CHAINED FREQUENCY SPECIFIC TONE BURST STIMULI FOR AIDED ABR THRESHOLD ESTIMATION IN INDIVIDUALS WITH SNHL

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APRIL, 2018

CERTIFICATE

This is to certify that this dissertation entitled '**Chained frequency specific tone burst stimuli for aided ABR threshold estimation in individuals with SNHL'** is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number: 16AUD029. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
April, 2018

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CERTIFICATE

This is to certify that this dissertation entitled '**Chained frequency specific tone burst stimuli for aided ABR threshold estimation in individuals with SNHL'**has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **‘Chained frequency specific tone burst stimuli for aided ABR threshold estimation in individuals with SNHL’**is the result of my own study under the guidance a faculty at All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru, **Registration No. 16AUD029**
April, 2018

DEDICATED TO MY SUPERWOMAN

“AMMA”

AND MY KUDALAN

“ACHA”

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract

Auditory brainstem responses (ABRs) are clinically used to evaluate the peripheral auditory system. As one of its primary clinical application, ABRs serve to estimate hearing thresholds in difficult to test population wherein reliable behavioral thresholds cannot be obtained. The present study tried to explore the use of ABR in the estimation of aided hearing thresholds with the use of multi-frequency ABR (MFABR) which gives frequency specific ABRs of multiple frequencies simultaneously. The aim of this study is to check whether aided ABRs elicited by multi frequency chain of tone burst (MFTB) can be used as a clinical tool for obtaining aided hearing thresholds. Thirty naïve adult male hearing aid users with mild, moderate and severe sensori-neural hearing loss (10 in each group) in the age range of 18 to 50 years participated in the study. The aided thresholds obtained through behavioral and MFABR methods were compared across the three groups at 500Hz, 1000Hz, 2000Hz and 4000Hz. The MFABR thresholds were also compared at all the test frequencies across all the three groups with different degrees of hearing losses. Results showed that aided MFABR thresholds were in close agreement with the aided behavioral thresholds in majority of the test frequencies and across severity of hearing loss. Therefore, it is a promising time efficient tool in rehabilitative audiology as it is in diagnostics, particularly in difficult to test population.

Chapter 1

Introduction

The conventional approach to evaluate hearing aid benefit is comparison method where patient's performance with two or three hearing aids is evaluated using traditional word recognition tests, such as NU-6 and CID W-22 monosyllabic word lists (Carhart, 1946). Such tests are administered to the patient in the sound field, while speech recognition thresholds (SRTs) and word recognition scores are recorded in both unaided and aided conditions to determine if the hearing aids provided benefit. Comparisons are also made among the aided conditions to evaluate the hearing aids to determine which among the hearing aids tested, provided the lowest SRT and the best word recognition score. Unfortunately, these speech perception measures cannot be assessed in very small children and in difficult to test population. In such cases, there are other objective tests which help in hearing aid selection (Mendel, 2007).

Electroacoustic measures, such as real ear measurements, can also be used for selection of hearing aids. However, these have limitations. Real ear measurements are very susceptible to error based on probe tube placement. When comparing devices it is very important to maintain probe tube depth between the two measurements, as subtle changes in placement can offset measurements greatly, especially in the high frequencies. Also, there is a possibility for an outflow of amplification from the open ear canal to reach the reference microphone of the real ear probe. Therefore, the reference microphone receives a combined signal of the test stimulus from the test speaker, and the outflow of amplification from the ear canal. Therefore, the resultant insertion gain indicated by the real ear equipment may be less than what is actually present in the ear canal (Hallenbeck, Coughlin, Whitmer, Dittberner & Bondy, 2008). It was also said that the reliability of real ear measurements is a concern (Bentler &

Niebuhr, 1999). Considering all such factors, it might be difficult to test in children and sometimes, due to the procedural variability, the results might be erroneous.

Electro-physiological tests play an important role while testing difficult to test or pediatric population. Auditory evoked potentials such as tone burst Auditory Brainstem Responses (ABR), Auditory Steady State Responses (ASSR) and Late Latency Responses (LLR) are known to be reliable techniques for estimating frequency specific hearing thresholds. However, these test procedures are not practiced in all clinical set ups due to time constraints. Although ASSRs are quicker in acquisition of frequency specific auditory thresholds, they are highly contaminated by stimulus related artifacts resulting in high false positives (Gorga, Neely, Hoover, Dierking, Beauchaine, & Manning, 2004; John, Brown, Muir, & Picton, 2004; Small & Stapelles, 2004). Even though it is possible to obtain frequency specific thresholds with LLR, its susceptibility to the state of arousal, drugs and longer test duration limits their usefulness. Frequency specific auditory thresholds are vital for fitting hearing aids.

