EFFECT OF COCHLEAR HEARING LOSS ON TONE BURST EVOKED STACKED AUDITORY BRAINSTEM RESPONSE

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APRIL 2007.

DEDICATED TO

MY PAPA AND MUMMY

&

TO MY TEACHERS

CERTIFICATE

This is to certify that this dissertation entitled **"Effect of CoChlear hearing loss on tone burst evoked stacked auditory brainstem response"** is a bonafide work in part fulfillment of degree of Master of Science (Audiology) of the student registration no: 05AUD020. This has been carried under the guidance of a faculty of this institute and has not been submitted earlier to any other university for award of any diploma or degree.

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DECLARATION

This is to certify that this dissertation entitled **"Effect of cochlear hearing loss on tone burst evoked stacked auditory brainstem response"** is the result of my own study and has not been submitted earlier to any other university for that award of any degree or diploma.

Register Number: 05 AUD020

Mysore
April 2007

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CHAPTER 1

INTRODUCTION

The auditory evoked potentials (AEPs) are the electrical responses of the nervous system to auditory stimuli (Stapells, Picton, Perez-Abalo, Read & Smith, 1985). AEPs have assumed an essential role in the clinical practice of Audiology and the auditory brainstem response (ABR) is the most widely used AEP in clinical Audiology because of its ability for objective threshold estimation without the active participation of subjects in the difficult to test population. Other applications of ABR include detection, localization and monitoring of auditory and neurological deficits which is accomplished by various measures of ABR.

The auditory brainstem response (ABR) has been well accepted as a procedure to detect retrocochlear pathology (Selters & Brackmann, 1977; Chandrasekhar, Brackmann & Devgan, 1995; Selesnick & Jackler, 1992; Welling, Glasscock, Woods & Jackson, 1990; Jerger, Oliver, Chmiel & Rivera, 1986; Starr et al, 1996). However, the sensitivity of ABR in detection of acoustic neuroma, the most common space occupying lesion on the auditory nerve depends on its size and location. There are reports indicating that conventional ABR is not sensitive in detecting small acoustic tumors and small intracanalicular tumors. Tumors of sizes less than 10 mm and small intracanalicular tumors 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).

Studies have reported an increase in incidence of small acoustic tumors over the years (Stangerup et al., 2004). Tos, Charabi and Thomasen (1999) investigated the distribution of diagnosed vestibular schwanomas (VS) of various sizes in Denmark from 1976 to 1995 and reported an increased incidence of intracanalicular tumors (from 0. 4 to 7. 9 VS/million/year) and small tumors (from 13. 3 to 29. 0 VS/million/year). Similar findings have been reported in other parts of the world also (Nestor, Karol, Nutik & Smith, 1988; Moffat, Hardy, Irving, Beynon & Baguley, 1995). Therefore it is essential that audiological tests are developed to identify small acoustic tumors.

To overcome the disadvantage of standard ABR methodology Don, Masuda, Nelson and Brackmann (1997) developed a new ABR measure, called the 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 various regions of the auditory nerve, so desynchronization resulting from compression of a small tumor may be evident in reduction of stacked ABR wave V amplitude (Don, Kwong, Tanaka, Brackmann & Nelson, 2005; Chandrasekhar, Brackmann & Devgan, 1995). Don, Kwong, Tanaka, Brackmann and Nelson (2005) reported that this method has demonstrated 95% sensitivity and 88% specificity in detecting small acoustic tumors.

Need for the study

There is a dearth of literature on stacked ABR especially tone burst evoked stacked ABR. Limited research available on stacked ABR indicates that stacked ABR is sensitive in identification of small acoustic tumors. However, there is a need to standardize this procedure and also study the factors that can affect the amplitude of stacked ABR.

Several investigators have reported that cochlear hearing loss affects various ABR measures such as absolute latencies, inter peak latencies, latency intensity function and amplitude measures (Watson, 1996; Oates & Stapells, 1992; Elberling & Parbo, 1987; Watson, 1999; Coats & Martin, 1977; Rosenhamer, Lindstrom & Lundborg, 1981; Keith & Greville, 1987). There are very few reports investigating effect of cochlear hearing loss on amplitude of wave V. Fowler and Durrant (1994) reported that the amplitude of the waves for click evoked ABR might be smaller in subjects with cochlear hearing loss than in normal hearing subjects. Similar findings have been reported by Xu, Vinck, De Vel and Cauwenberge (1998). There is a dearth of investigations evaluating the effect of cochlear hearing loss on amplitude of wave V for different tone burst frequencies.

As stacked ABR is constructed from conventional ABR obtained at different frequencies, it can be hypothesized that any factor which affects conventional ABR will affect stacked ABR measure. So it can be hypothesized that cochlear hearing loss has an effect on the amplitude of stacked ABR. However, there is a dearth of studies in this area. It is essential to determine the effect of cochlear hearing loss on stacked ABR and consider the effect if any, while using stacked ABR for neurodiagnostic applications. 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 that of those with small tumors with normal hearing. But it is not known whether the amplitude reduction was due to the cochlear hearing loss or due to tumor on the auditory nerve. Further studies need to be carried out to investigate the effect of cochlear hearing loss on stacked ABR.

ABR for five frequencies have been used to obtain stacked ABR to assess the neural integrity across different frequency regions (Don, Kwong, Tanaka, Brackmann & Nelson, 2005; Philibert et al, 2003). However, using lesser number of frequencies may reduce the test time. Also in subjects with mild high frequency loss, ABR for tone bursts of 4000Hz &/or 2000Hz might be absent, but present for tone bursts of other frequencies. At such time it will be useful if stacked ABR can be obtained from ABRs of only two or three frequencies. The amplitude of stacked ABR will depend on the number of waveforms stacked and the frequency of the stimuli used for recording frequency specific ABR. Don, Masuda, Nelson & Brackmann (1997) reported a reduction of 33% of amplitude of derived band stacked ABR when two bands of frequencies were removed in subjects with normal hearing. So a separate normative data needs to be established for stacked ABR obtained from adding different frequency specific ABRs.

