Development of Normative for Stacked Auditory Brainstem Response using Derived-band Technique

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Registration No: 10DNA005

Independent Project as a fulfillment of the Post Graduation Diploma in NeuroAudiology, submitted to University of Mysore, Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI

MYSORE – 570006

June 2011

Dedicated to Bawa

And

My Parents

CERTIFICATE

This is to certify that this independent project entitled **"Development of Normative for Stacked Auditory Brainstem Response using Derived band technique."** is a bonafide work in part fulfillment of degree of Post Graduate Diploma in Neuroaudiology of the student registration no: 10DNA005. 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

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Director

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CERTIFICATE

This is to certify that this independent project entitled **"Development of Normative for Stacked Auditory Brainstem Response using Derived band technique"** 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

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DECLARATION

This independent project entitled '**Development of Normative for Stacked Auditory Brainstem Response using Derived band technique'** 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. 10DNA005**

June, 2011

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CHAPTER 1

INTRODUCTION

The Auditory evoked potentials (AEPs) plays an essential part in the clinical practice of Audiology and the Auditory Brainstem Response (ABR) is particularly the most widely used AEP in clinical audiology. This is due to its ability of objective threshold estimation without the active participation of subjects in difficult to test population.

The auditory brainstem responses have been well accepted as a procedure to detect retrocochlear pathology (RCP) (Setlers & Brackmann, 1977; Jerger, Oliver, Chmiel & Rivera, 1986; Selesnick & Jackler, 1992; Chandrasekhar, Brackmann, & Devgan, 1995; Starr, Picton, Sininger, Hood, & Berlin, 1996). However, there are reports indicating that conventional ABR is not sensitive in detecting small acoustic tumours and small intracanalicular tumours. Tumours of sizes less than 10mm and small intracanalicular tumours are often missed by standard ABR methodology (Telian, Kileny, Niparko, Kemink & Graham, 1989; Wilson, Hodgson, Gustafson, Hogue & mills, 1992; Eggermont, Don & Brackmann, 1980; Schmidt, Satallof, Newmann, Spiegel and Myers, 2001).

Studies have reported an increase in incidence of small acoustic tumours over the years (Stangerup, Caye-Thomsen, Tos, Klokker, & Thomsen, 2004). Therefore it is essential that sensitive audiological protocols are developed to identify small acoustic tumours.

Two requirements for the ABR measure to be abnormal in ears with tumor are: one, the tumor must exert sufficient pressure to desynchronize, block, or alter the

conduction properties of the eighth nerve and second, the tumor must affect sufficient number of these nerve fibers. An ABR method would fail if these two requirements are not met. However, in standard ABR latency measures, there is an additional third requirement that: the tumor must affect the activity of those neural elements that determine the peak latency of the brainstem response. The normal standard ABR latency measures are only determined by a small subset of auditory nerve fibers, mostly representing the high frequency fibers. Thus, even if a small tumor affected the a considerable number of nerve fibers, representing the low to mid-frequencies, the peak latency may not change much because the active fibers do not determine the ABR peak latency. If a standard ABR detects the tumor, this would indicate that a sufficient number of high frequency nerve fibers are affected.

ABR amplitude measures are variable when compared to the latency measures. The two major contributors to this variability are: (1) the residual noise in the average and (2) phase cancellation of activity related to progressive activation and response time variations across the cochlea. Standard ABR evoked by clicks do not reflect all the neural activity because of phase cancellation. Studies have shown that activity from the low-frequency regions of the cochlea contribute little to the standard ABR amplitude. (Don, Ponton, Eggermont and Masuda, 1994, Don, Masuda, Nelson and Brackmann, 1997; Don, Kwong, Tanaka, Brackmann & Nelson, 2005).

Therefore, the standard ABR latency and amplitude measures will miss tumors that will not sufficiently affect the high-frequency fibers. To overcome these disadvantages of standard ABR methodology, Don, Masuda, Nelson and Brackmann (1997) developed a new ABR procedure of called stacked ABR.

The stacked ABR is a measure which reflects the overall neural activity from a wide frequency region of the cochlea in response to auditory stimulation. This overall neural activity is a result of synchronized activity from the various regions of auditory nerve, so that the desynchronization resulting from the compression of a small tumour may be evident in the reduction of stacked ABR. Wave V amplitude in the stacked ABR is reported to be a sensitive measure in identifying small tumours (Don, Kwong, Tanaka, Brackmann & Nelson, 2005; Chandrasekhar, Brackmann & Devgan, 1995). Don et al., (2005) reported that this method has demonstrated 95% sensitivity and 88% specificity in detecting small acoustic tumours.

1.1 Justification for the study

Tumours of size less than 10 mm and small intracanalicular tumours are often missed by standard ABR methodology (Telian, Kileny, Niparko, Kemink & Graham, 1989; Wilson, Hodgson, Gustafson, Hogue & Mills, 1992; Eggermont, Don & Brackmann, 1980; Schmidt, Satallof, Newmann, Spiegel & Myers, 2001). Research available on stacked ABR indicates that it is sensitive in identification of small acoustic tumours. However, it is important that separate normative is developed for each clinical set up, as the environmental condition and the amplifier of the equipment influences the amplitude measure. Hence, the present study was taken up.

1.2 Objective of the study

The sole objective of the present study was to develop normative data for stacked ABR using the derived band method.

CHAPTER 2

REVIEW OF LITERATURE

Auditory Brainstem Response (ABR) is one of the most useful clinical procedures for the examination of auditory sensitivity and integrity of the auditory system. ABR as a measure has been used successfully in site of lesion testing (Selters & Brackmann, 1997; Chandrasekhar, Brackmann & Devgan, 1995; Selesnick & Jackler, 1992; Barrs, Blackmann, Olsen & House, 1985; Jerger, Oliver, Chmiel & Rivera, 1986; Starr, Picton, Sininger, Hood, & Berlin, 1996). It has been reported that the sensitivity of ABR in detection of tumors is 95% or greaters. However, the sensitivity of ABR in detection of acoustic neuromas must depend on its size and location. In earlier report which advocated ABR as useful tool for detecting acoustic tumors, the size of the tumors assessed was fairly large. This was realized in the other group of studies (Levine, Antonelli, Le & Haines, 1991; Chandrasekhar, Brackmann & Devgan, 1995; Eggermont, Don & Brackmann, 1980) which proved that ABR cannot be used for tumor diagnosis because of lack of adequate sensitivity to small acoustic tumor despite their excellent sensitivity to medium and large tumors.

Levine, Antonelli, Le & Haines, (1991) reported that 19 patients with large tumors (>10 mm) were detected by standard ABR methodology but there were false negative ABRs when the tumor size was <10 mm. The incidence of false negative ABR appears to be greatest in small intracanalicular tumors particularly those involving the superior vestibule nerve (Telian, Kileny, Niparko, Kemink & Graham, 1989; Josey, Glasscock & Jackson, 1988; Josey, Glasscock & Musiek, 1988). Wilson, Hodgson, Gustafson, Hogue and Mills (1992) found that while the sensitivity of ABR in tumor detection was 96% in patients with extracanalicular tumor, it dropped to 67% with intracanaliacular 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 2 cm in 18 patients. However as the size of the tumor decreased ABR sensitivity also decreased dropping to 69% for tumors less than 1 cm 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 1 cm. They concluded that with strict adherence to optimal technique and evaluation criteria, the conventional ABR is a viable option for acoustic neuroma screening. Robinette, Bauch, Olsen and Cavette (2000) reviewed 75 patients with acoustic neuromas and divided tumors into 3 groups of small (<1cm), medium (1.1-2.0 cm) and large (>2cm). Twenty two patients had small, 30 had medium sized tumors and 23 had large tumors. ABR testing correctly identified 100% of the large tumors, 93% of medium sized tumors and 82% of small tumors. Zappia, O'Conner, Wiet and Dinces (1997) conducted a retrospective study of 388 surgically treated patients with acoustic tumors and found that while sensitivity was 100% for tumors larger than 2 cm in diameter, it was only 89% for tumors of 1 cm or less in diameter.

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 >1.5 cm but the sensitivity gradually decreased to 58% for the acoustic tumor size < 1cm. 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.