Aided Auditory Brainstem Response (ABR) has the potential to provide objective information concerning hearing aid functional benefit. The most common stimulus used for ABR testing is click, but when it comes to aided ABR threshold estimation it has a few pitfalls. Click stimulus, being very brief, can be significantly distorted both in a sound field speaker and in the hearing aid. The resultant stimulus artifacts may obscure interpretation of the responses. Also, it predominantly estimates hearing between 1000 Hz to 4000 Hz (Emanuel, 2002); but these estimates are not frequency specific.

However, most reports considered use of click evoked ABR to assess how well a hearing aid is working (Kiessling, 1982; Hecox, 1983; Gorga et al., 1988; Davidson et al., 1990). Although some work has been attempted by the use of tone pip stimuli, results showed that the ringing of the tone pip, through the hearing aid, caused reduction in hearing threshold sensitivity (Kileny, 1982). Nevertheless, no ringing was observed and lack of sensitivity to tone pip stimuli was attributed to a smaller activation area of the basilar membrane and maximum stimulus intensity available (100 dB nHL compared with 105 dB nHL for the click stimulus) as stated by Granham, Cope, Durst, McCormick, & Mason, 2000. Responses of tone pip stimuli are inherently more difficult to identify than click-evoked waveforms (Stapells & Oates, 1997).

Kileny (1982) reported a series of case studies using analog hearing aids in which wave V thresholds were used successfully to measure hearing aid benefit in a group of children. He found lower (better) aided wave V thresholds compared with unaided wave V thresholds when the subject was fitted with a hearing aid appropriate for their degree of hearing loss. These results implied that wave V thresholds may be an appropriate measure of hearing aid benefit; however, there were several problems associated with the procedure used by Kileny (1982). For instance, only four cases were discussed in which aided thresholds were measured; therefore, these findings are difficult to generalize to a larger population.

Some researchers have come up with an alternative stimuli called ‘chained stimuli’ generated using tone bursts of different frequencies, chained one after the other with appropriate inter-stimulus interval. There are only a few studies assessing acquisition of ABR with multiple frequency and multiple intensity tone bursts (Mitchell, Fausti, & Frey, 1994; Mitchell, Kempton, Creedon, & Trune, 1996; Curtin, Mitchell, Kempton, Creedon, & Trune, 1999). A study (Mitchell et al., 1996; Mitchell et al., 1999) was done on mice at frequencies above 8000 Hz and there was no significant difference obtained between the single and multiple trains of tone bursts; but this result cannot be directly generalized to human population. In the study by Mitchell, Fausti, & Frey (1994) on humans, the results showed that wave V response latencies from the multiple-stimulus sequences are compared to those presented singly, with small but statistically significant longer latencies observed for all stimuli following the initial stimulus in the multiple sequence. However, they used stimulus frequencies above 8000 Hz, which limits the applicability of the results to study hearing thresholds in human beings.

Instead of eliciting ABRs for tone bursts individually with high repetition rate, a chained stimulus involving all tone bursts in one stimulus can be used with lower repetition rate without causing adaptation. This approach interleaves several discrete stimuli and maximizes acquisition efficiency, while minimizing response adaptation. It is assumed that if the frequency of each discrete stimulus is different enough, then different populations of neurons will be stimulated in sequence, and adaptation will be minimized or avoided even if the inter-stimulus interval is reduced to as low as 10 milliseconds (Mitchell, Fausti, & Frey, 1994; Mitchell, Henry, Kempton, Fausti, & Trune, 1994). Maruthy and Mamatha (2016) obtained hearing thresholds using this multi frequency chain of tone bursts (MFTB) within 30 minutes and found that thresholds obtained using single and multiple chain of tone bursts are comparable and recommended to use MFABR as a routine audiological test to estimate frequency specific hearing thresholds objectively.

This study is mainly focused on using this chained stimulus MFTB to find aided thresholds using ABR as it is frequency specific and not time consuming.