Aims of the study

This study was designed to investigate the following aims:

1) To investigate the effect of cochlear hearing loss on amplitude of tone burst ABR.
2) To investigate the effect of the cochlear hearing loss on the tone burst evoked Stacked ABR.
3) To obtain separate normative data for amplitude of stacked ABR obtained from
    - ABR for 500Hz, 1000Hz, 2000Hz & 4000Hz tone bursts.
    - ABR for 500Hz, 1000Hz & 2000Hz tone bursts.
    - ABR for 500Hz & 1000Hz tone bursts.

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; Starr et al, 1996). 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) reported that ABR can be used successfully in detecting acoustic tumors. But in these studies the sizes of the tumors studies were 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).

Levine, Antonelli, Le and Haines (1991) reported that 19 patients with large tumors (>10mm) were detected by standard ABR methodology but there were false negative ABRs when the tumor size was <10mm. The incidence of false negative ABR appears to be greatest in small intracanalicular tumors particularly those involving the superior vestibular nerve (Telian, Kileny, Niparko, Kemink & Graham, 1989; Josey, Glasscock & Jackson, 1988; Josey, Glasscock & Musiek, 1988). 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 lcm 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. 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 <l cm. 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.

Robinette, Bauch, Olsen and Cevette (2000) reviewed 75 patients with acoustic neuromas and divided tumors into 3 groups of small (<l cm), medium (1.1- 2.0cm) and

large (>2cm). 22 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 the small tumors. Zappia, O'Connor, 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 2cm in diameter, it was only 89% for tumors 1 cm or less in diameters.

Thus results of a majority of investigations indicate that conventional ABR measures are ineffective in detecting small acoustic tumors (<lcm). However, a review of literature suggests that the incidence of small acoustic tumours is not very rare. Tos, Stangerup, Caye-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 20vestibular schwanomas /million/yea from 1981 to 1991 in Cambridge region of England. A few investigators report an increase in annual incidence of small acoustic tumors (Stangerup et al., 2004; Tos, Charabi & Thomasen, 1999). Therefore, there is a need to develop Audiological tools to identify small acoustic tumors. Development of stacked ABR is one of the attempts in that direction.

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 freqeuency region of the cochlea in response to auditory stimulation. Using appropriate technique the responses from the 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 the 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 is also hypothesized that the stacked ABR reduces the background residual noise in the ABR waveform and hence reduces the variability seen in the amplitude measures of the ABR (Don, Ponton, Eggermont & Masuda, 1994).

Methods to record stacked ABR

Primarily two methods have been used to record Stacked ABR. They are derived band technique and tone burst method. The procedure used in these methods is described briefly in this section,

a) 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) on 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 clicks 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 cochlear response times 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 is 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 clicks 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 ~ 1 octave wide. The theoretical centre frequency for each derived band is computed as the square root of the product of the two successive high pass filter cutoff frequencies used to form the band (Parker & Thornton, 1978). Thus the theoretical center frequencies of the derived bands used in that investigation are 11.3, 5.7, 2.8, 1.4 & 0.7 kHz. 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 peal latencies of wave V in each derived band coincide, and then adding the shifted derived band waveforms.

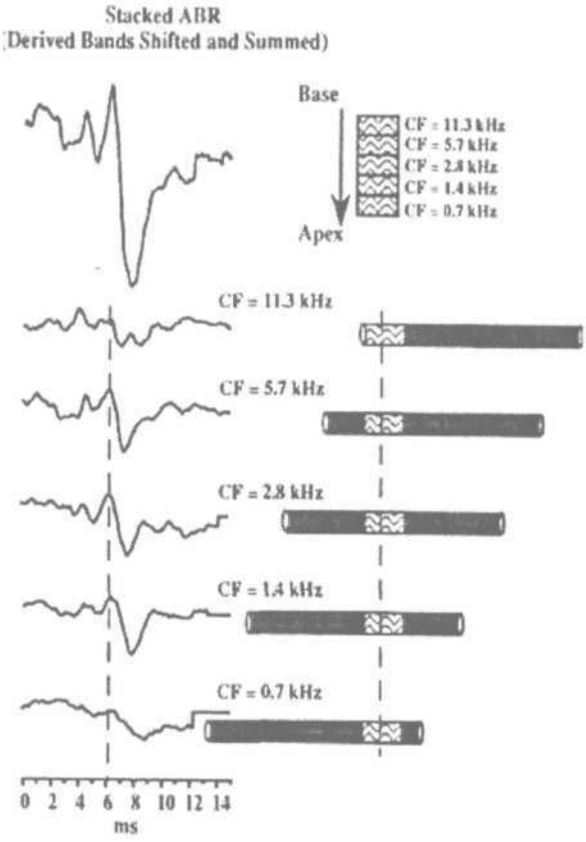

Figure 1. Construction of stacked ABR

(Adopted from Don, Masuda, Nelson & Brackmann, 1997)

The amplitude of the stacked ABR wave V 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, Ponton, Eggermont & Masuda, 1994). The derived band method requires a masking technique that may not be readily available to the clinicians. Furthermore, relatively high level noise required for masking may be annoying to the patient,

b) Tone burst method

Philibert, Durrant, Ferber-Viart, Duclaux, Veuillet and Collet (2003) developed an alternative method called stacked tone burst evoked ABR to overcome the disadvantages of the derived band stacked ABR. It is 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 higher frequencies in the sound will vibrate only the basal region of the basilar membrane and lower frequencies 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; Laikli & Mair, 1986; Gorga & Thornton, 1989). But when stimulus intensity is decreased and 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 hearing individuals subsequently stacked tone burst method was used 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, Masuda, Nelson and Brackmann (1997). The stimulus were presented at 40dBSL (mean = 60dBHL) to record tone burst ABR at different frequencies. Stacked ABR was constructed by temporally aligning the ABR waveforms recorded from different frequencies and subsequently adding them. Wave V was 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.