Thus the review of major investigations reveal that there are equivocal findings about the sensitivity of conventional ABR measures in detecting small acoustic tumors (<1cm). Furthermore, a review of literature suggests that the incidence of small acoustic tumors is not very rare. Tos, Stangerup, Cay-Thomasen, Tos and Thomasen (2004) reported a realistic incidence of approximately 13 vestibular schwanomas per million inhabitants per year in Denmark. An incidence of 12 vestibular schwanomas/million/year from 1985 to 1988 has also been reported in a North America community with 2 million inhabitants (Nestor, Karol, Nutik & Smith, 1988). Moffat, Hardy, Irving, Beynon and Baguley (1995) reported an incidence of 20 vestibular schwanomas/million/year from 1981 to 1991 in Cambridge region of England. A few investigators report an increase in annual incidence of small acoustic tumors (Stangerup, Tos, Caye-Thomsen, Klokker, & Thomsen, 2004; Tos, Charabi & Thomasen, 1999). Therefore, there was a need to improve ABR technique to identify small acoustic tumors. Development of stacked ABR is one of the attempts in that direction.

2.1 Stacked ABR

The stacked ABR as described by Don, Ponton, Eggermont and Masuda (1994) is a measure which records the sum of the neural activity across entire frequency region of the cochlea in response to auditory stimulation. Using appropriate technique the responses from different frequency regions of the cochlea will be recorded. These responses will then be added together to approximate the total neural activity (stacking method). So it is assumed that the final response will include synchronized activity from essentially whole of the cochlea. Stacked ABR uses wave V amplitude as a measure to depict the overall activity (neural) from the cochlea. It I also hypothesized that the stacked ABR reduces the back ground residual noise in the

ABR waveform and hence reduces the variability seen in the amplitude measure of the ABR (Don, Ponton, Eggermont & Masuda, 1994).

2.2 Anatomical basis of Stacked ABR

Acoustic tumors generally arise from Schwann cells in the vestibular division of the 8th nerve in the internal acoustic meatus and eventually extend into the Cerebellopontine angle. The tumors can arise from either the superior or inferior divisions of the vestibular nerve and encroach upon the cochlear nerve. To understand the effect of small tumor on the cochlear nerve, we need to understand the tonotopic neuroanatomic organization of the fibers in the cochlear nerve. In the transverse section of the internal auditory canal (figure 2.1), we see the 7th (facial) nerve (VII; upper left) and three divisions of the eighth (auditory and vestibular) nerve. Clockwise from upper right, the divisions of the 8th nerve are as follows first the superior vestibular nerve; second the inferior vestibular nerve; and third the auditory (cochlear) nerve. In the auditory nerve the high frequency fibers arising from the lower upper basal turns of the cochlea lie inferiorly (Ia) and superiorly (Ib), respectively. Fibers from the second and apical turns of the cochlea lie in the medial portion of the cochlear nerve (II), adjacent to the inferior vestibular nerve.

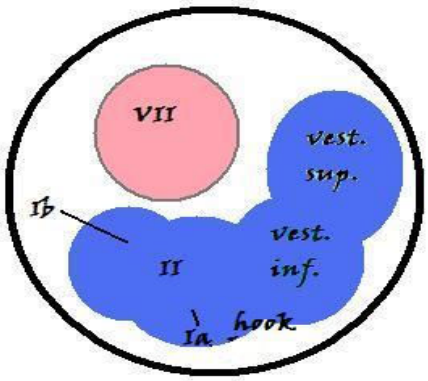

Figure 2.1: Transverse section of the internal auditory canal showing the position of the facial nerve (VII), the superior division of the vestibular nerve (vest. sup.) the inferior division of the vestibular nerve (vest. inf.) and the auditory nerve with the nerve fibers with the most basal end (hook), for the lower basal turn (Ia), the upper basal turn (Ib) and the second apical turn (II).

The figure 2.1 clearly shows that, if a tumor arises from that adjacent portion of the inferior vestibular nerve, it would affect the lower-frequency fibers in the second and apical turns first. Depending on where the vestibular schwannoma arises, high or low frequency fibers can be affected first.

2.3 Methods to record stacked ABR

Primarily two methods have been used to record stacked ABR, one derived band technique and, the second, tone burst method. The procedure used in these methods is described briefly in the following section.

2.3.1 Derived band technique:

This technique basically has been used to record frequency specific responses from the cochlea. The first major study of the use of derived masking methods in generating frequency specific auditory evoked responses is that of Teas, Eldrege and Davis (1962) in an animal model. With the derived response method, an ABR is generated by a sound that includes the stimulus (generally clicks) plus a masker

(narrow band noise, high pass noise or a pure tone masker) that has contributions from portions of cochlea other than those underlying the stimulus. The ABR waveform for clicks is subtracted from the ABR waveform for the noise plus click condition. Theoretically during the subtraction process, the contribution of the masker to the waveform (and non stimulus frequency regions of the cochlea) is removed leaving only the ABR for the spectrally constrained stimulus (Hall, 1992).

Don, Ponton, Eggermont and Masuda (1994) were the first to record stacked ABR. They obtained frequency specific ABR using derived band technique and summed these responses after temporally aligning wave V in each response. They used stacked ABR to investigate whether variability in the timing of cochlear response would also lead to variability in click evoked ABR amplitudes. They compared stacked ABR recording with unmasked ABR recordings and concluded that variability in amplitudes of ABR related to temporal aspects of cochlear activation and response times and not related to the central conduction time. Stacked ABR reduces the residual noise and hence reduces the variability of amplitudes of ABR peaks between runs.

Don, Masuda, Nelson and Brackmann (1997) were the first to use derived band technique to record stacked ABR to detect small acoustic tumors. They adopted the technique given by Don and Eggermont (1978) in which derived ABRs are obtained using ipsilateral pink noise masking. The noise was presented at a level sufficient to mask the ABR to the clicks. There were six stimulus conditions click presented alone (unmasked condition) and click presented with ipsilateral noise high pass filtered at 8, 4, 2, 1 and 0.5 kHz. This procedure resulted in five derived band ABRs representing activity initiated from regions of the cochlea that are 1 octave wide. The derived bands were obtained by subtracting the response for one run from

the previous run (Don, Kwong, Tanaka, Brackmann & Nelson, 2005). Here, the response to clicks + 8 kHz high-pass masking noise was subtracted from the response to clicks alone to form a derived-band ABR with center frequency (CF) = 11.3 kHz. The response to clicks + 4 kHz high-pass masking was subtracted from the response to clicks + 8 kHz high-pass masking to form a derived band ABR with CF = 5.7 kHz. The response to clicks + 2 kHz high-pass masking was subtracted from the response to clicks + 4 kHz high-pass masking to form a derived band ABR with CF = 2.8 kHz. The response to clicks + 1 kHz high-pass masking was subtracted from the response to clicks + 2 kHz high-pass masking to form a derived band ABR with CF = 1.4 kHz. The response to clicks + 1 kHz high-pass masking was subtracted from the response to clicks + 0.5 kHz high-pass masking to form a derived band ABR with CF = 0.7 kHz. The theoretical centre frequency for each derived band is computed as the square root of the product of the two successive high pass filter cut-off frequencies of the derived bands used in that investigation are 11.3, 5.7, 2.8, 1.4 and 0.7 Hz. Then at each derived band ABR wave V was identified and peak to peak wave V amplitude is measured. The stacked ABR was constructed by time shifting the waveforms so that peak latencies of wave V in each derived band coincide, and then adding the shifted derived band waveforms.

The amplitude of the wave V in the stacked ABR reflects more directly the total amount of cochlear activity (Don, Ponton, Eggermont & Masuda, 1994). The ABR amplitude for the wave V increases with derived band temporally aligned responses (stacked ABR) as compared to summed natural derived band responses in individuals with normal hearing (Don, et al., 1994). However, the derived band method requires a masking technique that may not be readily available to the

clinicians and relatively high level noise required for masking may be annoying to the patient.