1.1 Need of the study

Hearing aid selection, fitting and evaluation in non-co-operative subjects tend to be very challenging. Very young children or those with developmental difficulties are often unable to provide conclusive behavioral responses. Without these reliable responses, it is difficult to assess the performance of hearing aids even when the theoretical amplification specification is known. Thus, methods of behavioral observation are needed to optimize the fitting of hearing aids in such cases. Objective measures to assess hearing aid performance would potentially aid the management of these subjects. Even though several electrophysiological tests are available for hearing aid selection and verification, there are various limitations to all these tests and the most significant of them all is time constraints along with frequency composition.

The MFABR method was proposed to provide a potential time-efficient objective tool for hearing threshold estimation (Maruthy & Mamatha, 2006). The most common use of objective measures of hearing levels are in infant hearing assessment and hearing aid fitting (Maruthy & Mamatha, 2006). If aided MFABR thresholds can be acquired in adult group with good correlation obtained between behavioral and electrophysiological thresholds, it can be a promising tool in infants as well; for measuring the frequency specific aided thresholds.

Since there is a need for acquisition of aided ABR responses across frequencies within relatively less time duration and on comparing the thresholds between behavioral and electrophysiological results, this technique using chained stimuli with multiple frequency tone bursts could be a promising tool to find aided thresholds.

1.1 Aim of the study

To study aided ABRs elicited by multi frequency chain of tone burst (MFTB) as a clinical tool for obtaining aided hearing thresholds.

1.2 Objectives of the study

1. To compare findings of aided behavioural threshold (the conventional method) and aided ABR threshold using multi frequency chain of tone burst (MFTB).
2. To compare findings of aided ABR threshold estimation using multi frequency chain of tone burst (MFTB) across different degrees of hearing impairment.

1.3 Hypotheses

The null hypotheses of the present study are as follows:

1. There is no significant difference between the aided behavioural threshold (conventional method) and aided ABR threshold obtained using multi frequency chain of tone burst.
2. There is no difference in aided MFABR threshold across different degrees of hearing impairment.

Chapter 2

Review of Literature

Hearing threshold estimation plays a significant role in appropriate diagnosis and rehabilitation. Conventionally, threshold is estimated using behavioral methods such as pure-tone audiometry, behavioral audiometry and visual reinforcement audiometry depending on the age of the patient. Frequency specific threshold estimation is crucial in young children and other difficult to test population (Hall, 1992) to facilitate early identification, precise fitting of hearing aids and rehabilitation (Hoke, Pantev, Ansa, Lutkenhoner, & Herrmann, 1991). Inconsistent behavioral thresholds necessitate the use of objective methods to estimate frequency specific auditory thresholds.

It was the advent of auditory brainstem responses (ABRs) that substantially helped audiologists to estimate auditory thresholds in patients who are not able to provide reliable behavioral thresholds. Click evoked ABRs are generally used in threshold estimation due to its fast acquisition compared to other techniques. However, click being a broadband stimulus does not represent accurate measures of hearing thresholds for any specific frequency, and may completely miss or underestimate hearing loss in particular frequency regions (Eggermont & Don, 1982; Stapells et al., 1994). Hence, frequency specific auditory thresholds are essential for accurate diagnosis and hearing aid fitting.

2.1 Methods to obtain Frequency Specific Auditory Brainstem Responses

There are three general methods to obtain frequency specific information from ABR (Stapells, 1994). They are masking method, derived band technique and the tonal method. The conventional tonal method which is used to obtain frequency specific ABR, stimulates the auditory system with brief tone bursts of short rise times (Suzuki & Horiuchi, 1977; Klein & Teas, 1978; Kodera, Yamada, Yamane & Suzuki, 1978). This approach is limited, however by its excessively long testing time of approximately 2 hours (Karzon & Lieu, 2006; Stueve & O'Rourke, 2003). Furthermore, at high intensities, tone bursts leads to significant spectral splatter degrading the frequency specificity. Consequently, masking techniques have been suggested to obtain frequency specific responses. The masker is meant to eliminate unwanted non-frequency-specific contributions to the ABR by selectively masking cochlear regions which are outside the region to be stimulated either by using notched-noise masking or high-pass masking noise (Terkildsen, Osterhammel, & Huis, 1975; Picton, 1979; Pratt & Bleich, 1982; Jacobson, Deppe, & Murray, 1983; Stapells, Picton, Durieux- Smith, Edwards, & Moran, 1990; Beattie & Kennedy, 1992; Conijn, 1992; Abdala & Folsom, 1995; Oates & Stapells, 1997). Alternatively, the neural activity in specified cochlear regions can also be selectively suppressed by computing the off-line difference-waveform between the masked and unmasked responses by using derived response technique (Eggermont, 1976; Eggermont & Don, 1982) or by using pure-tone masking methods (Pantev, Lagidze, Pantev, & Kevanishvili, 1985).