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 methodology (Don, Masuda, Nelson & Brackmann, 1997; Philibert et al, 2003; Don, Kwong, Tanaka, Brackmann & Nelson, 2005). Don, Masuda, Nelson and Brackmann (1997) demonstrated in a series of 25 tumor cases, five small (≤1cm) 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 1cm in size). These tumors were undetected by standard ABR methodology. The same stringent criteria of amplitude <2SD from mean from 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 0.40μV interaurally. This preliminary study also showed a high sensitivity in detecting small vestibular schwanomas (<l cm). 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^{l} nerve fibers not just a few fibers. The small acoustic tumors often do not affect a sufficient number of 8th 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 the 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 (<l cm).

Factors 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 technique 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 due to 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 0.65μV to 1.3μV (Don, Masuda, Nelson & Brackmann, 1997) in individuals with normal hearing with a mean of around 0.95uV. The Stacked wave V amplitude varied from 0.90μV to 2.2μV in their 10 young normal hearing individuals when tone burst method was used (Philibert et al., 2003).

b) *Frequency:* The ABR to brief tone stimuli consists primarily of wave V and negative following wave V (Stapells & Picton, 1981). The absolute latencies of the responses to low frequency tones are longer than those for high frequency tones presented at the same intensity (Stapells, Picton, & Durieux-Smith, 1994). The prolonged wave V latency for 500 Hz may be due to the longer rise time of the low frequency stimulus (Schwartz, Morris, & Jacobson, 1994; Stapells & Picton, 1981). Gorga, Kaminski, Beauchaine and Jesteadt (1988) studied ABR to tone bursts ranging in frequency from 250 to 8000Hz in normally hearing individuals. The responses were highly reproducible with in individual subjects and ABR thresholds were higher than behavior 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 (500-4000Hz), they 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 will not affect 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 500Hz -2000Hz 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 bursts 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 nonlinear 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 (Stapells & Picton, 1981; Gorga

& Thornton, 1989). When the 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 functions and/or rise time may have an effect on the amplitude of the response and requires separate normative data.

d) *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, Beauchaine & 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 components reaches a plateau in the 40-50dB region, but the fast components (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 500Hz, 1000Hz, 2000Hz, and 4000Hz from 20 adult subjects with normal hearing. The ABRs were detected in 53-73% of the subjects at lOdB SL (sensation level) and 89-100% at 20dBSL.

Philibert et al (2003) used 40dBSL (mean = 60dB HL) presentation to record the tone burst evoked stacked ABR. They reported that difference in sensation levels of the stimuli used 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 population 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 waves progressively increases with 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 Philibert 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 noncephalic placement may evoke ABRs of larger amplitude. It has been reported in literature that vertical montage (vertex to noncephalic placement) enhances wave V of ABR (Schwartz, Morris & Jacobson, 1994). Further studies need to be carried out on effect of electrode montage on stacked ABR.

h) *Filter settings:* It is considered to be a crucial acquisition parameter to consider in recording frequency specific ABR. A high pass setting of 30Hz 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 detectability (Kavanagh & Franks, 1989). A standard filter setting of 30- 3000Hz is recommended for stacked ABR.

i) ***Age:*** The ABR waveform is incomplete at birth (Hall, 1992), with only three major waves observed (I, III & V). Latencies, inter peak latencies progressively shortens, amplitude increases with age and it reaches adult like morphology by 18 months to 2 years (Hecox & Galambos, 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 not a consistent finding (Johansen & Lehn, 1984). Since acoustic neuroma is rare in infants and children but seen more frequently in adults and geriatrics. There is a need for investigate the effect of advancing age on stacked ABR amplitude. 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,

j) *Gender:* Females tend to have shorter latency (about 0. 2 msec 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 method also females had more amplitude than males but the sample size was very small to make any conclusive statement (Philibert et al, 2003).

k) *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 affects 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 a prolongation of all waves, with interpeak intervals remaining with in normal limits (Hood, 1998). The shift in the latency of entire wave form is a result of the reduction in the level of the signal reaching the cochlea by conductive hearing loss. The conductive hearing loss also affects the amplitude of all the waves and reduces the amplitude (Fowler & Durrant, 1994). It primarily attenuates the sound reaching the cochlea producing significant morphological changes. 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 a 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 reduced I-V interval identification (Watson, 1996; Oates & Stapells, 1992; Elberling & Parbo, 1987; Watson, 1999). Similarly wave V latency increases with increasing 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, Worthington, Reilnad, Beauchaine & Goldgar, 1985; Coats & Martin, 1977; Hall, 1992; Coats, 1978; Shepard, 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 hearing 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, 1977).

There is a dearth of literature investigating the effect of cochlear hearing loss on ABR amplitude measures. This scarcity of research may be attributed to the highly variable nature of ABR amplitude measures 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 emissions 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 the hearing loss increased indicating the adverse effect of cochlear loss on wave I and wave V, leading to abnormal ratio. It can be inferred from these results that cochlear hearing loss will have an effect on the amplitude on tone burst evoked stacked ABR

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 that of those with small tumors with 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. Further studies need to be carried out to investigate the effect of cochlear hearing loss on stacked ABR.

Thus a review of literature indicates that there is a dearth of research investigating stacked ABR especially tone burst evoked ABR in individuals with normal hearing. Moreover the effect of cochlear hearing loss on TB evoked stacked ABR is not known. So an attempt has been made in this investigation to assess the effect of cochlear hearing loss on TB evoked stacked ABR and to compare with the norms being established from individuals with normal hearing.

CHAPTER 3

METHOD

The following method was adopted to investigate the effect of cochlear hearing loss on tone burst evoked stacked ABR and amplitude of wave V of tone burst ABR.

A) **Participants:**

Participants of the present study were divided into two groups. Group 1 included individuals with normal hearing and group 2 included individuals with cochlear hearing loss.

Group 1: Thirty five ears of normal hearing individuals aged 15-50 years, who met the following criteria were included in this group.

- Hearing sensitivity with in 15dBHL at octave frequencies between 500Hz and 8000Hz (ANSI-1996).
- Normal middle ear functioning as assessed by tympanometry and acoustic reflex threshold.
- No history of associated otological or neurological disorders.