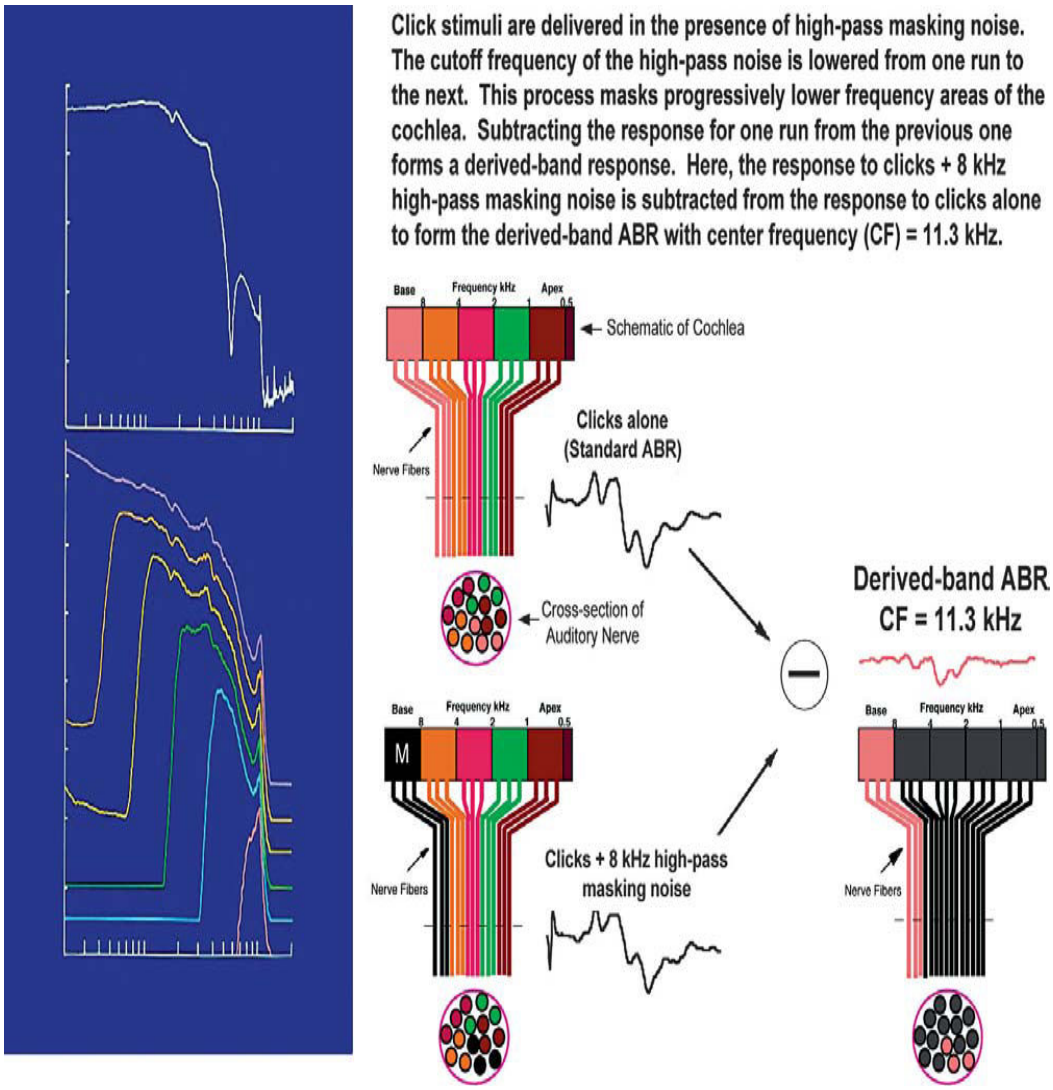

Figure 2.2- Left pane: power spectra of the broad-band click and the high-pass filtered pink noise with varying cut-off frequencies are shown in the top and bottom of the left (blue background) panel respectively. Right panel: example of forming a derived-band response; the response to the clicks + 8 kHz high-pass masking noise is subtracted from the response to clicks alone to form the derived-band ABR with a theoretical CF = 11.3 kHz.

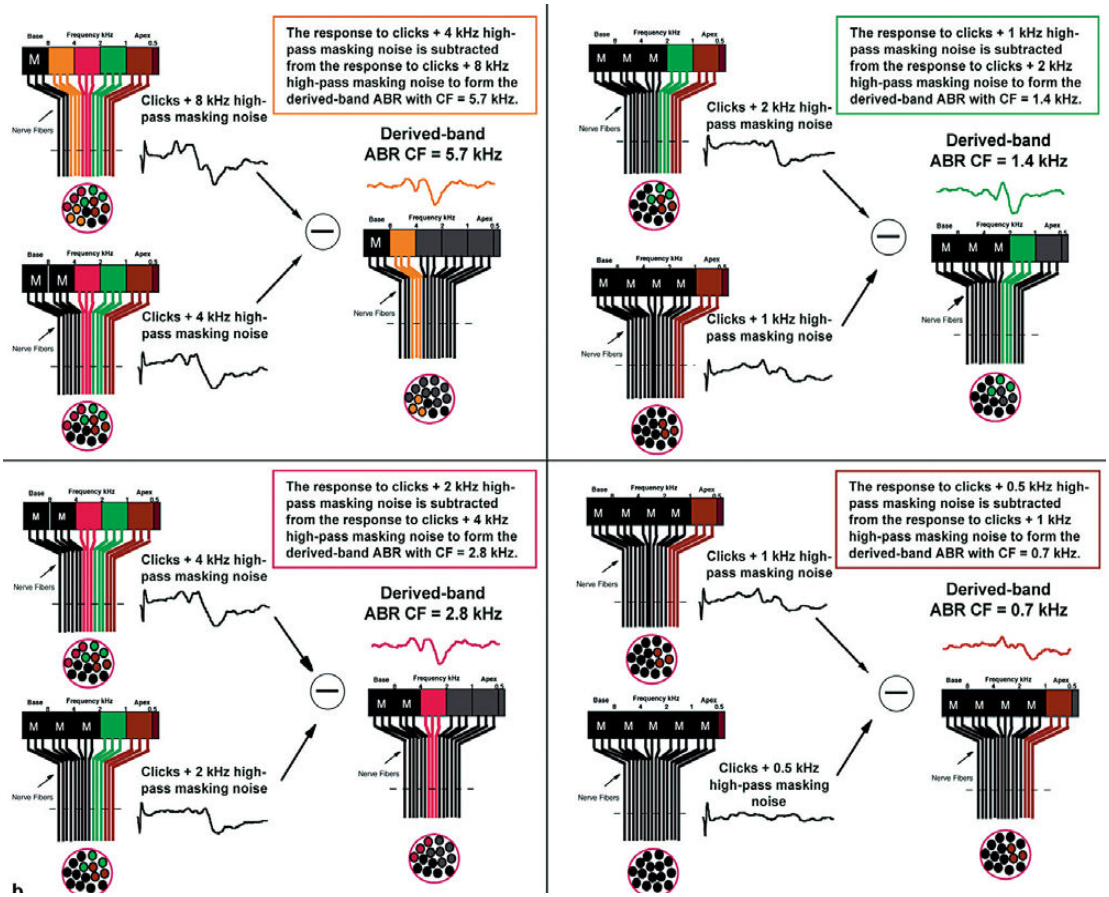

Figure 2.3: Repeating the response subtraction process for the remaining clicks + high-pass masking noise conditions to obtain the other derived-band ABRs

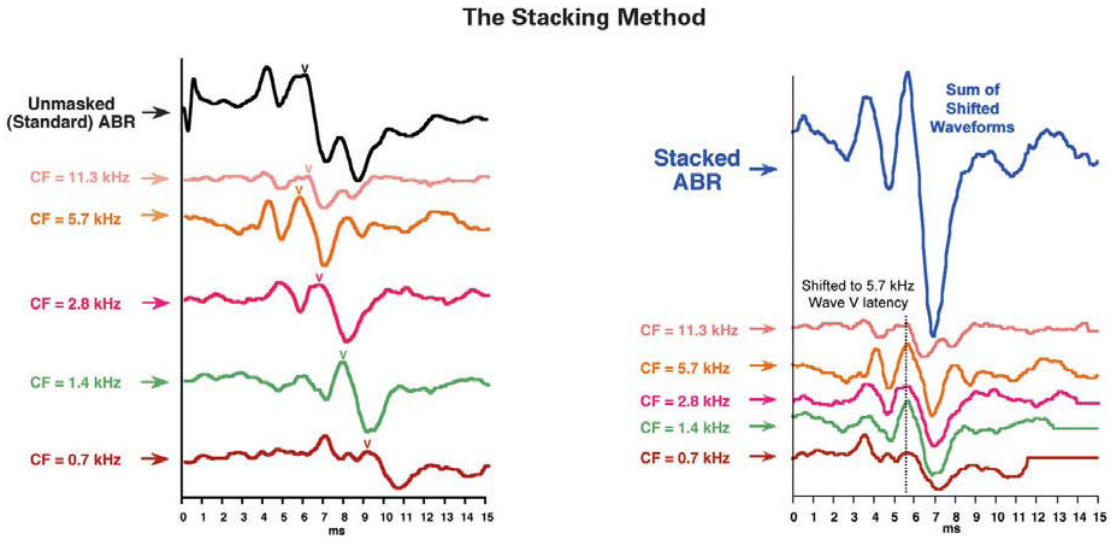

Figure 2.4- The standard ABR to clicks presented alone (top trace) and the five derived-band ABRs from a non tumor normal hearing (NTNH) subject.