2.1.1 Auditory Brainstem Responses for Tone Bursts. Gorga, Kaminski and Jesteadt (1988) recorded ABR from 20 normal hearing individuals using tone-burst stimuli which were gated with cosine-squared functions. Responses were obtained for a wide range of frequencies and intensities. In the results, they found that the ABR thresholds were higher than behavioral pure tone thresholds for all the frequencies and more so for lower frequencies such as 250 Hz and 500 Hz. Inter-subject variability was also greater for lower frequencies. Peak V latencies decreased with increase in frequency and intensity. Better responses at higher frequencies were attributed to shorter rise times of the tone burst. The rapid rise times at higher frequencies result in greater discharge synchrony, which in turn results in greater amplitude of the response relative to the background noise. Additionally, the basal end of the cochlea has greater nerve fiber density per unit area when compared to apical turns which also is likely to have contributed, according to Spoendlin (1972). This increased density results in a greater number of neural fibers discharging synchronously for high frequency stimuli.

Dündar et al. (2014) compared thresholds of tone-burst ABR and pure tone audiometry. Eighty patients with sensori-neural hearing loss were part of this study. Tone-burst ABR thresholds were estimated at 500 Hz, 2000 Hz and 4000 Hz, and the differences between tone-burst ABR thresholds and pure-tone thresholds were calculated. The mean difference was found to be 4.75 dB, 6.25 dB, and 4.87 dB at 500 Hz, 2000 Hz and 4000 Hz respectively.

Suzuki, Kodera, and Kaga (1982) compared ABR and behavioral thresholds at 500Hz and 1000Hz, and reported that ABR thresholds were higher than behavioral thresholds. Hayes and Jerger (1982) reported that there is an inherent difference in our ability to elicit an ABR for lower frequencies. The greater variability in the differences between ABR and behavioral thresholds for lower frequencies may be the limiting factor in using tone-burst ABRs to predict behavioral thresholds. However, utility of tone burst ABR to obtain frequency specific responses for all frequencies is limited by its excessively long test time of approximately 2 hours (Stueve & O’Rourke, 2003; Karzon & Lieu, 2006).

Orsini (2004) reported that ABRs obtained by tone bursts which have brief stimulus onset may cause excessive spectral splatter due to the response elicited by adjacent regions of the cochlea which in turn reduces the frequency specificity of the

ABR. It was suggested that introducing notched noise along with the tone burst, limits the evoked response to those frequencies within the notch, thereby reducing the likelihood of spectral splatter and improving frequency specificity.

2.2 Methods to obtain aided thresholds

Aided threshold estimation tests are similar to that of diagnostic hearing threshold estimation. The only difference is the use of amplification device in aided threshold estimation testing.

Behavioral testing is where the individual does something like pressing the response key or raise their hand to let us know that they have heard the sound. In certain other cases, the individual is asked few questions along with traditional word recognition tests to determine the aided thresholds. Comparison between hearing aids also could be done using this method. Thus, this has the advantage of telling us the complete picture about the function of the auditory pathway. This may not be possible to administer in case of difficult-to-test population and pediatric population.

Objective testing does not require the client to participate. The objective tests commonly used for aided thresholds are Acoustic Reflex Audiometry, Auditory Brainstem Responses (ABR), Auditory Late Latency Responses (ALLR), Auditory Steady State Response (ASSR), Mismatch Negativity, Acoustic Change Complex (ACC) and Electro-acoustic tests such as Insertion Gain measurements and Real Ear to Coupler Difference measurements. Hearing aid parameters such as Saturation Sound Pressure Level (SSPL), Dynamic Range, VC setting, gain etc. can be found using Acoustic Reflexes. Unfortunately, this technique is very time consuming and demands subject's patience (Olsen, 1999; Rawool, 2001).