Group 2: This group included 22 ears with cochlear hearing loss of subjects in the age range of 15-50 years. The other criteria for selection of participants were as follows:

- Pure tone thresholds of less than 55dBHL at octave frequencies between 500Hz and 4000Hz.
- Air bone gap of less than 10dB.
- Normal middle ear functioning as indicated by immittance evaluation.
- Speech identification scores proportional to pure tone average of 500Hz, 1000Hz & 2000Hz.

- No abnormality in click evoked ABR.
- No history of neurological problems

B) **Instrumentation**

The following instruments were used for the study:

- 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. Radio ear B-71 bone vibrator was used for bone conduction testing.
- A calibrated GSI Tympstar middle ear analyzer was used to rule out middle ear pathology.
- Tone burst evoked stacked ABR was recorded using Intelligent Hearing Systems (Smart EP version 3.86) evoked potential systems.

C) **Procedure**

Pure tone audiometery: Pure tone thresholds were obtained at octave frequencies between 250Hz and 8000Hz for air conduction stimuli and from 250Hz to 4000Hz for bone conduction stimuli using modified Hughson-Westlake method (Carhart & Jerger, 1959) in an acoustically treated double room situation.

Immittance evaluation: Tymapanometry was carried out using low frequency probe tone of 226Hz and reflexometery was carried out at 500Hz, 1000Hz, 200Hz and 4000Hz both ipsilateraly and contralteraly to rule out any middle ear pathology.

Tone burst evoked auditory brainstem responses: The participants were instructed to sit comfortably and relax on a reclining chair facing away from the instrument. They were instructed to avoid extraneous movements of head, neck and limbs for the duration of the test. Three silver chloride disc type electrodes were used to record ABR. The inverting electrode was placed on the test ear mastoid, with non inverting electrode on forehead (Fpz) and non test ear mastoid served as ground. Electrode sites were first cleaned by scrubbing with cotton wool dipped in skin preparing paste. It was ensured that electrode impedance was less than 5kohms at each site and inter electrode impedance less than 2kohms. ABR was recorded for the tone bursts using the test protocol given in Table 1.

Table 1: Test protocol for recording ABR.

Type of stimuli	Tone bursts
Transducer	Insert ear phones ER-3 A
Test frequency	500Hz, 1000Hz, 2000Hz, 4000Hz
Duration	2-0-2cycles
Envelope(Gating)	Exact Blackmann
No. of stimuli	2000
Repetition rate	11. 1/s
Test intensity	90dBnHL*
Time window	20ms
Electrode montage	Two channel
Polarity	Alternate
Sensitivity	50uV
Filter settings	30Hz-3000Hz

* OdBnHL = 22dBSPL for 500Hz, 17dBSPL for 1000Hz, 20dBSPL for 2000Hz & 20dBSPL for 4000Hz

The wave V was identified at all test frequencies. The presence of tone ABR was determined by replicating the wave V vertex. The change in latency with change in frequency of the stimuli was also used to confirm the presence of response. The wave V recorded at all frequencies were time aligned and these aligned waveforms were added. The peak-to-trough amplitude of the added waveform was measured.

CHAPTER 4

RESULTS

The aim of the present study was to evaluate effect of cochlear hearing loss on tone burst evoked stacked ABR and amplitude of tone burst ABR. The participants of the present study included two groups, individuals with normal hearing and individuals with cochlear hearing loss. Participants with cochlear hearing loss were further divided into two subgroups:

Group 2a: Individuals with mild cochlear hearing loss whose pure tone average between 26dBHL and 40dBHL were included in this group (N=12 ears).

Group 2b: Individuals with moderate cochlear hearing loss whose pure tone average between 41dBHL and 55dBHL were included in this group (N=10 ears).

Latency and amplitude of wave V of tone burst ABR in individuals with normal hearing:

Table 2 shows the mean latency, amplitude and standard deviation values of wave V for tone bursts of different frequencies for 35 ears with normal hearing. The mean latency for wave V increased with decrease in frequency. The mean amplitude for wave V was largest for 2000Hz tone burst and least for 500Hz tone burst.

Table 2: Latency and amplitude of wave V of tone burst ABR in individuals with normal hearing.

Frequency	Latency in msec		Amplitude in uV	
	Mean	Std Deviation	Mean	Std Deviation
4000Hz	5.80	0.17	0.56	0.15
2000Hz	6.33	0.28	0.60	0.18
1000Hz	6.89	0.34	0.59	0.17
500 Hz	7.74	0.48	0.46	0.14

Latency and amplitude of wave V of tone burst ABR in individuals with cochlear hearing loss:

Table 3 shows the mean latency, amplitude and standard deviation values of wave V at tone bursts of different frequencies for 22 ears with cochlear hearing loss. Here also the same trend was observed i.e. the latency increased with decrease in frequency. The mean amplitude for wave V was largest for 1000Hz tone burst and smallest for 500 Hz tone burst.

Table 3: Latency and amplitude of wave V of tone burst ABR in individuals with cochlear hearing loss.

Frequency	Latency in msec		Amplitude in μV	
	Mean	Std Deviation	Mean	Std Deviation
4000Hz	6.21	0.44	0.31	0.15
2000Hz	6.74	0.45	0.34	0.15
1000Hz	7.56	0.56	0.38	0.13
500 Hz	8.66	0.58	0.27	0.13

Comparison of latency and amplitude of wave V of tone burst ABR in individuals with normal hearing and individuals with cochlear hearing loss

Independent samples t test was carried out to investigate if the difference in mean latency and amplitude is statistically significant. Results revealed that there was a significant difference ($p< 0.001$) in mean latency and mean amplitude of wave V of individuals with normal hearing and individuals with cochlear hearing loss for tone bursts of all the frequencies. The latencies were longer and amplitude was lesser in individuals with cochlear hearing loss when compared to those of individuals with normal hearing.

This was true for ABRs obtained at all the frequencies. Table 4 shows the t values for latency and amplitude of wave V for tone burst of different frequencies.

Table 4: t values between latency and amplitude of wave at tone burst of different frequencies.

Frequency	Latency		Amplitude	
	df	t	df	t
4000Hz	52	-4.834*	52	5.601*
2000Hz	54	-4.145*	54	5.459*
1000Hz	55	-5.631*	55	5.040*
500 Hz	55	-6.504*	55	5.046*

* p<0.00l

Stacked ABR

Separate stacked ABRs were obtained by stacking ABRs for all four frequencies (hereafter called SA), stacking ABR for 500Hz, 1000Hz & 2000Hz (hereafter called SA_3) and stacking ABR for 500Hz & 1000Hz (hereafter called SA2). Mean, standard deviation values and 95% confidence interval for mean amplitude of all the three stacked ABRs were calculated for all the groups. Paired samples t test was performed to check if there is a significant difference among SA, SA3 & SA2. Independent samples t test was carried out to find out if there is a significant difference between amplitude of stacked wave V of individuals with normal hearing and those with cochlear hearing loss. Mann Whitney U test was carried out to check if the mean amplitude of stacked wave V for individuals with mild and moderate hearing loss differed significantly from that of individuals with normal hearing.

Stacked ABR in individuals with normal hearing:

Table 5 shows the mean amplitude and standard deviation values of stacked ABR for 35 ears with normal hearing. The lower and upper bounds of amplitude at 95% confidence interval for mean are also shown for three different stacking are also shown. . The mean amplitude for stacked wave V was largest for SA followed by SA3 and SA2.

Table 5: Amplitude of stacked ABR for individuals with normal hearing for different stacked ABRs in micro volts (µV)

Stacked ABR	N	Mean	Std. Deviation	95% Confidence Interval for Mean	
				Lower bound	Upper bound
SA	35	0.54	0.09	0.50	0.57
SA_3	35	0.53	0.11	0.49	0.57
SA_2	35	0.50	0.14	0.45	0.55

Paired samples t test results revealed that (Table 6) there was no significant difference between amplitude of wave V in SA and SA_3 between SA_3 and SA_2. However there was a significant difference between SA and SA_2 ($p < 0.05$).

Table 6: t values between different stacked ABRs for individuals with normal hearing.

Pairs	df	t
SA - SA_3	34	1.166^+
SA - SA_2	34	2.415*
SA_3 - SA_2	34	1.776^+

* $p<0.05$ $^+$ Not significant

Stacked ABR in individuals with cochlear hearing loss:

Table 7 shows the mean amplitude and standard deviation values of stacked ABR for 22 ears with cochlear hearing loss. The lower and upper bounds of amplitude at 95% confidence interval for mean across three different stackings are also shown. It can be observed from the table that there is not much difference between mean values for amplitude for SA, SA_3 & SA_2. Paired samples t test results revealed that (Table 8) there was no significant difference between amplitudes of SA & SA3, between SA_3 & SA_2 and between SA & SA_2

Table 7: Amplitude of stacked ABR for individuals with cochlear hearing loss for different stacked ABRs in micro volts

Stacked ABR	N	Mean	Std. Deviation	95% Confidence Interval for Mean	
				Lower bound	Upper bound
SA	19	0.30	0.11	0.25	0.36
SA_3	21	0.30	0.11	0.25	0.35
SA_2	22	0.30	0.12	0.25	0.36

Table 8: t values between different stacked ABRs for individuals with cochlear hearing loss

Pairs	df	t
SA - SA_3	18	$.553^+$
SA - SA_2	18	$-.686^+$
SA_3 - SA_2	20	$-.516^+$

Not significant

Table 9 shows the mean amplitude and standard deviation values of 12 ears with mild cochlear hearing loss. The lower and upper bounds of amplitude at 95% confidence interval for mean across three different stackings are also shown. The mean amplitude for stacked wave V is largest for SA than other two stacked ABRs. Paired samples t test results revealed that (Table 10) there was no significant difference between amplitudes of SA & SA_3, between SA_3 & SA_2 and between SA & SA_2.

Table 9: Amplitude of stacked ABR for individuals with mild cochlear hearing loss for different stacked ABRs in micro volts (µV)

Stacked ABR	N	Mean	Std. Deviation	95% Confidence Interval for Mean	
				Lower bound	Upper bound
SA	10	0.36	0.11	0.28	0.44
SA_3	12	0.34	0.09	0.27	0.40
SA_2	12	0.34	0.14	0.25	0.43

Table 10: t values between different stacked ABRs for individuals with mild cochlear hearing loss

Pairs	df	t
SA - SA_3	9	1.857^{+}
SA - SA_2	9	$.045^{+}$
SA_3 - SA_2	11	$-.298^{+}$

Not significant

Table 11 shows the mean amplitude and standard deviation values of 10 ears with moderate cochlear hearing loss. The lower and upper bounds of amplitude at 95% confidence interval for mean across three different stacking are also shown. Here the largest mean amplitude for stacked wave V is largest for S A$_2$ than other two stacked ABRs i.e. SA and SA$_3$. Paired samples t test results revealed that (Table 12) there was no significant difference between amplitudes of SA & SA$_3$, between SA$_3$ & SA$_2$ and between SA & SA$_2$.

Table 11: Amplitude of stacked ABR for individuals with moderate cochlear hearing loss for different stacked ABRs in micro volts (μV)

Stacked ABR	N	Mean	Std. Deviation	95% Confidence Interval for Mean	
				Lower bound	Upper bound
SA	9	0.24	0.08	0.18	0.30
SA$_3$	9	0.25	0.11	0.16	0.34
SA$_2$	10	0.26	0.08	0.20	0.32

Table 12: t values between different stacked ABRs for individuals with moderate cochlear hearing loss

Pairs	df	t
SA-SA$_3$	8	-.858^{+}
SA - SA$_2$	8	-1.083^{+}
SA$_3$ - SA$_2$	8	-.43^{+}

Not significant

Comparison of stacked ABR in individuals with normal hearing and individuals with cochlear hearing loss

Results of independent samples t test revealed that there was a significant difference ($p<0.001$) in mean amplitude of stacked wave V for all stacked ABRs between individuals with normal hearing and individuals with cochlear hearing loss, t-values for different stacked ABRs are shown in table 13.

Table 13: t values at different stacked ABRs

Stacked ABR	df	t
SA	52	7.857*
SA_3	54	7.189*
SA_2	55	5.100*

*P<0.001

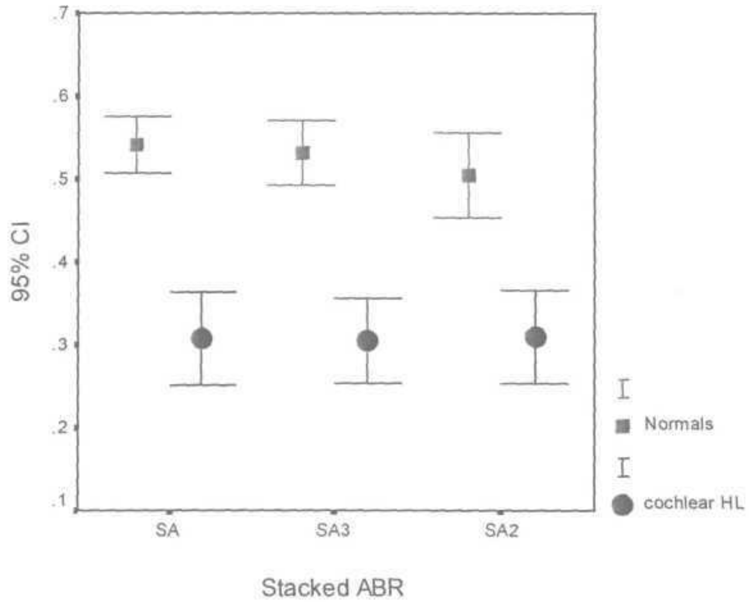

Figure 2: Error bars showing the upper and lower bounds of amplitude at 95% confidence interval at different stacked ABRs for two groups

It can be observed from figure that there is no overlap between the range of 95% confidence interval for individuals with cochlear hearing loss and those with normal hearing for all stacked ABRs. There is a large gap between lower bound of normal hearing and upper bound for cochlear hearing loss group. Due to unequal sample sizes Mann Whitney U test was performed to check if there is a significant difference between individuals with normal hearing and individuals with mild and moderate cochlear hearing loss.

Results of Mann Whitney U test revealed that there is a significant difference ($p<0.01$) in mean amplitude of stacked wave V for all stacked ABRs between individuals with normal hearing and individuals with mild cochlear hearing loss and a significant difference was observed between amplitude of stacked wave V between individuals with normal hearing and individuals with moderate cochlear hearing loss for all stacked ABRs. Amplitude of stacked wave V differed significantly ($p<0.05$) between the individuals with mild hearing loss and individuals with moderate hearing loss for only SA. z-values for different stacked ABRs is shown in table 14.

Table 14: z values of different stacked ABRs for individuals with normal hearing and individuals with cochlear hearing loss.

Stacked ABR	Normal Vs Mild	Normal Vs Moderate	Mild Vs Moderate
	z	z	z
SA	-3.566*	-4.499*	-2.250**
SA_3	-4.189*	-4.063*	-1.460^{+}
SA_2	-3.224*	-4.318*	-1.161^{+}

p<0.001, ** p< 0.01, '"'Not significant

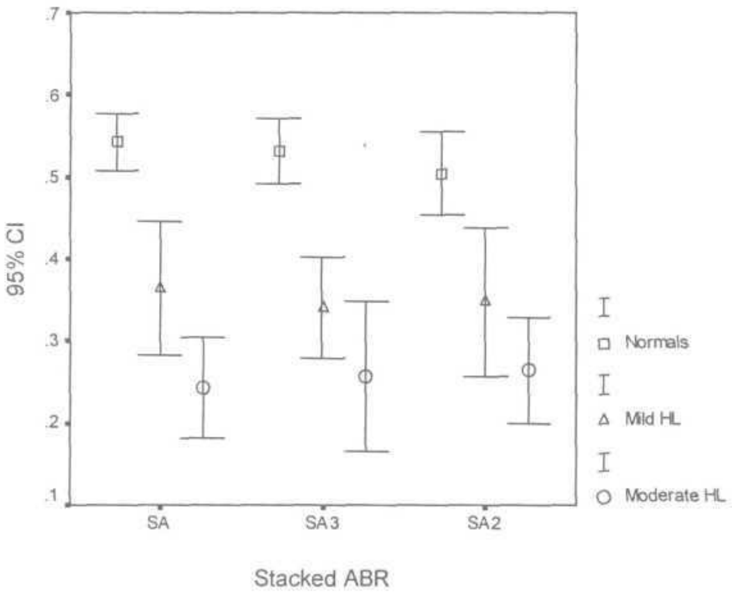

Figure 3: Error bars showing the upper and lower bounds of amplitude at 95% confiden interval at different stacked ABRs for three groups.

It can be observed from figure that the range of 95% confidence interval for individuals with normal hearing loss is extremely different from range for individuals with mild cochlear hearing loss or moderate cochlear hearing at all frequencies. But the ranges of 95% confidence interval for mild hearing loss and moderate hearing loss are overlapping for all stacked ABRs.

So the results revealed that presence of cochlear hearing loss had an effect on amplitude of both standard tone burst ABR and tone burst evoked stacked ABR. The results of the present study in the context of other studies reported in literature are discussed in next chapter.

CHAPTER 5

DISCUSSION

The data analysis revealed that the stacked amplitude was largest when wave V of all the four frequencies were stacked. This amplitude was significantly different from stacked ABR for two frequencies but not from stacked ABR for three frequencies in ears with normal hearing. Such difference in amplitude was not observed for ears with mild or moderate cochlear hearing loss. A significant difference was observed in mean amplitude of stacked wave V for all stacked ABRs between individuals with normal hearing and individuals with mild and moderate cochlear hearing loss, but mean amplitude of stacked wave V differed significantly only for S A between individuals with mild hearing loss and individuals with moderate hearing loss. A significant difference was also observed between mean latency and mean amplitude value of wave V of tone burst ABR at different frequencies between individuals with normal hearing and cochlear hearing loss.

Effect of cochlear hearing loss on tone burst ABR

The latency of tone burst ABR was different for different frequencies in both the group of participants which supports the fact that the different tone bursts stimulated different regions in the cochlea. This finding also gives an indication that even though a high intensity was used to record the ABR in the present study frequency specific information was obtained. In some of the individuals with hearing loss ABR was absent for high frequency tone bursts but present for low frequency tone bursts. The absence of

ABR correlated with degree of hearing loss supporting the fact that tone bursts of different frequencies stimulated different regions in cochlea.

It was observed that there was a decrease in latency with increase in frequency of tone bursts which indicates that cochlear response time for lower frequencies is more than that of higher frequencies (Don, Ponton, Eggermont & Kwong, 1998; Don & Eggermont, 1978). The other possible reason for increase in latency for low frequency TB is the rise time of the stimulus. It has been reported in literature that latency increases with increase in rise time of the stimuli and low frequency stimuli have longer rise time (Stapells & Picton, 1981). The amplitude of wave V was lesser for low frequency stimuli than that of high frequency stimuli. This result is consistent with findings of Gorga, Kaminski, Beauchaine and Jesteadt (1988).

The amplitude of wave V for tone bursts of all the frequencies was reduced in individuals with cochlear hearing loss than those of individuals with normal hearing. Similar results are reported in the literature (Fowler & Durrant, 1994; Xu, Vinck, De Vel & Cauwenberge, 1998). This may be attributed to the fact that amplitude of wave V depicts total neural activity from a particular region of cochlea and cochlear hearing loss reduces this neural activity leading to reduction in amplitude of wave V in individuals with cochlear hearing loss. Also due to increased cochlear response time as a result of cochlear hearing loss (Don, Ponton, Eggermont & Kwong, 1998) latency of wave V of different tone bursts frequencies were delayed in individuals with cochlear hearing loss as compared to individuals with normal hearing. These results are consistent with findings of Gorga, Kaminski, Beauchaine and Scholle (1992).

Effect of cochlear hearing loss on Stacked ABR

Amplitude of stacked wave V in individuals with normal hearing ranged from 0.50uV to 0.57uV for SA, which is lesser than the range reported by Philibert et al (2003). This can be attributed to the differences in the methodology used in the two studies. Philibert et al (2003) tried to approximate the methodology of Don, Masuda, Eggermont and Nelson (1997) and hence used five frequencies to obtain frequency specific ABR. In the present study standard audiometric frequencies were used due to time constraints. Also the duration of the stimuli in the present study was 2-0-2 cycle as compared to 2-1-2 cycle used by Philibert et al (2003).

Results of the present study also showed an increase in stacked wave V amplitude with the increase in the number of frequencies included for stacking in individuals with normal hearing. This may be due to the increase in number of neural elements that contribute to the response (Don, Ponton, Eggermont & Masuda, 1994). So it was observed that SA had more amplitude as it involves four frequencies, which results in more synchronization and higher amplitude in individuals with normal hearing. Don, Masuda, Nelson and Brackmann (1997) also reported similar results in which there were a reduction of 33% of amplitude of derived band evoked stacked ABR when two bands were removed and waveforms were stacked. The reduction in amplitude of stacked wave V with reduction in number of frequencies used in stacking could be because of lesser number of averages in the final stacked ABR. It has been reported in literature that the amplitude of wave V increases with increase in number of averages (Hall, 1992; Hood, 1998). However, studies also indicate that change in amplitude is not significant when the number of averages is increased beyond 2000 (Hall, 1992). In the present study at each frequency 2000 sweeps were averaged. Therefore the effect of number of sweeps on amplitude of ABR would be minimal. Also as the latency was different for different frequencies, it can be hypothesized that reduced stimulation to neural fibers due to cochlear hearing loss lead to the reduction in amplitude of stacked ABR.

In individuals with cochlear hearing loss there was a significant reduction in stacked wave V amplitude for all the stacked ABRs when compared to those of individuals with normal hearing. This may be attributed to the fact that cochlear hearing loss results in abnormal functioning of different neural elements across the cochlea. It is known that stacked ABR is a result of total synchronized neural activity from different neural elements (Don, Kwong, Tanaka, Brackmann & Nelson, 2005). So reduction in input to neural fibers due to cochlear hearing loss will result in a significant reduction in stacked ABR amplitude.

Though the amplitude values of stacked wave V of different stacked ABRs were not significantly different in individuals with mild and moderate cochlear hearing loss, the amplitude was reduced in individuals with moderate hearing loss. This may be attributed to the fact that with the increase in hearing loss there will be more damaged regions in the cochlea which consequently reduces the number of neural fibers stimulated leading to reduced amplitude.

Philibert et al (2003) in their study used equal sensation levels for presentation of stimuli to record tone burst evoked stacked ABR. They reported that there should not be a larger difference in sensation levels of the stimuli between normals and clinical population as it can lead to erroneous results. They further reported that level should be sufficiently high to overcome the hearing loss. There has been a long standing controversy in the field of Audiology as to whether testing should be done carried at equal sensation level or equal hearing level while evaluating individuals with hearing loss. However, there is no satisfactory answer for this. Investigators have reported that in neurodiagnostics it is best to use high stimulus intensity as it is necessary to maximize synchronous neural discharge so that the ABR reflects optimal auditory system capability (Schwartz, Morris, & Jacobson, 1994). It is suggested that to optimize neural discharge a high stimulus level should be used so that wave V latency for most cochlear losses will achieve or come very closer to asymptote, thus falling with in the normal range. Therefore the testing needs to be carried out at equal hearing level.

Don, Kwong, Tanaka, Brackmann and Nelson (2005) also have remarked that compensating for hearing loss might be inappropriate because it may improve specificity of stacked ABR but reduces the sensitivity of stacked ABR. Hence in the present study testing was carried out at equal hearing level. A high intensity signal was used so that it will be possible to evoke ABRs, even when there is hearing loss. Further studies are needed to investigate effect of intensity on stacked ABR.

To summarize the results of the present study indicate that the amplitude of stacked ABR depends on number of tone bursts evoked ABRs used for stacking. The results also revealed that cochlear hearing loss affects the amplitude of stacked ABR and the reduction in amplitude increases with increase in severity of hearing loss.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Auditory brainstem response is readily used in detection of retrocochlear pathology such as acoustic tumors (Selters & Brackmann, 1977; Chandrasekhar, Brackmann & Devgan, 1995). Sensitivity of ABR is high in detecting acoustic tumors of size greater than lcm, but its sensitivity reduces when detecting acoustic tumors of size less than l cm and small intracanalicular tumors (Robinette, Bauch, Olsen & Cevette, 2000; Zappia, O'Connor, Wiet & Dinces, 1997). Stacked ABR is a measure which has been devised to detect small acoustic tumors (≤ l cm) which often go undetected by conventional ABR, the sensitivity and specificity of stacked ABR has been reported to be very high (Don, Masuda, Nelson & Brackmann, 1997; Don, Kwong, Tanaka, Brackmann & Nelson (2005). There is a dearth of research on factors affecting stacked ABR. It is known that cochlear hearing loss affects latency measures and amplitude measures of standard ABR (Watson, 1996; Watson, 1999; Fowler & Durant, 1994). Hence there is a possibility that cochlear hearing loss might affect the stacked ABR as it affects conventional ABR. So, while interpreting stacked ABR the effect of cochlear hearing loss on it should be known. Lesser amplitude of derived band stacked ABR has been observed in individuals with small tumors with hearing loss than that of those with small tumors with normal hearing (Don, Kwong, Tanaka, Brackmann & Nelson, 2005). But it is not known whether the amplitude reduction in those individuals was due to the cochlear hearing loss or due to tumor on the auditory nerve. There is also a dearth of studies investigating the effects of cochlear hearing loss on amplitude of tone burst ABR of different frequencies. Tone burst ABR for high frequencies might be absent in individuals with high frequency hearing loss. In such individuals it will be useful to obtain stacked ABR with two or three frequencies. However, separate normative data are required for the same. So the present study investigated following aims:

1) To investigate the effect of cochlear hearing loss on amplitude of tone burst ABR.
2) To investigate the effect of the cochlear hearing loss on the tone burst evoked stacked ABR.
3) To obtain separate normative data for amplitude of stacked ABR obtained from
    - ABR for 500Hz, 1000Hz, 2000Hz & 4000Hz tone bursts.
    - ABR for 500Hz, 1000Hz & 2000Hz tone bursts.
    - ABR for 500Hz & 1000Hz tone bursts.

Data were collected from a total of 57 participants in the age range 15-50 years, who were divided into two groups. Group 1 included 35 ears with normal hearing sensitivity and group 2 included 22 ears with cochlear hearing loss. Group 2 was further divided into individuals with mild hearing loss (N=12) and individuals with moderate hearing loss (N= 10).

Tone burst evoked stacked ABR was recorded using Intelligent Hearing Systems (Smart EP version 3.86) evoked potential systems. Four frequencies were used (4000Hz, 2000Hz, 1000Hz & 500Hz) to evoke tone burst ABR at 90dBHL. Wave V of ABRs marked at each frequency, were temporally aligned and added to obtain stacked ABR. Wave V peak to peak amplitude was measured for three different stacked ABRs i.e. stacking ABR for all frequencies (4000Hz, 2000Hz, 1000Hz & 500Hz; SA), stacking ABR for three frequencies (2000Hz, 1000Hz & 500Hz; SA_3), stacking ABR for two frequencies (1000Hz & 500Hz; SA_2).

The data obtained from the participants of the study was subjected to statistical analysis using SPSS version 10.0 for windows. Mean, standard deviation values and 95% confidence interval for mean amplitude of stacked V was calculated for all the groups. Independent samples t test was carried out to find out if there is a significant difference between amplitude of stacked wave V, latency and amplitude of wave V of different tone burst frequencies of individuals with normal hearing and those with cochlear hearing loss. Mann Whitney U test was carried out to check if the mean amplitude of stacked wave V for individuals with mild and moderate hearing loss differed significantly from those of individuals with normal hearing.

The following conclusions were drawn from the study

- The amplitude of ABR is largest when ABRs for all the four frequencies are stacked.
- There is a significant difference between mean amplitude of stacked ABR of individuals with normal hearing and individuals with cochlear hearing loss.
- The amplitude of stacked ABR for individuals with mild hearing loss as well as moderate hearing loss is significantly lesser than that of normal individuals.
- Though not statistically significant the amplitude of stacked ABR reduces with increase in degree of hearing loss.
- The latency of wave V of tone burst ABR for all the frequencies is significantly longer in individuals with cochlear hearing loss than those of normal hearing individuals.

- The wave V amplitude of tone burst ABR for all the frequencies is significantly lesser in individuals with cochlear hearing loss than those of normal hearing individuals.
- Amplitude values (in µV) of stacked ABR for individuals with normal hearing and those with cochlear hearing loss are shown in Table 15.

Table 15: Amplitude values for individuals with normal hearing and cochlear hearing loss.

Stacked ABR	Normal hearing	Cochlear hearing loss
SA (4000Hz + 2000Hz + 1000Hz + 0.5 kHz)	0.50-0.57	0.25-0.36
SA_3(2000Hz+1000Hz + 0.5 kHz)	0.49-0.57	0.25-0.35
SA_2 (1000Hz + 0.5 kHz)	0.45-0.55	0.25-0.36

Implications of the study:

Criterion value can also be derived from the data of tone burst evoked ABR and tone burst evoked stacked ABR can be used in differentiating cochlear and retrocochlear pathology. Tone burst evoked stacked ABR may be useful while evaluating individuals with sloping hearing loss, in whom click evoked responses are absent.

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