2.3.2 Tone burst method

Philibert, Durrant, Ferber-Viart, Duclaux, Veuillet and Collet (2003) developed an alternative method called stacked tone burst ABR to overcome the disadvantages of the derived band stacked ABR. It was assumed that, using brief tone stimuli such as tone bursts for recording ABR, the responses are elicited from narrow region along the basilar membrane corresponding to the stimulus frequency. Bekesy (1960) demonstrated that the high frequencies in the sound will vibrate only the basal region of the basilar membrane and lower frequencies in the sound will vibrate apical regions. However several investigators have reported that when using low frequency stimuli at suprathreshold levels, the responses are mediated by high frequency regions of the cochlea (Oates & Stapells, 1997; Laukli & Mair, 1986; Gorga & Thronton, 1989). But when stimulus intensity is decreased, tone evokes a response through the region of cochlea specific to its frequency (Stapells, Picton & Durieux-Smith, 1994).

Philibert et al (2003) compared tone burst stacked ABR with derived band method in 10 young normal individuals. Subsequently stacked tone burst method was used also in six cases of unilateral vestibular schwanomas confirmed by MRI. The tone bursts were synthesized at same centre frequencies as derived noise bands used by Don et al. (1997). The stimulus were presented at 40 dBSL (mean = 60 dBHL) to record tone burst ABR at different frequencies. Stacked ABR was conducted by temporally aligning the ABR wave forms recorded from different frequencies and subsequently adding them. Wave V marked in the final summed waveform and its peak to peak amplitude was measured. It was concluded that TB method shows good approximation of the derived band method in achieving stacked wave V amplitude enhancement**.**

2.4 Application of stacked ABR

The main advantage of the stacked ABR is successful detection of small intracanalicular acoustic tumors that are missed by standard ABR protocol (Don, Masuda, Nelson & Brackmann, 1997; Philibert et al, 2003; Don, Kwong, Tanaka, Brackmann & Nelson, 2005). Don, Masuda, Nelson & Brackmann (1997) demonstrated in a series of 25 tumor cases, five small (≤ 1 cm) intracanalicular tumors which were missed by standard ABR latency measures, were detected by stacked ABR method. The stacked wave V ABR amplitudes in all the five subjects were significantly lower than those obtained from normal hearing individuals without tumors. A small tumor was suspected if the amplitude of stacked wave V was lesser than 2 standard deviations (SD) away from mean. Further Don, Kwong, Tanaka, Brackmann and Nelson (2005) reported 95% sensitivity and 88% specificity of the stacked ABR technique for detecting small acoustic tumors in their 54 patients with acoustic tumors identified by MRI (less than 1 cm in size). These tumors were undetected by standard ABR methodology. The same stringent criterion of amplitude less than mean - 2 SD of normal subjects was applied to detect the tumors.

Philibert et al (2003) also reported a statistically significant difference between ears for the tone burst evoked stacked wave V amplitude in the same five patients with small vestibular tumors which showed no abnormalities on standard ABR measures. The criterion used here to detect the tumor was difference of 0.04 μV interaurally. This preliminary study also showed a high sensitivity in detecting small vestibular schwanomas (< 1cm). This high sensitivity and specificity of the stacked ABR method may be due to the fact that it represents a measure that assesses the activity essentially of all the 8^{th} nerve fibers whose activity dominate generator of the peak latency of wave V response to click stimuli (Don, Kwong, Tanaka, Brackmann

& Nelson, 2005). So the standard ABR measures are normal in patients with small acoustic tumors, hence goes undetected. The stacked ABR wave V amplitude is more sensitive to a small reduction in or desynchronization of auditory neural activity that may result from compression by a small tumor which in turn increases its sensitivity and specificity in detection of small acoustic tumors. Thus a review of literature shows that the stacked ABR is a very useful measure for detecting small intracanalicular tumors (< 1cm).

2.5 Factor Affecting Stacked ABR

There is a dearth of literature pertaining to factors which can affect the stacked ABR. However the factors affecting conventional ABR can be expected to have an effect on stacked ABR also as it uses wave V amplitude as a measure. Some of the major factors that may affect stacked ABR are discussed here.

a) *Method Used to Record Stacked ABR:* there are primarily two methods to record stacked ABR i.e. derived band and tone burst method. Philibert et al (2003) compared these two methods in young normal hearing individuals. There was no significant difference between ABRs obtained using the two methods and tone burst method demonstrated similar enhancement of wave V as that obtained from derived band method. The morphologies differed between two methods and relatively high reproducibility was noted with tone burst evoked stacked ABR particularly at lower frequencies. This may be because of more basal-ward spread of excitation potentially gives a more synchronous response to low frequency tone bursts than the derived band ABR. The amplitude value of stacked ABR wave V with derived band method ranged from 0.65 μV to 1.3 V (Don, Masuda, Nelson & Brackmann, 1997) in

individuals with normal hearing with a mean of around 0.95 μV. The stacked wave V amplitude varied from 0.90 to 2.2 μV in their young normal hearing individuals when tone burst method was used (Philibert et al., 2003).

b) *Frequency:* The ABR to brief tone stimuli consist of primarily of wave V and negative following wave V (Stapells & Picton, 1981). The absolute latencies of the response to low frequency tones are longer than those for high frequency tones presented at the same intensity (Stapells, Picton & Duricux-Smith, 1994). The prolonged wave V latency for 500 Hz may be due to the longer rise time of the low frequency stimulus (Schwartz, Morrris, & Jacobson, 1994; Stapells & Picton, 1981). Gorga, Kaminiski, Beauchaine and Jesteadt (1988) studied ABR to tone bursts ranging in frequency from 250 to 8000 Hz in normal hearing individuals. The responses were highly reproducible within individual subjects and ABR thresholds were higher than behavioural thresholds for all frequencies especially at lower frequencies. It can be inferred from this that either the absolute amplitude of ABR or the signal to noise ratio was poorer for low frequency. On the contrary, Takagi, Suzuki and Kobayashi (1985) reported that the amplitude of the ABR remains relatively constant across frequency (500-4000 Hz) the observed a tendency for the response to be larger for low frequency stimuli when compared to that of high frequency stimuli.

As latencies are not considered for interpretation of stacked ABR, the effect on latency should not affected stacked ABR but the effect on amplitude of individual ABR will have an effect on stacked ABR. It can be hypothesized that the amplitude of stacked ABR will vary depending on the frequencies

used for obtaining individual waveform and the number of frequencies used for stacking.

c) *Gating Function:* The gating function is used in determining the frequency specificity of the stimuli used. Oates and Stapells (1997) conducted a study to assess differences in frequency specificity of ABR for 500-2000 Hz tones gated through exact Blackman and linear functions on normal hearing subjects. They reported no significant differences in the frequency specificity of the ABR to these two functions despite the acoustic spectral differences that exist between the stimuli. Purdy and Abbas (1989) also investigated the frequency specificity of ABR to Blackman versus linearly gated brief tones, by assessing the ABR thresholds in individuals with steep high frequency sensorineural hearing loss. The thresholds predicted in both the conditions were comparable. Pant (2000) reported better waveform morphology for tone burst gated through Blackman window than for stimuli gated through cosine cube gating function. No significant difference was observed in wave V latency between normal hearing adults and adults with high frequency hearing loss for 4 non linear and 1 linear window conditions (Robier, Farby, Leek & Van Summers, 1992). Another factor which has a direct relationship with its frequency specificity is the rise time of the stimulus. Tones with longer rise times had greater frequency specificity (Stapela & Picton, 1981; Gorga & Thomton, 1989). When rise time is increased beyond 5ms, however there is a significant decrease in amplitude of wave V (Stapells & Picton, 1981).