Lightfoot and Kennedy (2006) showed that the mean agreement between audiometric and electrophysiological threshold was 6.5dB and 94% of threshold estimates were within 15 dB. Apeksha and Devi (2010) showed that aided LLRs can also be used to elicit frequency specific responses using speech stimulus such as /ba/ (spectral energy concentration in low frequency), /ga/ (syllable dominated by mid frequency spectral energy) and /da/ (syllable dominated by the high frequency spectral content) to estimate hearing threshold. Results showed that aided ALLR can help in the selection of hearing aids as it mimics the hearing aid processing. However, LLRs are susceptible to the state of arousal and drugs, as well as its longer test duration curtails its practical utility in case of infants and children.

Rance, Dowell, Rickards, Beer, & Clark (1998) found that steady state responses (ASSR), which can be presented at higher levels and at specific frequencies, could provide precise estimates of hearing threshold in children with little or no residual hearing. The literature suggests the existence of many works regarding ASSRs which were recorded when multiple stimuli were presented simultaneously through a sound field speaker and amplified using a hearing aid. Responses were recorded at carrier frequencies of 500, 1000, 2000, and 4000 Hz .The physiologic responses were recorded at intensities close to the behavioral thresholds for sounds in the aided condition, with average differences between the physiologic and behavioral thresholds of 17, 13, 13, and 16 dB for carrier frequencies 500, 1000, 2000, and 4000 Hz. The technique showed great promise as a way to assess aided thresholds objectively in subjects who cannot reliably respond on behavioral testing. (Picton et al., 1998)

Electro-acoustic measurement has some limitations; real ear measurements are very susceptible to errors on probe tube placement. When comparing devices it is very important to maintain probe tube depth between the two measurements as subtle changes in placement can offset measurements greatly, especially in the high frequencies. Also, there is a possibility for an outflow of amplification from the open ear canal to reach the reference microphone of the real ear probe. Therefore, the reference microphone receives a combined signal of the test stimulus from the test speaker, and the outflow of amplification from the ear canal. Therefore, the resultant insertion gain indicated by the real ear equipment may be less than what is actually present in the ear canal (Hallenbeck, Coughlin, Whitmer, Dittberner, & Bondy, 2008). It was also said that the reliability of real ear measurements is a concern (Bentler & Niebuhr, 1999). Considering all such factors, it might be difficult to test in children and also sometimes due to the procedural variability, the results might be erroneous.

2.3 ABR using Multi Frequency Chain of Tone Bursts.

Multi frequency ABR (MFABR) is a new technique, promising to be a valuable addition to the audiological test battery. There have been several noteworthy studies relating to tone bursts on estimating frequency specific hearing thresholds using multi frequency chain of tone bursts.

Mitchell, Kempton, Creedon, and Trune (1996) obtained ABR in mice, for single tone burst and multiple stimulus sequence of tone bursts. The latency and amplitude functions were noted in both the conditions. The stimuli used were 4 kHz to 32 kHz tone bursts. The multiple stimulus sequence consisted of 20 tone-burst sequences of four different frequencies, at five different intensities, each separated by 12ms. Comparison of ABRs for single frequency tone bursts with that of 20 stimulus train showed that there are no significant differences in thresholds. Further, the response latencies or amplitudes showed no significant differences, indicating that the responses from multiple stimuli sequences were not adapted or affected in terms of latency and amplitude of responses. The findings suggested that the use of 20-stimulus train can result in a significant time reduction for acquisition of data compared to single tone burst stimuli. These findings demonstrated the practicality of the acquisition of ABR at different frequencies using a multiple sequence of tone-bursts at different frequencies and intensities. However, the study was carried out on mice and not on human population and also the stimulus frequencies in the current study are above 4 kHz up to 32 kHz. Hence, the results of the study cannot be generalized due to structural and functional differences between the two species. Further, the test frequencies are higher and the results are not applicable to lower audiometric frequencies.

Mitchell, Fausti, and Frey (1994) had also used a similar stimulus for eliciting frequency specific ABRs. Stimuli were tone bursts at 21 frequencies, from 1000 Hz to 32,000 Hz approximately in 1/4-octave steps. These tone- bursts had duration of 2ms, with rise/fall time of 1ms and no plateau, and were produced by gating a continuous sine wave from a synthesizer with an electronic switch. Five experiments in guinea pigs using single and paired tone-burst stimuli were conducted. The intra-pair time and frequency were varied to determine when adaptation measured by a latency delay occurred. Results showed that the adaptation effects are minimal when the time separation is 10 ms or greater in paired-stimulus. Adaptation was reported to be generally less if the frequency of the second stimulus was either above or below that of the first stimulus in paired stimulus. However, this study has been conducted on guinea pigs for a frequency range of 1 kHz to 32 kHz which again cannot be generalized for human population.

Fausti, Mitchell, Frey, Henry, and O'Connor, (1994) recorded ABRs for high-frequency tone bursts in two different methods in a single session. Ten normal hearing subjects participated in the study. Step one involved presentation of four high-frequency tone burst stimuli (14 kHz, 12 kHz, 10 kHz, & 8 kHz) individually to elicit ABRs. Step two involved presentation of multiple stimulus sequence with stimulus onsets separated by 10 ms. Wave V latencies from the multiple stimulus sequences were compared to those presented individually. Results showed that there were small but statistically significant longer latencies observed for all stimuli following the initial stimulus (14 kHz) in the multiple sequence. Test-retest reliability was good between multiple and single conditions. The findings of the above study support the development of this technique for clinical auditory monitoring for threshold estimation with relatively lesser time duration. However, the above study has not been done for frequencies below 8 kHz, which limits the applicability of the results to estimate hearing thresholds in the audiometric frequencies.

Petoe, Bradley, and Wilson (2009) analyzed the variance in latency of Wave V for ABRs evoked by conventional tone bursts and chained stimuli of tone-pulse series stimulation with simultaneous gliding high pass noise Masker 'GHINOMA'. Results showed that frequency-specific ABR can be obtained in less time compared to conventional tone burst stimuli, without compromising on the quality of response.

Maruthy and Mamatha (2016) obtained hearing thresholds using a multi frequency chain of tone bursts 4000, 2000, 1000, and 500 Hz (MFTB) which was of a total duration of 68ms. MFABR thresholds were achieved within 30 minutes and found that thresholds obtained using single and multiple chain of tone bursts are comparable and recommended to use MFABR as a routine audiological test to estimate frequency specific hearing thresholds objectively. They gave several ways to utilize this method such as hearing aid fitting measurements, frequency specific hearing threshold estimation, and time efficiency as it takes only 1/4th of the time that of conventional tone burst ABR.

Overall, the literature suggests that the test-retest reliability of chained stimuli is good and the responses are similar to that with single frequency tone burst. Considering that ABR for chained stimulus is time efficient, its clinical utility if validated in audiometric frequencies seems promising. Furthermore, it could be of great advantage especially in the assessment and rehabilitation of the difficult to test population.

Chapter 3

Methods

The present study aimed to validate aided ABRs elicited by multi frequency chain of tone burst (MFTB) as a clinical tool for obtaining aided thresholds for accurate and appropriate hearing aid fitting. The null hypotheses stated were; 1) there is no significant difference in the aided behavioral threshold (the conventional method) and aided ABR threshold using multi frequency chain of tone burst (MFTB). 2) there is no significant difference between the aided MFABR thresholds obtained across the three groups. The following methodology was adopted to test the above-mentioned hypotheses.

3.1 Participants

Thirty male adult hearing aid users in the age range of 18-50 years divided into three groups of 10 individuals each participated in the study. Group 1, 2, & 3 included individuals with mild, moderate and severe sensori-neural hearing impairment respectively; primarily of cochlear origin. The individuals having a flat audiometric configuration i.e. approximately equal degree of hearing in all test frequencies, the magnitude of difference not exceeding 5-20 dB (Johnson, 1966; Davis, 1998) were considered for the study. The subjects willingly participated in the study and gave written consent prior to the evaluations.

3.1.1 Inclusion criteria. As a criterion for selection, newly fit hearing aid users were selected with flat audiometric configuration in each group. Individuals with at least 75% Speech Identification Scores (SIS) were considered. Only non-smokers and non-alcoholics were considered for the study.

3.1.2 Exclusion criteria.

Participants presented with any of the following conditions were excluded from the study:

- Any history or presence of middle ear disorders
- Any psychological or neurological dysfunction
- Any other condition like tinnitus and ANSD
- If they were under medications for any other ailments

3.2 Test environment

All the participants were subjected to all the audiological tests in an air conditioned acoustically treated and electrically shielded room where the ambient noise levels were within the permissible limits as specified by ANSI S3.1 (R2008).

3.3 Procedure

The test procedure involved preliminary audiological evaluations to qualify the individuals as participants and the actual experimental procedures.

3.3.1 Preliminary Audiological Evaluations.

Pure tone thresholds were estimated in both the ears using modified Hughson and Westlake procedure (Carhart & Jerger, 1959). Hearing thresholds were estimated at octave frequencies between 250 Hz and 8000 Hz for air conduction and from 250 Hz to 4000 Hz for bone conduction stimulation using a dual channel diagnostic audiometer.

Immittance evaluation involved recording tympanograms and acoustic reflexes using a GSI-Tympstar middle ear analyzer. A 226 Hz probe tone at approximately 85 dB SPL was used to obtain the tympanograms by varying the air pressure in the ear canal from +200 to -400 daPa. Ipsilateral and contralateral acoustic reflex thresholds were measured for 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz using the same probe tone frequency. The static admittance and peak pressure were recorded to rule out middle ear pathologies in both the groups. Participants with type 'A' or 'As' tympanogram with reflexes present were selected for the study.

Aided behavioral threshold estimation was done for all subjects in all the groups with a strong class BTE hearing aid of a particular brand. The four channel hearing aid was programmed in first fit with NAL-NL2 prescription formula and acclimatization level two based on their individual hearing sensitivity. The compression settings in the device were turned off, giving linear amplification. Volume control, digital noise reduction, and automatic program selector features were disabled. The same settings were followed for the aided MFABR testing. Aided audiogram was procured at 500, 1000, 2000, & 4000 Hz. Masking was provided whenever it was necessary.

3.3.2 Recording aided ABR using multi frequency chain of tone-burst. The participants were seated on a reclining chair and instructed to relax and minimize extraneous movements. The surface electrode sites were cleaned before placing electrodes and inter electrode impedance was maintained below 5kΩ. Three silver-chloride disc electrodes were placed in vertical montage with Cz being positive, A2 being negative and A1 being the ground electrode sites, and the EEG was recorded. The aided ABR was done in a sound treated room using Biologic Navigator Pro system. The stimulus was presented through FBT Jolly 5R A speaker which was kept at an azimuth of 45^0 and a distance of one meter from the microphone of the hearing aid. The assessment was done using multi frequency chain of tone burst (MFTB) stimuli and the level was decreased in 10 dB steps from 70 dB SPL till the threshold was obtained. The thresholds were converted into dB nHL values after applying the required correction. The threshold in MFABR was defined as the lowest intensity at which ABR V^{th} peak is present in the waveform. All the recordings were replicated and only replicable responses were considered for further analysis. The peaks were marked by two experienced audiologists for reliable measures.

Table 3.1

Stimulus and acquisition parameters for recording ABR

Stimulus parameters	
Transducer type	FBT Jolly 5RA Speaker
Type of stimulus	Multi frequency chain of tone burst
Intensity	Swept from 70dBnHL till threshold
Stimulus polarity	Rarefaction
Stimulus rate	9.1/s
Acquisition parameters	
Analysis time	85ms
Gain	100000
Data points	1024
Artifact rejection	20Mv
Filter setting	100-1500Hz
No of sweeps	1500
Electrode montage	Vertical
Electrode sites	Cz (+) A2(-) A1(ground)

3.4 Test Stimulus

Tone bursts (TBs) of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were used to elicit frequency specific auditory brainstem responses. They were generated using Praat software (version 6.0.30) with 2-0-2 envelope and Hanning window. Accordingly the duration of the stimuli for 4000 Hz, 2000 Hz, 1000 Hz and 500 Hz TBs were 1 ms, 2 ms, 4 ms, and 8 ms respectively. The output SPL of each of the four TBs and the chain were recorded using an SLM (Bruel & Kjaer with Pressure-field 1" microphone type 4144) using standard settings.

To generate a multi frequency chain of tone bursts (MFTB), the same four tone bursts were sequentially linked in the order of 4000 Hz, 2000 Hz, 1000 Hz, and

500 Hz with onset to onset interval being 20 ms. Depending on the stimulus duration, the inter-stimulus interval was (offset of a tone burst to onset of subsequent tone burst) 19 ms (between 4000 Hz & 2000 Hz), 18 ms (between 2000 Hz & 1000 Hz), 16 ms (between 1000 Hz & 500 Hz) and 12 ms (between 500 Hz & 4000 Hz). The total duration of the MFTB was 68 ms. The waveform of the MFTB stimulus is given below in Figure 3.1.

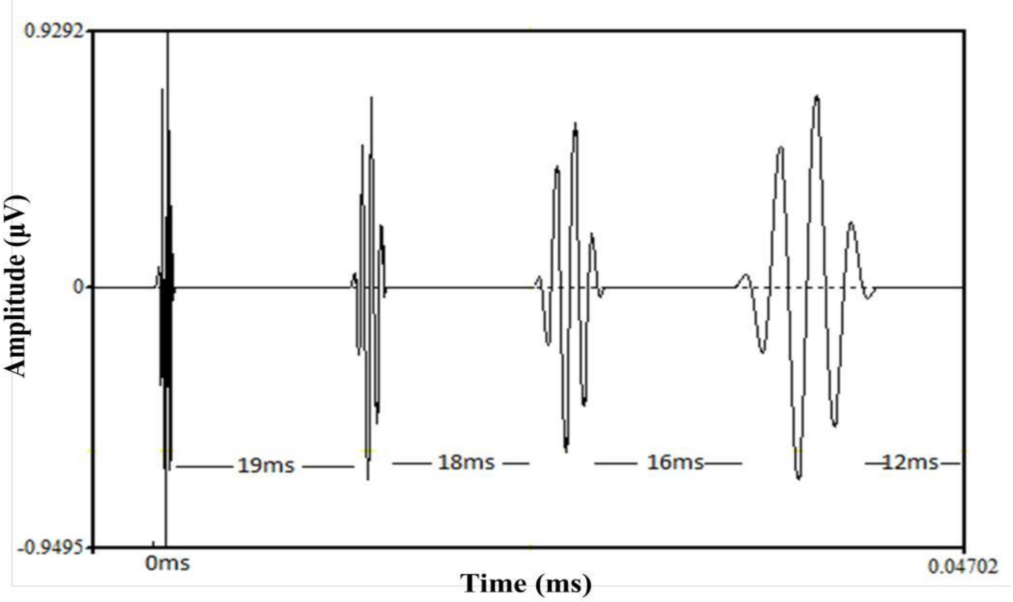

*Figure 3.1.*Waveform of the multi frequency chain of tone bursts.

3.5 Response Analysis

The averaged ABRs were visually analyzed to mark the presence of Jewett waves: I, III and V. The responses were analyzed by two experienced audiologists, with high proficiency in the area of electrophysiology. They judged a response to be present or absent, based on replicability, negative slopes, and latency characteristics. Peak latency of the waves present were noted down from each individual wave. Threshold of ABR was judged based on the lowest intensity at which an ABR (wave V) was visually detected in the waveform.

3.6 Data Analysis

Data were entered on a spreadsheet and correct entry was confirmed prior to analysis. The data was imported into IBM SPSS statistics (version 21) for analysis. The group data was analyzed to derive mean, median and standard deviation of the response parameters. Initially the data were tested for its distribution using Shapiro-Wilks test of normality. Accordingly, Wilcoxon singed rank test was used for comparison between aided thresholds procured through behavioral and MFABR across the three groups- mild, moderate and severe. Further, Spearman’s rank correlation test was used to test the relation between aided thresholds of behavioral and MFABR at each frequency across the three degrees of hearing losses. Kruskal-Wallis test for comparison among the three groups were done. To verify the statistical significance of the comparison Mann-Whitney U test was administered.

Chapter 4

Results

The aim of the present study was to check if aided ABRs elicited by multi frequency chain of tone burst (MFTB) could be used as a clinical tool for obtaining aided hearing thresholds. The measures used for analysis include conventional aided behavioral thresholds and aided ABR thresholds using MFTB. Aided threshold was procured for both behavioral and ABR testing at the frequencies 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. The threshold in MFABR was defined as the lowest intensity at which ABR V^{th} peak is present in the waveform. