suzuki, 1983). Davis,, Hirsh and Popelka (1994) recommended the use of 2-0-2 cycles, which approximates critical duration, be used for recording tone-ABR.

Generally windowing functions, either linear or nonlinear are used to reduce the spectral splatter of the signal. Linear windowing function results in a 27 dB difference between the main lobe and the first side lobe and a further decrease of 12dB/ octave in the side lobe amplitude as one move away from the first side lobe. Blackman window, a non-linear windowing of higher order trigonometric function reduces the energy splatter in the stimulus (Harris, 1978 cited in Stapells, Picton and Duriex- Smith, 1994). There is a tendency that center lobe widens as side lobe decrease for some gating functions. For a Blackman gated tonal stimuli the first side lobe is -58 dB relative to the energy in the main lobe with slightly wider main lobe than that achieved in linear windows. Side lobe amplitude continues to decrease at a rate of 18 dB/ octave after this first side lobe.

2.2 Frequency of the Stimulus

The ABR to tonal stimuli is generally recorded in the frequency range of 500 Hz to 4000 Hz. This can also be recorded to higher frequency stimuli above 8000 Hz (Gorga, Kaminski, Beauchanie & Bergman, 1993). The latency of wave V decreases with increase in frequency. The wave morphology of wave V recorded to decreases with increase in frequency. The wave morphology of wave V recorded to the 500 Hz tones is broader in comparison to the response recorded to the 2000 Hz and 4000 Hz tonal stimuli. Though it has been reported that there is no change in amplitude of the response across frequency (Gorga, Kaminski, Beauchaine & Jesteadt, 1988; Stapells & Oates, 1997), the thresholds estimated at low frequency is slightly higher than that observed at high frequency (Stapells, 2000).

2.3 Intensity of the Stimulus

As the stimulus intensity decreases, wave latency increase and amplitude decreases. Theses latency and amplitude changes occur for all stimulus frequencies (Gorga, Kaminski, Beauchanie & Jesteadt, 1988). When presented in quiet, the latency and amplitude changes are greater for response to low frequency tones (Suzuki, Hirai & Horiuchi, 1977). When masked by notched noise, these latency and amplitude changes are same across stimulus frequency (Stapells & Oates, 1997). Many studies carried out on infants, children and adults have shown that tone-ABR can be recorded at 10- 30 dB n HL for tone bursts of 500 to 4000 Hz presented in quiet or in noise (Stapells, Picton & Duriex- Smith, 1994). ABR to brief tones does not appear to distinguish between severe and profound hearing loss. The limitation of tone-ABR for evaluation of profound hearing loss is due to the 25 to 35dB peak to peak SPL calibration level for 0 dBnHL, and the output limitations of ear phones.

It can be observed from Figure 2.1 and 2.2, that spectrum of the modulated signal is less than that seen in tone burst stimulus (Lins, Picton & Picton, 1995). This shows that modulated tone is more frequency specific than tone burst. However, tone burst gated stimuli gives frequency specific information at octave frequencies (Gorga, 1999). For this it can be said that tone burst gated stimuli is as frequency specific as modulated signal for threshold estimation. Purdy and Abbas (2002) reported that tone-ABR using linear window and Blackman window has same frequency specificity and underestimates hearing loss only in steep sloping hearing loss.

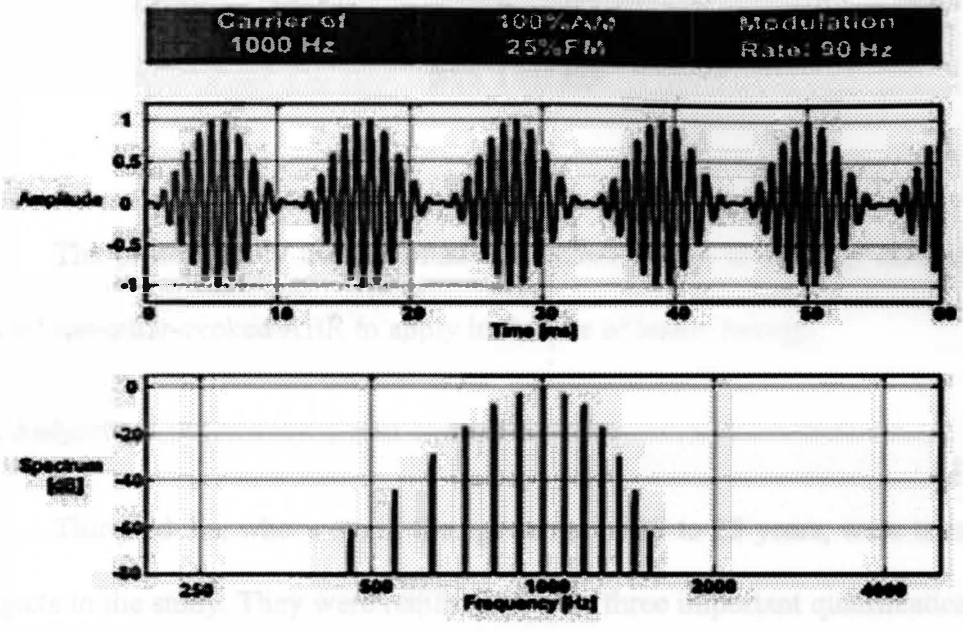

Figure 2.1: Stimulus waveform and frequency spectrum of 1000 Hz tone burst.

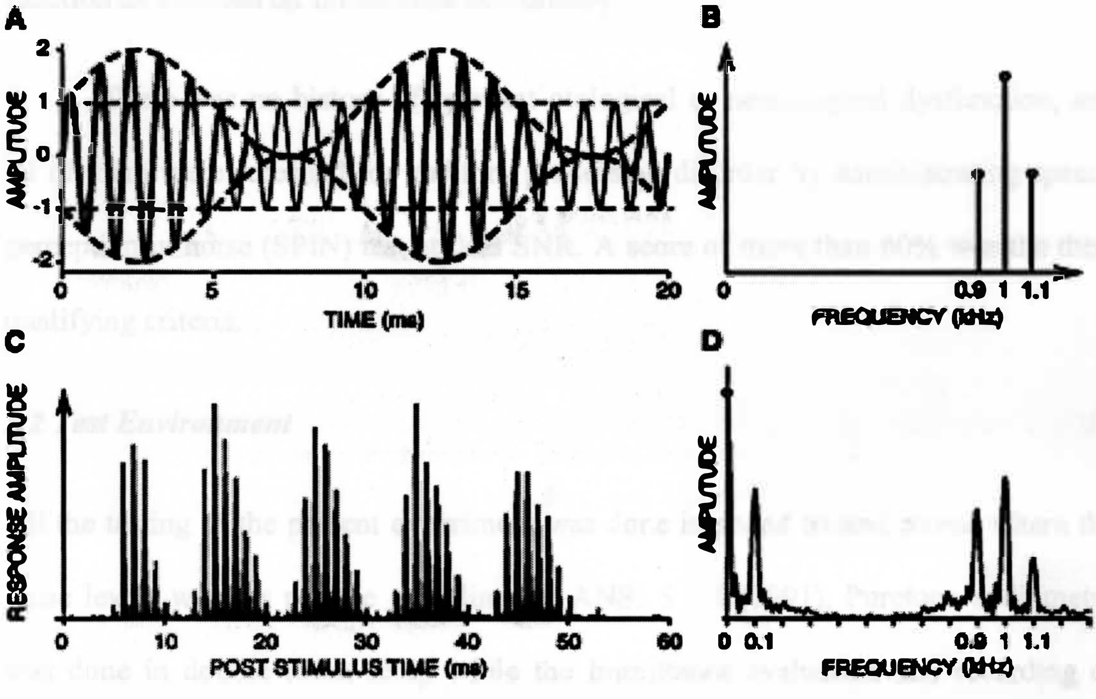

Figure 2.2: A superimposed waveforms of an unmodulated 1,000-Hz tone (thin line) and the same tone sinusoidally amplitude modulated (AM) (thick line) at 100% with a modulation frequency of 100 Hz.

Chapter 3

METHOD

The present study used normative research design to develop normative data of the tone-burst-evoked ABR to apply in the site of lesion testing.

3.1 Subjects

Thirty adults, who were in the age range of 18 to 25 years, were taken as the subjects in the study. They were required to have three important qualifications. First, they had to have normal hearing (hearing acuity within 15dBHL) at octave frequencies between 250Hz and 8000Hz. Second, they had to have normal middle ear function as assessed on Immittance audiometry.

There was no history of relevant otological or neurological dysfunction, and all of them were screened for auditory processing disorder by administrating speech perception in noise (SPIN) test at 0dB SNR. A score of more than 60% was the third qualifying criteria.

3.2 Test Environment

All the testing of the present experiment was done in sound treated rooms where the noise levels were as per the guidelines in ANSI S 3.1 (1991). Puretone audiometry was done in double room setup while the Immittance evaluation and recording of brainstem responses were carried out in a single room suite. The rooms were also electrically shielded.

3.3 Test Procedure

Test procedure involved 2 steps:

1. Preliminary audiological evaluations
2. Recording of brainstem responses

3.3.1 Preliminary Audiological evaluation

The preliminary evaluations involved Pure-tone audiometry, Speech audiometry, and Immittance evaluation. Pure-tone audiometry was done to ensure normal hearing (hearing acuity within 15dBHL) at octave frequencies between 250Hz and 8000Hz for air conduction and, between 250Hz and 4000Hz for bone conduction. A calibrated diagnostic audiometer (Grason Stadler, Inc. SI-61) with TDH 39 supra aural earphones and Radio ear B-71 BC vibrator as transducers, was used for the testing.

The same audiometer was also used to obtain speech identification scores in quiet, and in the presence of ipsilateral noise. Speech to noise ratio of 0dB was used in order to screen for auditory processing disorder.

The middle ear was evaluated on Immittance testing using a calibrated middle ear analyzer (GSI Tympstar). Tympanogram and acoustic reflexes were obtained. In the acoustic reflexes, both ipsilateral and contralateral reflexes were tested at 500 Hz, 1000 Hz, 2000 Hz and 4 kHz.

3.3.2 Recording of the Brainstem Responses

Auditory brainstem response (ABR) were recorded for the four frequencies using to two repetition rates in a sound treated room where the noise levels were as per the guidelines in ANSI S 3.1 (1991). The clients were seated comfortably in a reclining chair. The skin surface at the vertex (Cz), test ear mastoid (M1/M2), and lower forehead (Fpz) was cleaned with skin abrasive gel, to obtain the absolute electrode impedance of less than 5 kΩ and inter-electrode impedance of less than 2 kΩ. The electrodes were placed with the help of skin conduction paste and secured tightly in their respective places using surgical plaster. Participants were instructed to relax and refrain from extraneous body movements to minimize artifacts. The testing was done monaurally in one of the ears. The ear to be tested within each subject was chosen randomly. The stimulus and acquisition parameters used for recording brainstem responses are given in Table 3.1.

Table 3.1: *Protocol for recording tone-burst auditory brainstem responses*

Parameters	Target Settings
Stimulus Parameters	
Stimulus	Tone bursts of at 500 Hz, 1000 Hz, 2000 Hz and 4 kHz Blackman window (2-0-2)
Duration	Depended on the frequency
Polarity	Rarefaction and condensation
Stimulus Intensity	80 dB nHL
Repetition Rate	11.1Hz & 80.1 Hz
Acquisition Parameters	
Mode	Ipsilateral
Analysis Time	15 ms
Band Pass Filter	30 to 3000Hz
Electrode Montage	Vertical - Fpz, Cz, M1/M2
Sweeps	1500
Transducer	Insert ER-3A
Electrode Impedance	<5 k Ohms
No. of Channels	One
No. of Replications	Two

3.4 Response Analysis

Brainstem responses elicited by the each tone bursts were visually analyzed independently by two experienced audiologists in the area of electrophysiology. Only the replicated waves were considered for the analysis. The marking of the wave in a representative is shown in Figure 3.1. The peak latency, inter-wave interval and the peak amplitude were noted down from each response.

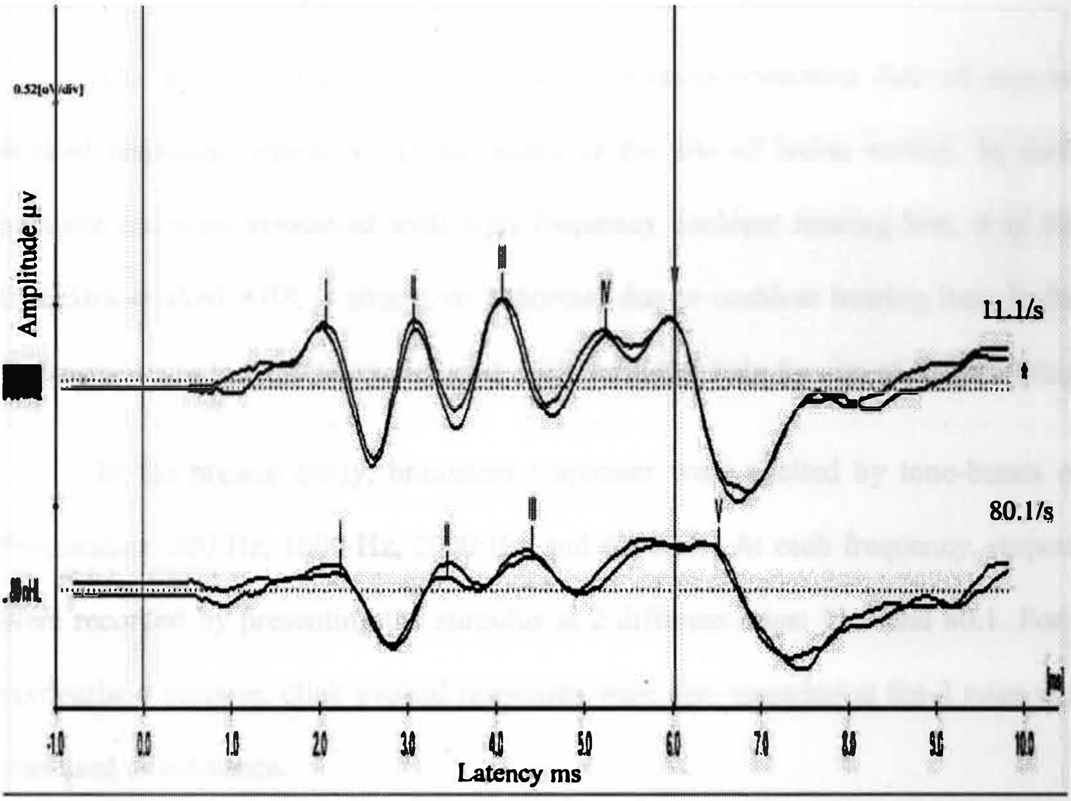

Figure 3.1: Brainstem response evoked by tone burst of 4 kHz, with the peaks marked.

Chapter 4

RESULTS

The aim of the present study was to develop normative data of tone-burst evoked responses which would be useful in the site of lesion testing. In ears of acoustic neuroma associated with high frequency cochlear hearing loss, it is likely that click-evoked ABR is absent, or abnormal due to cochlear hearing loss. In those instances it was thought that tone-burst ABR would be help for site of lesion testing.

In the present study, brainstem responses were elicited by tone-bursts of 4 frequencies: 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. At each frequency, responses were recorded by presenting the stimulus at 2 different rates: 11.1 and 80.1. For the comparison purpose, click evoked responses were also recorded at the 2 rates which was used as reference.

4.1 Percentage of occurrence of Jewett Waves

To consider tone-burst ABR for site of lesion, first of all it was important that the prevalence of wave I, III and V is high. Only then we could have measured absolute latency, inter-wave intervals, and amplitude ratio, which are considered to be sensitive parameters in click-evoked ABR. The prevalence in this study was assessed in terms of percentage. Table 4.1 gives the prevalence (in percentage) of wave I, III and V in the 4 stimulus frequencies at 11.1 and 80.1.

Table 4.1: *Percentage of occurrence of the waves elicited by click and tone bursts at 11.1 and 80.1 rates*

Wave	11.1 Hz					80.1 Hz				
	Clicks	*500Hz*	*1000Hz*	*2000Hz*	*4000Hz*	*Clicks*	*500Hz*	*1000Hz*	*2000Hz*	*4000Hz*
I	80.76	65.38	61.53	96.15	100	65.38	26.92	15.38	65.38	84.61
II	76.92	65.38	19.23	76.92	100	50	30.76	0	23.07	46.15
III	96.15	84.61	65.38	100	100	84.61	57.96	61.53	96.15	84.16
IV	50	88.46	11.53	46.15	88.46	53.84	42.3	0	30.76	26.92
V	100	100	100	100	100	100	96.15	100	100	100

The data in the Table 4.1 can be summarized as follows:

1. Percentage of V peak was maximum (100 %) in all the frequencies and at both the rates (except 500 Hz at 80.1). Percentage of I and III wave was better than II and IV wave.
2. At 11.1. percentage of all the other waves was maximum at 4000 Hz followed by 2000 Hz, clicks, 500 Hz and 1000 Hz.
3. Percentage of all the waves was more at 11.1 than 80.1 rate.

4.2 Results of Absolute Latency of Tone-burst Evoked Brainstem Responses

Results of absolute latency are discussed separately for 11.1 and 80.1 rates.

4.2.1 Results of Absolute Latency of Tone-burst Evoked Brainstem Responses at 11.1

The mean and standard deviation (SD) of absolute latency of waves I, II, III, IV and V, at 11.1 repetition rate are given in Table 4.2. The confidence intervals of the absolute latency for each wave are given in Table 4.3. Fig 4.1 shows the responses recorded from click and tone burst evoked ABR with 11.1/s repetition rate.

Table 4.2: *The mean and standard deviation (SD) of absolute latency of waves I, II, III, IV and V at different stimulus frequencies at 11.1 repetition rate*

Wave	Clicks		500Hz		1000Hz		2000Hz		4000Hz	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
I	1.56	0.14	3.85	0.05	3.14	0.24	2.61	0.13	2.19	0.12
II	2.66	0.15	4.66	0.08	4.34	0.67	3.60	0.14	3.19	0.13
III	3.67	0.14	5.49	0.14	5.00	0.34	4.57	0.21	4.18	0.15
IV	4.77	0.10	6.34	0.19	6.15	0.18	5.62	0.11	5.30	0.17
V	5.46	0.24	7.14	0.27	6.80	0.25	6.33	0.19	6.03	0.16

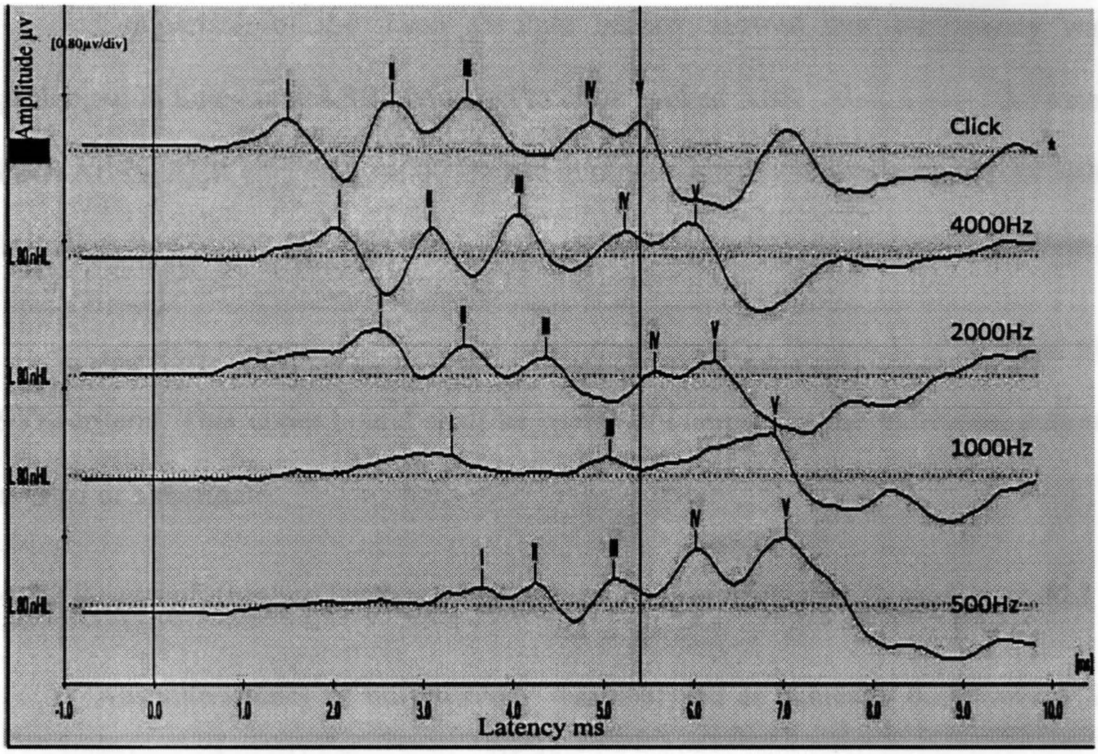

Figure 4.1: shows the responses recorded from click and tone burst evoked ABR with 11.1/s repetition rate.

Table 4.3: *Confidence intervals (CI-lower bound & upper bound) of absolute latency of waves I, II, III, IV and V at different stimulus frequencies at 11.1 repetition rate*

Wave	Confidence Interval	Clicks	500Hz	1000Hz	2000HZ	4000Hz
I	*Lower Bound*	1.43	3.68	3.01	2.50	2.13
	Upper Bound	1.60	4.03	3.26	2.69	2.13
II	*Lower Bound*	2.50	4.46	3.50	3.49	3.11
	Upper Bound	2.71	4.85	5.18	3.67	3.22
III	*Lower Bound*	3.54	5.32	4.83	4.39	4.10
	Upper Bound	3.74	5.68	5.18	4.56	4.23
IV	*Lower Bound*	4.70	6.20	5.70	5.54	5.23
	Upper Bound	4.83	6.60	6.60	5.69	5.37
V	*Lower Bound*	5.39	7.06	6.69	6.24	5.94
	Upper Bound	5.63	7.40	6.90	6.41	6.09

Comparison of the mean absolute latency showed that the latency was prolonged in tone-burst ABR compared to click evoked ABR. Also, among the tone-burst ABRs, ABR elicited by 4000 Hz had minimum latency followed by that of 2000 Hz, 1000 Hz and 500 Hz. This was true for all the 5 waves.

The data of confidence interval of absolute latency (Table 4.3) is obtained for 95% criteria. This upper bound shall be useful in interpreting the individual data as normal or abnormal.

4.2.2 Results of Absolute Latency of Tone-burst Evoked Brainstem Responses at 80.1

Absolute latency of only wave V was analyzed as clinically only wave V is considered due to its high prevalence. The mean and standard deviation (SD) of absolute latency of waves V, at 80.1 repetition rate are given in Table 4.4. The confidence intervals of the absolute latency for wave V are given in Table 4.5

Table 4.4: *The mean and standard deviation (SD) of absolute latency of wave V at different stimulus frequencies at 80.1 repetition rate*

Wave	clicks		500Hz		1000Hz		2000Hz		4000Hz	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
V	5.82	0.14	7.96	0.42	7.48	0.26	6.81	0.23	6.47	0.24

Comparison of the mean absolute latency showed that the latency was prolonged in tone-burst ABR compared to click evoked ABR. Also, among the tone-burst ABRs, ABR elicited by 4000 Hz had minimum latency followed by that of 2000 Hz, 1000 Hz and 500 Hz. With the increase of rate by 69 Hz (between 11.1 & 80.1), there was mean difference of 0.36, 0.82, 0.68, 0.48, and 0.44 for clicks, 500 Hz TB, 1000 Hz TB, 2000 Hz TB and 4000 Hz TB respectively.

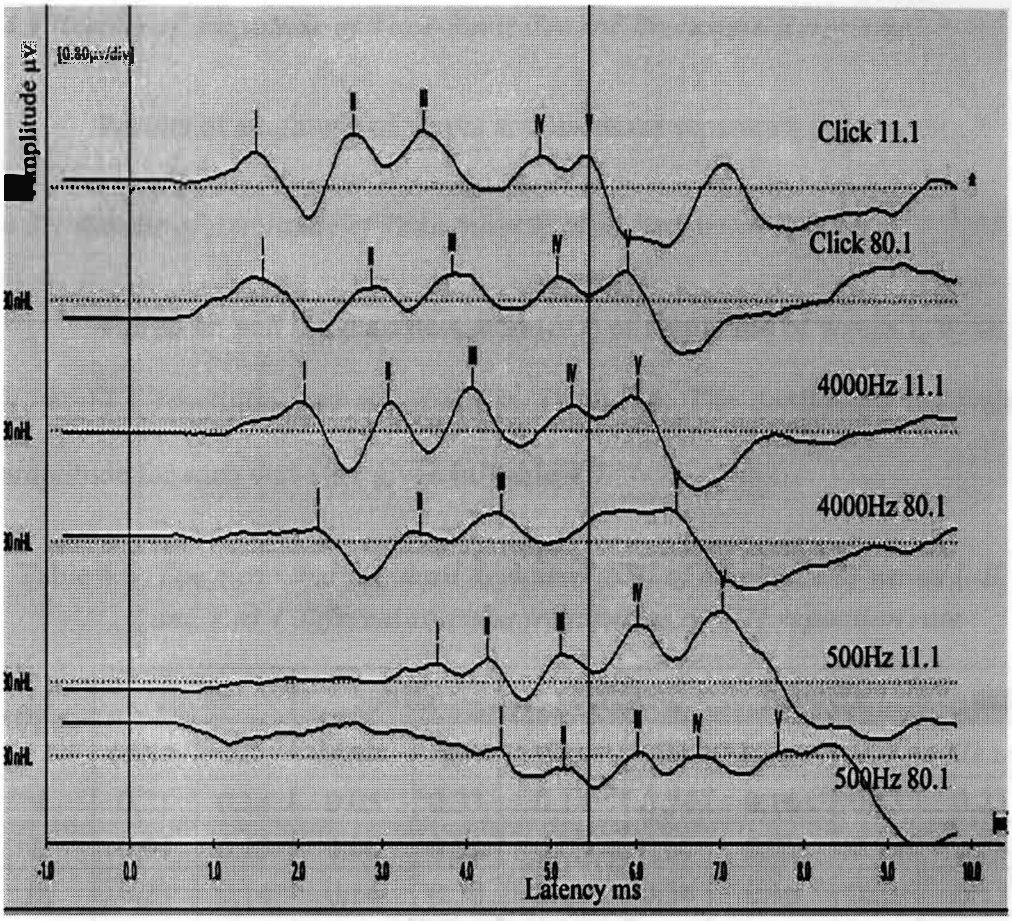

Figure 4.2: shows the click and Tone-burst evoked responses in 11.1 and 80.1 rate.

Table 4.5: *Confidence intervals (CI-lower bound & upper bound) of absolute latency of waves V at different stimulus frequencies at 80.1 repetition rate.*

Wave	Confidence Interval	Clicks	500Hz	1000Hz	2000HZ	4000Hz
V	*Lower Bound*	5.83	7.53	7.37	6.57	5.81
	Upper Bound	5.92	8.34	7.59	6.82	6.63

The data of confidence interval of absolute latency (Table 4.5) is obtained for 95% criteria. This upper bound shall be useful in interpreting the individual data as normal or abnormal.

4.3 Results of Amplitude of Tone-burst Evoked Brainstem Responses

Results of amplitude of waves are discussed separately for 11.1 and 80.1 rates.

4.3.1 Results of Amplitude of Tone-burst Evoked Brainstem Responses at 11.1

The mean and standard deviation (SD) of amplitude of waves I, II, III, IV and V, at 11.1 repetition rate are given in Table 4.6. The confidence intervals of the amplitude for each wave are given in Table 4.7

Table 4.6: *The mean and standard deviation (SD) of amplitude of waves I, II, III, IV and V at 4 different stimulus frequencies at 11.1 repetition rate*

Wave	**clicks**		**500Hz**		**1000Hz**		**2000Hz**		**4000Hz**	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
I	0.21	0.14	0.05	0.33	0.14	0.24	0.16	0.13	0.23	0.12
II	0.09	0.15	0.08	0.38	0.03	0.67	0.07	0.14	0.06	0.13
III	0.23	0.14	0.14	0.30	0.14	0.34	0.16	0.21	0.17	0.15
IV	0.23	0.10	0.19	0.36	0.15	0.18	0.13	0.11	0.16	0.17
V	0.23	0.24	0.27	0.34	0.25	0.25	0.18	0.19	0.19	0.16

Comparison of the mean amplitude showed that the amplitude was more for 4000Hz and 2000Hz and less for 500Hz and 1000Hz, whereas amplitude of click evoked responses similar to that of low frequencies. There was no clear trend in variation of amplitude across the responses evoked by different tone-bursts. This was true for all the 5 waves. For wave II and IV, at 1000 Hz, confidence intervals were not obtained due low prevalence.

Table 4.7: *Confidence intervals (CI-lower bound & upper bound) of amplitude of waves I, II, III, IV and V at different stimulus frequencies at 11.1 repetition rate*

Wave	Confidence Interval	Clicks	500Hz	1000Hz	2000HZ	4000Hz
I	*Lower Bound*	0.17	0.03	0.10	0.14	0.05
	Upper Bound	0.33	0.07	0.18	0.23	0.43
II	*Lower Bound*	0.01	0.06	-	0.02	0.02
	Upper Bound	0.13	0.11	-	0.12	0.09
III	*Lower Bound*	0.18	0.10	0.10	0.08	0.13
	Upper Bound	0.36	0.20	0.17	0.16	0.21
IV	*Lower Bound*	0.12	0.16	-	0.07	0.13
	Upper Bound	0.33	0.25	-	0.19	0.18
V	*Lower Bound*	0.09	0.19	0.21	0.11	0.14
	Upper Bound	0.28	0.32	0.30	0.20	0.26

The data of confidence interval of amplitude (Table 4.7) is obtained for 95% criteria. This lower bound shall be useful in interpreting the individual data as normal or abnormal.

4.3.2 Results of Amplitude of peaks of Tone-burst Evoked Brainstem Responses at 80.1

The mean and standard deviation (SD) of amplitude of wave V, at 80.1 repetition rate are given in Table 4.8. The confidence intervals of the amplitude for wave V are given in Table 4.9

Table 4.8: *The mean and standard deviation (SD) of amplitude of wave V at different stimulus frequencies at 80.1 repetition rate*

Peak	clicks		500Hz		1000Hz		2000Hz		4000Hz	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
V	0.11	0.14	0.12	0.21	0.20	0.26	0.18	0.23	0.14	0.24

Table 4.9: *Confidence intervals (CI-lower bound & upper bound) of amplitude of wave V at different stimulus frequencies at 80.1 repetition rate*

Peak	Confidence Interval	Clicks	500Hz	1000Hz	2000HZ	4000Hz
V	*Lower Bound*	0.12	0.09	0.11	0.07	0.13
	Upper Bound	0.17	0.15	0.30	0.24	0.29

Comparison of the mean amplitude of wave V at 80.1 showed that the there was no clear trend in variation of amplitude across frequencies. The data of confidence interval of absolute latency (Table 4.5) is obtained for 95% criteria. This lower bound shall be useful in interpreting the individual data as normal or abnormal.

4.4 Results of Inter-peak interval of Tone-burst Evoked Brainstem Responses

The mean and standard deviation (SD) of inter-peak interval of I-III, III-V and I-V, at 11.1 repetition rate are given in Table 4.10. The confidence intervals of the inter-peak interval for each wave are given in Table 4.11.

Table 4.10: *The mean and standard deviation (SD) of inter-peak interval of I-III, III-V and I-V at different stimulus frequencies at 11.1 repetition rate*

Peak	Clicks		500Hz		1000Hz		2000Hz		4000Hz	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
I- III	2.09	0.15	1.64	0.12	1.85	0.22	1.96	0.15	1.98	0.10
III-V	1.79	0.52	1.65	0.25	1.70	0.23	1.74	0.13	1.84	0.11
I-V	3.85	0.28	3.37	0.27	3.56	0.19	3.72	0.18	3.83	0.15

Comparison of the mean inter-peak interval showed that the inter-peak interval was lesser for tone-burst ABR compared to click evoked ABR. Also, among the tone-burst ABRs, ABR elicited by 4000 Hz had higher interval for all the inter-peak intervals followed by that of 2000 Hz, 1000 Hz and 500 Hz. This was true for all the 3 inter-peak intervals.

The data of confidence interval of inter-peak interval (Table 4.11) is obtained for 95% criteria. The upper bound shall be useful in interpreting the individual data as normal or abnormal.

Table 4.11: *Confidence intervals (CI-lower bound & upper bound) of inter-peak interval of I-III, III-V and I-V at different stimulus frequencies at 11.1 repetition rate*

Peak	Confidence Interval	Clicks	500Hz	1000Hz	2000HZ	4000Hz
I- III	*Lower Bound*	2.01	1.58	1.72	1.85	1.93
	Upper Bound	2.22	1.7	1.97	1.94	2.03
III-V	*Lower Bound*	1.79	1.61	1.60	1.74	1.80
	Upper Bound	1.95	1.84	1.82	1.91	1.90
I-V	*Lower Bound*	3.84	3.23	3.45	3.61	3.77
	Upper Bound	4.15	3.52	3.66	3.84	3.90

4.5 Results of V-I Amplitude Ratio of Tone-burst Evoked Brainstem Responses.

The mean and standard deviation (SD) of V-I amplitude ratio at 11.1 repetition rate are given in Table 4.12. The confidence intervals of the amplitude for each wave are given in Table 4.13.

Table 4.12: *The mean and standard deviation (SD) of V-I amplitude ratio at different stimulus frequencies at 11.1 repetition rate*

Peak	Clicks		500Hz		1000Hz		2000Hz		4000Hz	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
V-I	1.21	2.04	4.11	2.91	2.20	1.35	1.52	1.22	0.70	3.01

Comparison of the mean amplitude ratio showed that the ratio was least for 4000Hz and maximum for 500 Hz. Ratio successively lesser from 2.20, 1.52 and 1.21 for 1000 Hz, 2000 Hz and clicks respectively.

Table 4.13: *Confidence intervals (CI-lower bound & upper bound) of V-I amplitude ratio at different stimulus frequencies at 11.1 repetition rate*

Peak	Confidence Interval	Clicks	500Hz	1000Hz	2000HZ	4000Hz
V-I	*Lower Bound*	0.25	2.56	1.48	1.03	0.53
	Upper Bound	2.17	5.66	2.93	2.02	1.95

The data of confidence interval of V-I amplitude ratio (Table 4.13) is obtained for 95% criteria. The lower bound shall be useful in interpreting the individual data as normal or abnormal.

Chapter 5

DISCUSSION

The present study was taken up with the assumption that Tone-burst evoked responses may be clinically useful in the site of lesion testing in instances where click evoked brainstem responses are abnormal or absent due to high frequency cochlear hearing loss. The lack of normative of response parameters (inter-wave interval, V-I amplitude ratio etc.) used in the site of lesion testing justified for this study.

Results showed that there was high prevalence of wave I, III and V in responses elicited from all the frequencies used. Hence, it is recordable in most of the individuals and at both the rates (11.1 & 80.1 per second) provided hearing sensitivity is normal. However, these results are true for the stimulus and acquisition parameters used in the present study.

Results of the absolute latency of Jewett waves elicited by tone bursts showed increase in latency with decrease in the centre frequency of the stimulus. This was true for all the waves at 11.1. Hz, and even at 80.1 Hz for V peak. Brainstem responses to tone-bursts of different frequencies represent synchronous activity initiated from successive octave-wide regions across the cochlea. Hence, cochlear travelling wave velocity determines the latency of the tone-burst evoked responses. Because the nerve fibers responsible for low frequencies are connected to the apical part of the cochlea and the travelling reaches apical region later, the synchronous activity in the apical region of the cochlea has a prolonged latency with respect to the stimulus onset. On the other hand, because the excitation always starts from the basal end, the synchronous activity of the nerve fibers responsible for high frequencies will be earlier. Hence, progressively increasing latency in the tone-burst evoked responses ensured that the responses are from successive regions of the cochlea from base to apex. Also, the responses obtained from clicks, which is a broadband stimulus, have its latency closer to the latency obtained from the responses elicited 2 and 4 kHz tone-bursts. Therefore, it can be inferred that the click-evoked responses are primarily from high frequency nerve fibers innervating the basal region of the cochlea.

In the present study it was found that, as the repetition rate increased, there was a shift in the latency of V wave. This shift is attributed to the reduced inter-stimulus interval which affects the refractory period of the nerve. This notion was further supported by the difference in the shift across frequencies. Results showed that shift in latency increased with the decrease in stimulus frequency. This could be because difference in the duration of each sweep of tone burst. In a Blackman's window, each sweep will have 2 cycles of rise time, zero plateau and 2 cycles of fall time. In this pattern of sweep, a 4 kHz tone burst will have total duration of 1 ms while 500 Hz stimulus will be of 8 ms. Hence, at the same rate of stimulation, inter-stimulus interval for low frequency bursts will be less than that for high frequency tone bursts. This means that the refractory period is affected at lower frequency to a greater extent than higher frequency tone bursts, thus leading to larger shift in latency.

Among the amplitude measures taken in the study, absolute amplitude showed that the amplitude of tone-bursts in general were lesser compared to click evoked responses. This is because, clicks elicit responses from a broader area of basilar membrane but tone-bursts evoke responses from a narrow range depending on the frequency of the stimulus. Otherwise, within tone-bursts of different frequencies, there was no trend seen either with 11.1 or with 80.1 stimulus rates.

However, V-I amplitude ratio had a clear trend with higher ratio at 500 Hz progressively decreasing with increase in stimulus frequency. An inspection of the absolute values of wave I and V showed that wave V remained relatively constant across frequencies while wave I was lesser at low frequencies. Because apical region contributes less for early waves (I & II) amplitude of wave I was lesser and in turn leading to higher amplitude ratio.

Results of inter-wave interval also can be justified through the same reason. Inter-wave intervals increased with decrease in stimulus frequency. An inspection of the absolute latencies of wave I and V showed that the shift in latency with decrease in stimulus frequency was lesser compared to wave I. Also, shift in wave I-V was more than that in wave I-III. All these findings support that the wave I is contributed more by higher frequency and wave V is contributed more by low frequencies.

Overall results showed that there were difference in the absolute latency, absolute amplitude, inter-wave interval and amplitude ratios obtained for tone bursts and clicks. Also normative data of the response parameters differed across tone-bursts of different frequencies. Therefore, it is proved that the normative developed for clicks cannot be used for tone burst-evoked responses. Also, there is a need to use the different normative for responses elicited for different frequencies.

The present study has given confidence intervals for each of the response measure. In the absolute latency and inter-wave intervals, the upper bound values are important. Any response which crosses the upper bound value should be abnormal. Similarly, in absolute amplitude and amplitude ratio, the lower bound values are important. Any response which is below the lower bound value should be abnormal.

However, these normatives are applicable only if the responses are recorded with the stimulus and acquisition parameters used in the present study.

Chapter 6

SUMMARY AND CONCLUSIONS

The present study aimed to develop normative for tone-burst ABR to be used for site of lesion testing. In ears of acoustic neuroma associated with high frequency cochlear hearing loss, it is likely that click-evoked ABR is absent, or abnormal due to cochlear hearing loss. In those instances it was thought that tone-burst ABR would be help for site of lesion testing.

Tone-Burst evoked ABRs were recorded from thirty adults, who were in the age range of 18 to 25 years, including both male and female participants. Responses were recorded for tone-bursts of 500Hz, 1000Hz, 2000Hz and 4000Hz centre frequency. At each frequency, responses were recorded with 2 stimulus repetition rates: 11.1 and 80.1.The absolute peak latency, inter-wave intervals, the peak amplitude, and amplitude ratio were noted down from each response.

The data obtained from the participants was then subjected to statistical analysis using SPSS version 10.0. Mean, standard deviation, and 95% confidence intervals of each response measure were determined. Percentage of occurrence of Jewett waves was also determined. The data thus obtained was used to compare between clicks and tone-bursts, and also within different tone-bursts.

Overall results showed that there were difference in the absolute latency, absolute amplitude, inter-wave interval and amplitude ratios obtained for tone bursts and clicks. Also normative data of the response parameters differed across tone-bursts of different frequencies. Therefore, it is proved that the normative developed for clicks cannot be used for tone burst-evoked responses. Also, there is a need to use the different normative for responses elicited for different frequencies.

The present study has given confidence intervals for each of the response measure. In the absolute latency and inter-wave intervals, the upper bound values are important. Any response which crosses the upper bound value should be abnormal. Similarly, in absolute amplitude and amplitude ratio, the lower bound values are important. Any response which is below the lower bound value should be abnormal. However, these normatives are applicable only if the responses are recorded with the stimulus and acquisition parameters used in the present study.

References

American National Standards Institute. (1996). American National Standard Specification for Audiometers. (ANSI S3.6; 1996). New York: ANSI.

American National Standards Institute (1991). Maximum permissible ambient noise levels for audiometric test rooms. (ANSI S3.1; 1991) New York: American National Standards Institute.

Barrs, D.M., Brackmann, D.E., Olson, J.E., & House, W.F. (1985). Changing concepts of acoustic tumor diagnosis. *Archives of Otolaryngology, 111*, 17-21.

Bauch, C.D., Olson, W.O., Pool, A.F. (1996). ABR indices: sensitivity, specificity and tumor size. *American Journal of Audiology, 5*, 97-104.

Bauch, C.D., Rose. D.E., & Harner, S.G. (1980). Brainstem responses to tone pip and click stimuli. *Ear and Hearing*, 181-184.

Beattie R.C. (1988). Interaction of click polarity, stimulus level, and repetition rate on the auditory brainstem response. *Scandivian Audiology, 17,* 99-109.

Burkard, R.F., Don, M., & Eggermont, J.J. (2007). *Auditory Evoked Potentials: Basic Principles and Clinical Application.*

Campbell, K.C. M., & Abbas, P.J. (1987). The effect of stimulus repetition rate on the auditory brainstem response in tumour and nontumour patients. *Journal of Speech & Hearing Research. 30,* 494-502.

Carhart, R., & Jerger, J. (1959). Preferred methods for clinical determination of pure tone thresholds. *Journal of Speech and Hearing Disorder*, *16*, 340-345.

Chandrasekhar, S.S., Brackmann, D.E., & Devgan, K.K. (1995). Utility of auditory brainstem audiometry in diagnosis of acoustic neuromas. *American Journal of Otology*, *16*, 63-67.

Clemis, J & McGee, T. (1979). Brain stem electric response audiometry and the differential diagnosis of acoustic tumors. *Laryngoscope*, *89,* 31-42.

Davis, H., Hirsh, S.K., Turpin, L.L., & Peacock, M.E. (1985). Threshold sensitivity and frequency specificity in auditory brainstem audiometry. *Audiology, 24*, 54-70.

Don, M., Allen, A.R. & Starr, A. (1977). Effect of click rate on the latency of auditory brainstem responses in humans. *Annals of Otology,Rhinology and Layngology, 86,* 186-195.

Durrant, J., & Hyde, R. (1993). Observation on temporal aspects of bone-conduction clicks: Real head measurements. *Journal of American Academy of Audiology, 4*, 213-219.

Kashlan, E.L., Eisenmann, H.K., & Kileny, P.R. (2000). Auditory Brainstem Response in small Acoustic neuromas. *Ear and Hearing, 21,* 257 – 262.

Elberling, C, & Parbo, J. (1987). Reference data for auditory brainstem response in retrocochelear diagnosis. *Scandinavian Audiology, 16*, 49-55.

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 and Hearing Research, 26,* 560-567.

Galambos, R., Hecox, K.E. (1978). Clinical applications of the auditory brainstem response. *Otolaryngology North America, 11,* 709-722.

Gerling, I.J., Finitzo, T. (1983). Auditory brainstem response with high stimulus rates in normal and patient populations. *Annals of Otology, Rhinology and Layngology,, 92,* 119-123.

Gordon, M.L. & Cohen. (1995). Efficacy of auditory brainstem response as a screening test for small acoustic neuromas. *American Journal of Otology, 16,* 136-139.

Gorga, M.P. & Thornton, A.R. (1980). The choice of stimuli for ABR measurements, *Ear and Hearing, 10,* 217-230.

Gorga, M.P., Thorton, A.R. (1989). The choice of stimuli for ABR measurements. *Ear and Hearing, 10*, 217-230.

Gorga M.P., Kamniski, J.R., Beauchaine, K.A. Jesteadt, W. (1998). Auditory Brainstem Response to the tone bursts in normally hearing subjects. *Journal of Speech and Hearing Research, 31*, 87-89.

Gorga M.P. (1999). Predicting auditory sensitivity from the auditory brainstem response measurements. *Seminar on Hearing*, 20, 1, 29-42.

Hall, J.W. (1992). Handbook of auditory evoked responses. Massachusetts : Allyn and Bacon.

Harris, F.J. (1978). *On the use of windows for harmonic analysis with the discrete fourier transform*. Proceedings of the IEEE, 66, 51-83.

Hayes, D., & Jerger, J. (1982). Auditory brainstem response (ABR) to tone-pips: Results in normal and hearing-impaired subjects. *Scandivian Audiology, 11*, 133–142.

Hecox, K., & Galambos, R. (1974). Brainstem auditory evoked responses in human infants and adults. *Archives of Otolaryngology, 99*, 30-33.

Hood, L.J. (1998). Clinical applications of auditory brainstem response. San Diego : Singular publishing group, Inc.

Hood L.J, Berlin, C. (1986). Auditory Evoked Potentials, Austm, Pro-ed. Jacobson, J.T, & Hyde, M.L. (1985). *An introduction to auditory evoked potentials.*

In:Katz J, ed. Handbook of clinical Audiology. 3rd Ed. Baltimore: Williams & Wilkins, 496-533.

Jerger, J., Oliver, T., Stach, B. (1985). *Auditory brainstem response testing strategies*. In: Jacobson, J.,ed. The auditory brainstem response. London : Taylor & Francis, 371-88.

Jewett, D., Romano, M. & Williston, J. (1970). Human auditory evoked potentials: Possible brainstem components detected on the scalp. *Science*, *167,* 1517-1518.

Josey, A.F. (1985). *Auditory brainstem response in site of lesion testing*. In:Katz,J., ed.Handbook of clinical audiology. Baltimore:Williams & Wilkins, 534-548.

Josey, A.F., Jackson, C.G., & Glasscock, M.E. (1988). Preservation of hearing in acoustic tumor surgery: Audiologic indicators. *Annals of Otology, Rhinology and Laryngology, 97,* 626-630.

Josey, A.F., Glasscock, M.E., & Musiek, F.E. (1988). Correlation of auditory brainstem response and medical imaging in patients with Cerebellopontine angle tumors. *Archives of Otolaryngology, 110,* 6-12.

Kileny P. (1981). The frequency specificity of tone-pip evoked auditory brain stem responses. *Ear Hearing* 2, 270-275.

Kileny, P.R, Magathan, M.G. (1987). Predictive value of ABR in infants and children with moderate to profound hearing impairment. *Ear and Hearing, 8,* 217-221.

Kodera, K, Marsh, R.R., Suzuki, M., & Suzuki, J.I. (1983). Portion of tone pips contributing to frequency selective auditory brainstem responses. *Audiology, 22*, 209-218.

Levine, S.C., Antonelli, P.J., & Haines, S.J. (1991). Relative value of diagnostic tests for small acoustic neuromas. *American Journal of Otology, 12,* 341-345.

Lins, O.G., Picton, P.E., & Picton, T.W. (1995). Auditory steady-state response to tones amplitude-modulated at 80-110 Hz. *Journal of the Acoustical Society of America, 97,* 3051-3063.

Mahajan, Y. (2007). *Effect of Cochlear Hearing Loss on Tone Burst Evoked Stacked Auditory Brainstem Response.* Unpublished masters dissertation submitted in part fulfillment of M.Sc (Audiology) to University of Mysore.

Moller, M., & Moller, A. (1983). Brain stem auditory evoked potentials in patients with cerebellopontine angle tumors. *Annals of Otology, Rhinology and Layngology, 92,* 645-650.

Musiek, F, Josey, A., & Glasscock, M. (1986). Auditory brain stem response in patients with acoustic neuroma : Wave presence and absence. *Archieve of Otolaryngology Head Neck Surgery, 112*, 186-189.

McDonald, J.M., & Shimizu, H. (1981). Frequency specificity of the auditory brain stem response. *American Journal of Otolaryngology*, *2,* 36-42.

Narne,V. (2004). *Comparison of Tone ABR & ASSR in prediction of behavioral threshold.* Unpublished masters dissertation submitted in part fulfillment of M.Sc (Audiology) to University of Mysore.

Nestor , J.J., Korol, H.W., Nutik, S.L. & Smith, R. (1998). The incidence of acoustic neuromas. *Archives of Otolaryngology Head and Neck Surgery.*

Oates, P., & Stapells, D.R. (1998). Auditory brainstem response estimates of the pure-tone audiogram: current status .*Seminar on Hearing*, *19(1)*, 61-84.

Pant, K. (2000). *Tone burst auditory brainstem response in subjects with sloping sensori neural hearing loss*. Unpublished Independent project, University of Mysore.

Purdy, S.C & Abbas, P.J. (2002). ABR thresholds to tonebursts gated with Blackman and linear windows in adults with high frequency sensorineural hearing loss. *Ear & Hearing, 23,* 358-368.

Robinette, M.S., Bauch, C.D., Olsen, W.O., & Cevette, M.J. (2000). Auditory brainstem response and magnetic response imaging for acoustic neuromas, costs by prevalence. *Archives of Otolaryngology Head and Neck Surgery. 126,* 963-966.

Rowe, M.J. (1978). Normal variability of the brainstem auditory evoked response in young and old adult subjects. *Electroencephalography and Clinical Neurophysiology, 44,* 459-470.

Schmidt, R.J., Sataloff, R.T., Newman, J., Spiegel, J.R. & Mysers, D.L. (2001). The sensitivity auditory brainstem response testing for the diagnosis of acoustic neuromas. *Archives of* Otolaryngology *Head and Neck Surgery*, *127,* 19-22.

Selters, W.A., Brackmann, D.E. (1977). Acoustic tumor detection with brain stem electric response audiometry. *Archive of Otolaryngology, 103,* 181-187.

Selters, W., & Brackmann, D. (1979). *Acoustic tumor detection with brain stem electric response tumor detection*. In House W, Luetje C, Eds.Acoustic Tumors,Vol. 1. Baltimore: University Park Press.

Selesnick, S.H., & Jackler R.K. (1992). Atypical hearing loss in acoustic neuromas patients. *The Laryngoscope, 103,* 437-441.

Sininger, Y.S, & Don, M. (1989). Effects of click rate and electrode orientation on threshold of the auditory brainstem response. *Journal of Speech & Hearing Research, 32,* 880-886.

Suzuki, T., Hirai, Y., & Horiuchi, K. (1977). Auditory brainstem responses to pure tone stimuli. *Scandinavian Audiology, 6*, 51-56.

Stockard, J.J., Rossiter, V.S. (1978). Clinical and pathological correlates of brainstem response abnormalities, *Neurology,* 27, 316-325.

Stapells, D. R., Picton, T. W., Durieux-Smith, A. (1994). *Electrophysiologic measures of frequency-specific auditory function.* In Jacobson J.T. (Ed.), Principles and applications in audiotory evoked potentials, Needham Hill: Allyn and Bacon, pp 251- 283.

Stapells, D.R, & Picton, T.W., Perez-Abalo, M., Read, D., & Smith, A. (1985). *Frequency specificity in evoked potential audiometry.* In J.T. Jacobson (Ed.), The auditory brainstem response, (pp.147-177). San Diego: College-Hill Press,Inc.

Stapells, D. (2000). Threshold estimated by tone evoked ABR: a literature metanalysis. *Journal of Speech Language Pathology and Audiology*, *24,* 74-83.

Thornton, A.R.D. & Coleman, M.J. (1975). The adaptation of cochlear and brainstem auditory evoked potentials in humans. *Electroencephalography and Clinical Neurophyisology*, *39,* 399-406.

Wilson, D.F., Hodgson, R.S., Gustafson, M.F., Hogue, S., & Mills, L. (1992). The sensitivity of auditory brainstem response testing in small acoustic neuromas. *Laryngoscope*, *102,* 961-964.

Weber, B.A. (1994). *Auditory brainstem response: threshold estimation and auditory screening.* In :Katz J, ed. Handbook of Clinical Audiology. 4th Ed. Baltimore, Williams & Wilkins, 375-386.

Wilson, D.F., Talbot, J.M., & Mills, L. (1997). A critical appraisal of the role of auditory brainstem response and magnetic resonance imaging in acoustic neuroma diagnosis. *American Journal of Otology*, *18*, 673-681.

Welling, D.B., Glasscock, M.E., Woods, C.I. & Jackson, C.G. (1990). Acoustic neuroma: A cost effective approach. *Archives of Otolaryngology- Head and Neck Surgery, 103,* 364-370.

Yagi, T., & Kaga, K. (1979). The effect of the click repetition rate on the latency of the auditory evoked brain stem response and its clinical use for a neurological diagnosis. *Archive Otorhinolaryngology, 222*, 91-97.

Zappia, J.J., O'Connor, C.A., Wiet, R.J., & Dinces, E.A. (1997). Rethinking the use of auditory brainstem response in acoustic neuroma screening. *Laryngoscope, 107*, 1388-1392.