Philibert et al (2003) have advocated the use of 2-1-2 cycles with Blackman gating to record stacked ABR. Use of stimuli with different gating function

and/or rise time may have an effect on the amplitude of the response and requires separate normative data.

d) *Stimulus Intensity:* The stimulation level is an important parameter in recording of ABR. It is known that as the intensity is reduced the latency and the amplitude of the waves will be increased and reduced respectively (Gorga, Kaminski, Beauehaine & Jesteadt, 1988). There is a concomitant decrease in response amplitude with reduction in intensity of the stimulus. Intensity reduction also reduces the clarity of the waveform (Schwartz, Morris & Jacobson, 1994). As the stimulus intensity is increased, amplitude of the slow component reaches a plateau in the 40-50 dB region, but the fast component (wave I to V) shows the characteristic steady amplitude increase (Takagi, Suzuki & Kobayashi, 1985). Suzuki, Hirai and Horiuchi (1977) recorded vertex positive brainstem responses to tones at 500, 1000, 2000, and 4000 Hz from 20 adults with normal hearing. The ABRs were detected in 53-73% of the subjects at 10 dBSL and 89-100% at 20 dBSL.

Philibert et al (2003) used 40 dBSL (mean=60 dBHL) presentation to record the tone burst evoked staked ABR. They reported that difference in sensation levels of the stimuli to record stacked ABR is also important. A larger difference in sensation levels of the stimuli to record stacked ABR between normal controls and clinical populations may lead to erroneous results. They further reported that a higher stimulus levels might be useful to ensure, as much as possible, full recruitment of the ABR at all frequencies in the case of concomitant cochlear hearing loss. Don, Ponton, Eggermont and

Masuda (1994) also used higher sensation levels (92dBSPL) to record derived band stacked ABR. The effect of intensity on amplitude of stacked ABR is yet to be explored.

e) *Repetition Rate*: There is a general agreement that stimulus repetition rates up to 20/s have little effect on ABR, but above this level ABR wave's latency generally increases and amplitude decreases as rate increases (Sininger & Don, 1989; Malinoff & Spivak, 1990). However wave V amplitude appears to show less decrement with increasing rate than earlier waves. At the higher rate amplitude for wave V typically decreased about 10-30% relative to original amplitude (Hall, 1992). Philibert et al (2003) used a repetition rate of 11.1/s to record tone burst evoked stacked ABR. This repetition rate has the advantage of causing negligible adaptation during testing.

f) *Number of Sweeps:* The signal to noise ratio increases as a function of number of sweeps, leading to good morphology of any auditory evoked response (Hall, 1992). The amplitude of the waves progressively increases with the number of sweeps and there will be a substantial difference in amplitude for 250 versus 2000 sweeps. The measurable amplitude will increase as the background noise decreases. Latency values do not differ for responses averaged for various number of sweeps, although latency variability from one averaged waveform to the next is reduced for larger number of sweeps. 1600 sweeps were used by Philbert et al (2003) to record stacked ABR.

g) *Electrode Montage:* All the investigations on click evoked ABR have used vertex to mastoid electrode placement as montage. Conventionally this

montage is used for site of lesion testing. Vertex to mastoid electrode montage is preferred when the identification of all the peaks is essential. Since stacked ABR relies only on wave V, vertex to non-cephalic placement may evoke ABRs of larger amplitude. It has been reported in literature that vertical montage (vertex to non-cephalic placement) enhance wave V of ABR (Schwartz, Morris & Jackson, 1994). Further studies need to be carried out on effect of electrode montage on stacked ABR.

h) Filter Settings: It is considered to be crucial acquisition parameter to consider in recording frequency specific ABR. A high pas setting of 30 Hz or lower is essential in order to encompass the low frequency portion of ABR spectrum which is prominent for a low frequency stimulus (Stapells & Picton, 1981). Raising the cut off frequency of high pass filter and lowering the cut off for low pass filter has an effect on amplitude and latency of wave V and reduces response delectability (Kavanagh & Franks, 1989). A standard filter setting of 30-3000 Hz is recommended for stacked ABR.

i) ABR electrical fields are weak: The amplitude of the electrical activity recorded at the surface is very small, usually less than 1μV. This may be due to the distance and orientation of the neural generators from the recording electrodes. Thus, individual variations in the neuroanatomy and anatomy for example, head size (Stockar, J.J. & Rossiter; 1979), skull thickness (Trune, Mitchell, & Phillips, 1988), and skin impedance (Beagley and Sheldrake, 1978)

j) ABRs have poor signal-to-noise ratio(S/N): because the activity recorded at the surface is very small, ABRs have poor S/N ratio, that is, low evoked potential amplitudes relative to the amplitude of the physiologic background noise. Averaging fixed number of sweeps does not guarantee that the residual noise in the average will be lower enough for an accurate measure of the true amplitude of the response peak (Don & Elberling, 1994; 1996). Clinically, traces with S/Ns have produced major problems in identification of near-threshold response and in reliable measurements of the components of the ABR for otoneurogenic or neurologic diagnosis. Even after averaging, considerable residual noise can remain in the traces. The greater the residual noise, the more difficult it is to identify the peak. In addition, peaks in the residual noise may add to the response peaks and alter the original amplitude. However, even with several techniques, the amount of residual noise cannot be controlled. In addition, the variable amount of residual noise in the average leads to variable peak amplitudes even when stimulus conditions are identical (Don & Elberling, 1994; 1996)

k) Both peak and trough must be identified: Amplitude measures typically require identification of both the peak and the succeeding trough; latency measures require identification of only the peak. While identification of the peak can be difficult at times, trough identification can be equally problematic. Even when there is low residual noise in the average, identifying the peak and trough can be difficult because of great variations in waveform morphology. Therefore, amplitude measures are inherently more variable than latency measures because an additional component, a trough, must also be identified.

l) Phase cancellation of neural elements can be significant: The biphasic nature of the electrical neural activity means that, depending on the relative timing of activation, some neural elements can phase cancel the activity of others. In addition, a condition that causes a loss of phase-canceling neural activity could result in an increase in peak amplitude (Don, & Elberling,1994; 1996). With broadband stimuli, such as clicks, phase cancellations of field activity from more apical regions of the cochlea occur, so that the resulting peaks in the response largely reflect activity from the most basal regions. In addition, it has been demonstrated (Don, & Elberling, 1994) that the large amplitude variation in the standard ABR to click stimuli are mainly the result of iiregularitiees in cochlear response time (the degree of synchronization across the cochlea). Therefore, because of the variable amount of synchronization and phase cancellation, simple amplitude measures of ABR to clicks do not reflect the total neural response.

m) Age: The ABR waveform is incomplete at birth (Hall, 1992), with only the major waves observed (I, III & V). Absolute latencies and inter peak latencies progressively shortens, amplitude increases with age and it reaches adult like morphology by 18 months to 2 years (Hecox & Galamos, 1974; Zimmerman, Morgan & Dubno, 1987). There is some evidence that wave I amplitude in newborns is larger than wave V and can be up to twice as big as the amplitude in adults (Hall, 1992). With advancing age it has been reported that there is a significant decrease in amplitude of all ABR waves from wave I through VI (Jerger & Hall. 1980), although this is not a consistent finding (Johansen & Lehn, 1984). Since acoustic neuroma is rare in infants and children but seen

more frequently in adults and geriatrics. Don, Kwong, Tanaka, Brackmann and Nelson (2005) observed that the stacked ABR amplitude was lesser in older non tumor individuals with normal hearing when compared to young non tumor individuals with normal hearing.

n) Gender: Females tend to have shorter latency (about 0.2 ms shorter) and higher amplitude ABRs waves than males (Elberling & Parbo, 1987; Watson, 1996). Amplitude of waves is higher in females particularly for later waves (IV, V VI &VII) (Hall, 1992). The difference in amplitude of the response has also been observed in stacked ABR.

Don, Ponton, Eggermont and Masuda (1994) reported larger stacked wave V amplitude in females than males. Don, Masuda, Nelson and Brackmann (1997) also reported similar results. However the difference was not statistically significant. In tone burst methods also females had more amplitude than males but the sample size was very small to make any conclusive statement (Philbert et al, 2003).

o) Hearing loss: Although there is no investigation done on effect of hearing loss on stacked ABR, but there is ample research evidence that any type of hearing loss affect conventional ABR measures (Watson, 1996; Oates & Stapells, 1992; Keith & Greville, 1987; Coats, 1978). It can be inferred from these studies that conductive or cochlear hearing loss affects stacked ABR also.

Conductive Hearing Loss: Conductive hearing loss results in prolongation of all waves, with ineterpeak intervals remaining with normal limits (Hood,

1998). The shift in the latency of entire wave form is a result of the reduction in the level of signal reaching the cochlea by conductive hearing loss. The conductive hearing loss also affects the amplitude of all the sound reaching the cochlea producing significant morphological change. In the same way the conductive hearing loss can affect the amplitude of stacked ABR also. So a conductive pathology should be ruled out before interpreting stacked ABR.

Effect of Cochlear Hearing Loss on ABR: An abnormal ABR result is of little clinical value if there is high risk of such result occurring as a consequence of cochlear hearing loss (Watson, 1999). So before interpreting ABR one should know how ABR measures are affected by cochlear hearing loss. Increasing high frequency loss is reported to increase wave V latency and reduce I-V interval identification (Watson, 1996; Oates & Stapells, 1992; Elberling & Parbo, 1987; Watson, 1999). Similarly wave V latency increases with increase slope of high frequency hearing loss (Watson, 1996; Watson, 1999; Bauch & Olsen, 1986; Coats & Martin, 1977; Rosenhamer, Lindstrom & Lundborg. 1981; Keith & Greville, 1987). The slope of wave V L-I function is steeper in high frequency SN loss and shallower in flat loss as compare to normals (Gorga, Worthingtn, Reilnad, Beauchaine & Goldgar, 1985; Coates & Martin, 1977; Hall, 1992; Coates, 1978; Shepars, Webster, Bauma & schulka, 1992; Oates & Stapelles, 1992). If the hearing loss is flat or only mildly sloping and mild to moderate in severity, then the effect of hering loss on the ABR for high level stimuli are substantially reduced. The latency of waves is essentially equivalent to those collected at the same intensity level in normal hearing subjects (Selters & Brackmann, 1997).

There is a dearth of literature investigating the effect of cochlear loss on ABR amplitude measures. This scarcity of research may be attributed to the highly variable nature of ABR amplitude measure when those compared with latencies (Don, Masuda, Nelson & Brackmann, 1997). Fowler and Durrant, 1994 reported that the amplitude of the wave V in patients with cochlear loss may be slightly smaller than normal hearing individuals, presumably because of the loss of some neural contributions Xu, Vinck, De Vel and Cauwenberge(1998) evaluated 22 patients (44 ears) with noise induced permanent hearing loss using transient evoked oto acoustic emission and ABR.

In 24 ears the V/I amplitude ratio became smaller than the normal value as the hearing loss increased and maximum effect was seen when it extended to 3 kHz. The amplitude ratio became smaller as hearing loss increased indicting the adverse effect of cochlear loss on wave I and V, leading to abnormal ratio.

Don, Kwong, Tanaka, Brackmann and Nelson (2005) observed that the amplitude of derived band stacked ABR was lesser in individuals with small tumors with hearing loss than of those with small tumors and normal hearing. The hearing loss can be a consequence of a tumor either due to pressure exerted by the tumor on the nerve fibers blocking the neural activity or reduction in vascular supply to the cochlea. But it is not known whether the amplitude reduction is due to the cochlear hearing loss or due to tumor on the auditory nerve.

Due to the factors that affect the Stacked ABR, it is important that separate normative is developed for each clinical set up, as the environmental condition and the amplifier of the equipment influences the amplitude measure.

CHAPTER 3

METHOD

The following method is adopted to develop normative for click evoked stacked ABR using derived band technique.

3.1 Participants

The study comprised of 30 adult participants ranging in age from 17-25 years, including both male and female participants. They had to fulfil the following criteria to be included in the study:

1. Pure tone hearing sensitivity within 15 dBHL at octave frequencies between 250 Hz and 8000 Hz.
2. Normal middle ear functioning as assessed by tympanometry and acoustic reflex threshold. Participants having 'A' type of tympanogram and reflexes present were included.
3. No history of any otological or neurological dysfunction.
4. Retro cochlear pathologies were ruled out by administering the reflex decay test and further click evoked ABR.

A written consent about the participation was obtained from each participant.

3.2 Instrumentation

The following instruments were used in the study:

1. A calibrated Madsen Orbitter 922 diagnostic audiometer with TDH-39 earphones housed in MX-41/AR ear cushions was used for estimating the air conduction thresholds and bone conduction thresholds.

2. A calibrated Grason-Stadler Inc (GSI-TS) middle ear analyzer was used to rule out middle ear pathology.
3. Biologic Navigator Pro evoked potential system (version0.7) was used to record the click evoked stacked ABR. The transducers used were Broadband insert earphones.

3.3 Test Environment

The testing were carried out in a quiet environment which met the guidelines by ANSI S3.1; 1991. A sound treated room with appropriate acoustic isolation was chosen for the recording. Electrical shielding of the environment was ensured so as to reduce the electrical artifacts.

3.4 Test Procedure

Prior to the recording of ABR, Pure-tone audiometry, and Immittance evaluations were done. Pure tone thresholds were obtained at octave frequencies between 250 Hz and 8000 Hz for air conduction stimuli and from 250 Hz to 4000 Hz for bone conduction stimuli using modified Hughson-Westlake method (Carhart & Jerger, 1959). Tympanometry was carried out using low frequency probe tone of 226Hz and reflexometry was carried out at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz both ipsilateraly and contralateraly. The reflex decay test was carried out at 500 Hz and 1000 Hz. The stimulus tone was presented continuously for 10 seconds at a level 10 dB above the reflex threshold.

Recording of Click Evoked Stacked Auditory Brainstem Responses

The participants were instructed to sit comfortably and relax on a reclining chair facing away from the instrument. They were asked to avoid extraneous movements of the head, neck and limbs during the testing. Three silver chloride disc electrodes were used to record ABR which were placed in vertical montage. The inverting electrode was placed on the test ear mastoid, while the non-inverting electrode on C_z (vertex) and the ground electrode was placed on F_{pz} (forehead). Electrode sites were first cleaned by scrubbing with cotton wool dipped in skin preparing gel. It was ensured that electrode impedance was less than 5kOhms at each site and inter-electrode impedance less than 2 kOhms. ABR was recorded using test protocol given in the Table 3.1.

Table 3.1: *Test protocol used to record frequency-specific ABR to obtain stacked ABR*.

Stimulus Parameters	
Type of stimuli	Clicks
Type of masker	500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, & 8000 Hz high pass masking noise
Transducer	Broadband insert earphones
Test intensity	60dB nHL
Repetition rate	45.5/s
Polarity	Rarefaction
Acquisition Parameters	
Envelope (gating)	Blackmann
Time window	15 ms
Electrode montage	Single channel
No. of sweeps	2000
Sensitivity	30μV
Filter settings	100-3000 Hz

Responses were recorded ipsilateraly. ABR was recorded first for clicks only and then for clicks with maskers. In the conditions where masking is used, masker was presented ipsilateraly. The order of recording was randomized to avoid order effect.

The ABR elicited only for clicks was subtracted from the ABR elicited in the ipsilateral masking condition. The derived bands were obtained by subtracting the response for one run from the previous run (Don, Kwong, Tanaka, Brackmann & Nelson, 2005). Here, the response to clicks + 8 kHz high-pass masking noise was subtracted from the response to clicks alone to form a derived-band ABR with center frequency (CF) = 11.3 kHz. The response to clicks + 4 kHz high-pass masking was subtracted from the response to clicks + 8 kHz high-pass masking to form a derived band ABR with CF = 5.7 kHz. The response to clicks + 2 kHz high-pass masking was subtracted from the response to clicks + 4 kHz high-pass masking to form a derived band ABR with CF = 2.8 kHz. The response to clicks + 1 kHz high-pass masking was subtracted from the response to clicks + 2 kHz high-pass masking to form a derived band ABR with CF = 1.4 kHz. The response to clicks + 1 kHz high-pass masking was subtracted from the response to clicks + 0.5 kHz high-pass masking to form a derived band ABR with CF = 0.7 kHz.

The wave V was identified in each of the derived-bands. The wave V was then time aligned and these aligned waveforms were added to obtain the stacked ABR as represented in Figure 3.1 and 3.2.

The latencies of all the derived-bands were compared to the normal latency obtained with a click ABR. The amplitude of the derived-bands were analysed and the amplitude of the stacked ABR was found.

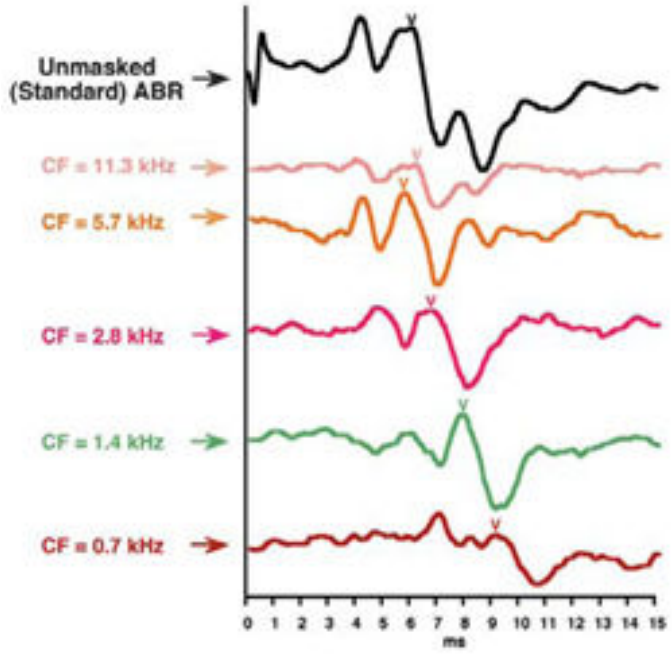

Figure 3.1: ABR responses to clicks and high-pass masking noise.

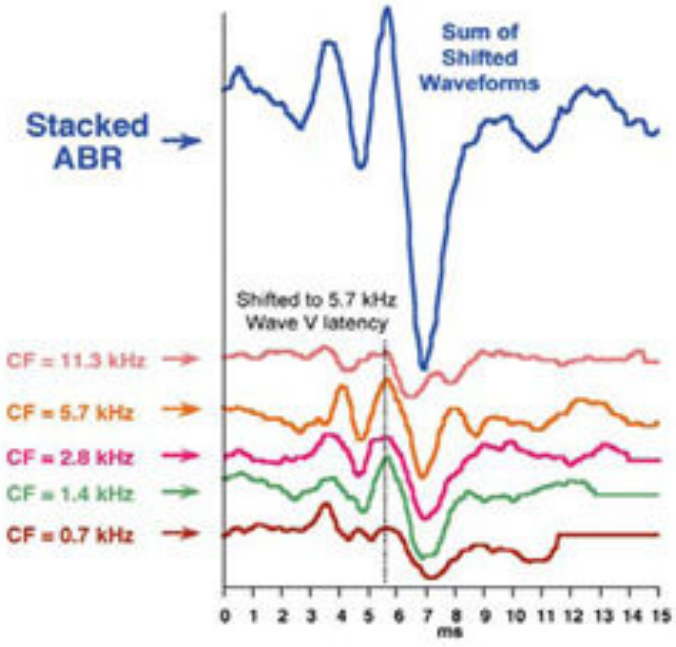

Figure 3.2: Aligned derived-band ABRs to form the Stacked ABR.

CHAPTER 4

RESULTS

The aim of the present study was to develop normative for stacked ABR for the clinical set-up at AIISH, using the derived band method. The study comprised of 17 participants with normal hearing sensitivity and normal neurological functioning. Stacked ABR was obtained for a total of 30 ears (14 right and 16 left ears; N=30). The analysis of the data was carried out using SPSS version 10.0 software.

From each subject, brainstem responses to clicks were recorded in the following stimulus conditions:

1. Click alone.
2. Click + 8000 Hz High-pass masking.
3. Click + 4000 Hz High-pass masking.
4. Click + 2000 Hz High-pass masking.
5. Click + 1000 Hz High-pass masking.
6. Click + 500 Hz High-pass masking.

Following this, the derived band responses were obtained by subtracting the response for one run from the previous run as recommended and standardized in the earlier study (Don, Kwong, Tanaka, Brackmann & Nelson, 2005). Here, the response to clicks + 8 kHz high-pass masking noise was subtracted from the response to clicks alone to form a derived-band ABR (hereafter referred as DB1) with center frequency (CF) = 11.3 kHz. The response to clicks + 4 kHz high-pass masking was subtracted from the response to clicks + 8 kHz high-pass masking to form a derived band ABR (hereafter referred as DB2) with CF = 5.7 kHz. The response to clicks + 2 kHz high-pass masking was subtracted from the response to clicks + 4 kHz high-pass masking

to form a derived band ABR (hereafter referred as DB3) with CF = 2.8 kHz. The response to clicks + 1 kHz high-pass masking was subtracted from the response to clicks + 2 kHz high-pass masking to form a derived band ABR (hereafter referred as DB4) with CF = 1.4 kHz. The response to clicks + 1 kHz high-pass masking was subtracted from the response to clicks + 0.5 kHz high-pass masking to form a derived band ABR (hereafter referred as DB5) with CF = 0.7 kHz. (Refer fig. 4.1)

4.1 Results of the Derived-Band Responses

The Table 4.1 gives the mean and standard deviation (SD) of latency of Wave V for the 5 derived-band responses (DB1, DB2, DB3, DB4 & DB5). The table also gives the mean and standard deviation of latency elicited by clicks alone.

Table 4.1: *The mean and standard deviation (SD) of latency of wave V in the 5 groups of derived-band responses*

Conditions	N	Latency in milliseconds	
		Mean	SD
Clicks	30	5.55	0.18
DB1	30	5.48	0.19
DB2	30	5.85	0.32
DB3	30	6.45	0.33
DB4	30	7.12	0.41
DB5	30	8.24	0.49

It can be seen from the mean data that the mean latency of wave V for derived-bands increases as the high-pass masker is shifted towards lower frequencies. The mean latency is maximum for DB5, followed by DB4, DB3, DB2, and is minimum for DB1.

The Table 4.2 gives the mean and standard deviation (SD) of amplitude of Wave V for the 5 derived-band responses (DB1, DB2, DB3, DB4 & DB5). The table also gives the mean and standard deviation of amplitude elicited by clicks alone.

Table 4.2: *Mean and standard deviation (SD) of amplitude of wave V for the 5 groups of derived-bands responses*

Condition	N	Amplitude in μV	
		Mean	SD
Clicks	30	0.17	0.077
DB1	30	0.068	0.065
DB2	30	0.066	0.161
DB3	30	0.034	0.033
DB4	30	0.048	0.046
DB5	30	0.033	0.031

The mean data showed that amplitude was maximum in click alone condition compared to that in derived band responses. Within the derived responses, the amplitude was maximum in DB1 followed by DB2, DB4, DB3 and DB5.

4.2 Stacked ABR

In each participant, the stacked ABR was calculated by time aligning the 5 derived-band responses and then adding all of them. The peak amplitude of wave V in the stacked response in 30 ears were analysed to obtain mean and standard deviation. Table 4.3 gives the mean, standard deviation (SD) and confidence intervals (CI) of the stacked ABR amplitude. Figure 4.1 shows ABR recordings with different high-pass masking noise derived-band responses.

Table 4.3: *Mean, standard Deviation and Confidence interval of stacked ABR responses.*

Subject no.	Amplitude in µV		Confidence Interval	
	Mean	SD	Lower bound	Upper bound
30	0.2477	0.1856	0.178	0.317

The data was also tested on Kolmogorov-Smirnov test of normality and the results (Z=1.178, p>0.05) showed normal distribution of the stacked ABR amplitudes.

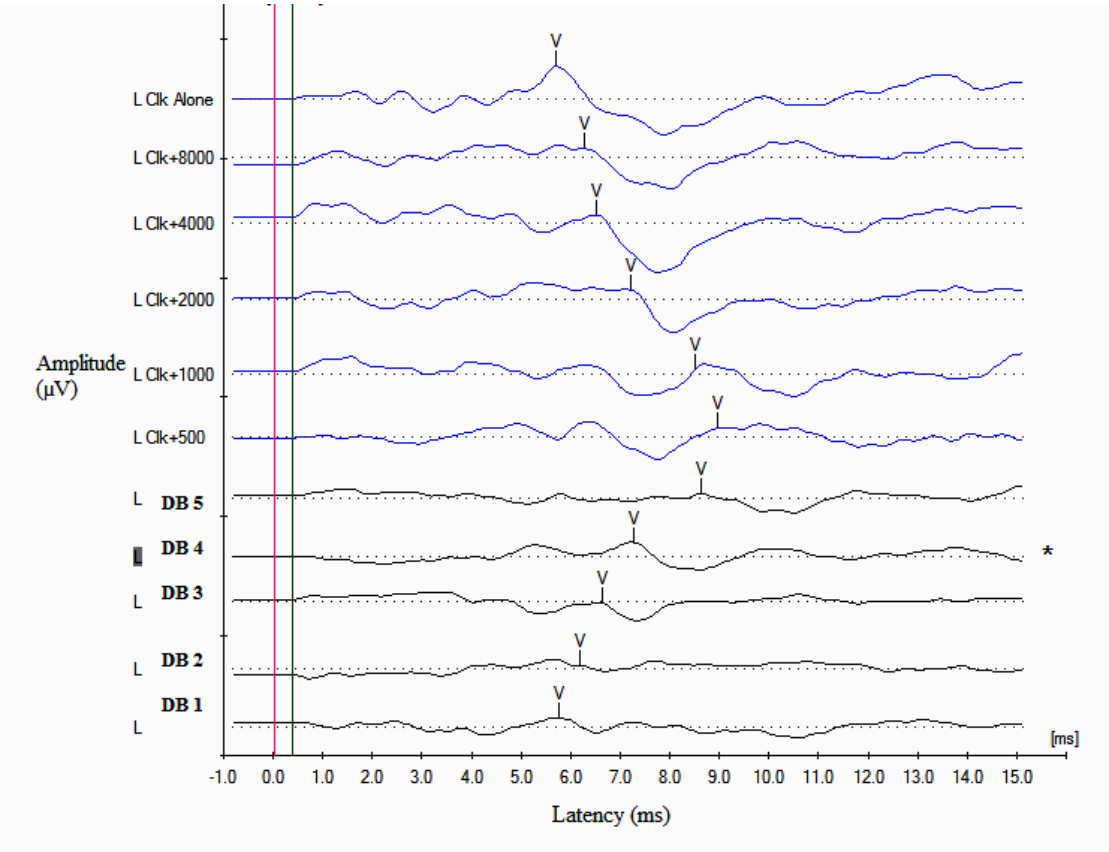

Figure 4.1: Shows the ABR waveforms obtained in different masking conditions and the calculated derived band responses.

CHAPTER 5

DISCUSSION

The results of the present study showed that the derived band responses representing the activity of low frequency nerve fibers had prolonged latency compared to that representing the high frequency nerve fibers. The derived-band responses represent synchronous activity initiated from successive octave-wide regions across the cochlea with the theoretical center frequency of each of the derived-bands (11.3 kHz, 5.7 kHz, 2.8 kHz, 1.4 kHz, and 0.7 kHz). Hence, cochlear travelling wave velocity determines the latency of the derived band 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 derived band 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 derived band responses elicited from high frequency regions. Therefore, it can be inferred that the click-evoked responses are primarily from high frequency nerve fibers innervating the basal region of the cochlea. This justifies the need for the use of stacked ABR as conventional procedure, as the responses evoked by clicks are likely to miss tumours that do not affect sufficient number of high frequency nerve fibers.

The amplitude of wave V of the derived band responses obtained from the lower frequency regions was smaller when compared to the responses obtained from higher frequency regions of the cochlea. This could be due to 2 reasons. One, because brainstem responses are primarily from higher frequency regions of the cochlea (as evident in the latency data), it can be inferred that the number of fibers contributing to the synchronous firing are higher in the basal end compared to apical end. Second, if one keeps the number of fibers constant in the two regions, the synchrony of the high frequency nerve fibers is better than the lower frequency nerve fibers due to the difference in the wave length.

The derived band responses were then time aligned and the amplitude was summed resulting in the Stacked ABR for each of the participants. Data distribution of the stacked ABR amplitudes was tested on Kolmogorov-Smirnov test of normality. Results showed that the data was normally distributed ($Z=1.178$, $p>0.05$).

The mean for the Stacked ABR Wave V amplitude was found to be 0.248μV with a standard deviation (SD) of 0.186. This is different from the earlier study by Don, Ponton, Eggermont, & Masuda (1994) who reported mean amplitude of 0.369 μV and SD of 0.035 μV. An attempt was made to keep the stimulus and acquisition parameters same as that in Don et al's (1994) study. However, there were some differences which could account for the difference in the mean stacked amplitude and standard deviation. One, the equipment and in turn amplifier used in the 2 studies were different. Second, in Don et al's (1994) study the responses were recorded until the background noise levels reached 20 nV or lesser. Whereas in the present study, responses were recorded for 2000 sweeps of clicks and background noise was not monitored. The third factor that is different between the 2 studies test set-up.

This high SD could be attributed to the high SD obtained from the derived band responses with a center frequency of 5.7 kHz. On visual inspection, it was observed that the wave morphology of derived band responses were poorer, particularly for lower frequencies.

Finally, to consider a Stacked ABR response as normal, it should fall within 0.178μV and 0.317μV. Stacked responses with amplitude less than 0.18μV will be indicative of space occupying lesion in the auditory nerve.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The stacked ABR is a measure which reflects the overall neural activity from a wide frequency region of the cochlea in response to auditory stimulation. This overall neural activity is a result of synchronized activity from the various regions of auditory nerve, so that the desynchronization resulting from compression of a small tumour may be evident in reduction of stacked ABR. However, it is important that separate normative is developed for each clinical set up, as the environmental condition and the amplifier of the equipment influences the amplitude measure. Hence the present study was taken up. So the present study aimed at developing normative for stacked ABR using the derived-band method.

ABRs were recorded from adult participants ranging in age from 17-25 years, including both male and female participants. The derived bands were obtained by subtracting the response for one run from the previous run (Don, Kwong, Tanaka, Brackmann & Nelson, 2005). Here, the response to clicks + 8 kHz high-pass masking noise was subtracted from the response to clicks alone to form a derived-band ABR with center frequency (CF) = 11.3 kHz. The response to clicks + 4 kHz high-pass masking was subtracted from the response to clicks + 8 kHz high-pass masking to form a derived band ABR with CF = 5.7 kHz. The response to clicks + 2 kHz high-pass masking was subtracted from the response to clicks + 4 kHz high-pass masking to form a derived band ABR with CF = 2.8 kHz. The response to clicks + 1 kHz high-pass masking was subtracted from the response to clicks + 2 kHz high-pass masking to form a derived band ABR with CF = 1.4 kHz. The response to clicks + 1 kHz high-pass masking was subtracted from the response to clicks + 0.5 kHz high-pass masking

to form a derived band ABR with CF = 0.7 kHz. Derived band responses were then temporally aligned and summed to get the resultant stacked ABR waveform, using Biologic Navigator Pro evoked potential system (version0.7). The peak amplitude of stacked ABR wave V was recorded for each participant.

The data obtained from the participants was then subjected to statistical analysis using SPSS version 10.0. Mean and standard deviation for latency and amplitude of wave V of the derived band responses was calculated. Further, mean, standard deviation and 95% confidence interval for the amplitude for the wave V of stacked ABR was calculated. Data distribution of the stacked ABR amplitudes was tested on Kolmogorov-Smirnov test of normality.

Results of the study showed the following:

1. The derived band responses representing the activity of low frequency nerve fibers had prolonged latency compared to that representing the high frequency nerve fibers.
2. Click, which is a broadband stimulus, have its latency closer to the latency obtained from the derived band responses elicited from high frequency regions.
3. The amplitude of wave V of the derived band responses obtained from the lower frequency regions was smaller when compared to the responses obtained from higher frequency regions of the cochlea.
4. The mean for the Stacked ABR Wave V amplitude was found to be 0.248μV with a standard deviation (SD) of 0.186.

Based on the results it was concluded that to consider a Stacked ABR response as normal, it should fall within 0.178μV and 0.317μV. Also, The equipment and in

turn amplifier used in each clinical setup influences the stacked ABR amplitude. Therefore, it is necessary to develop separated normative data for each clinical setup.

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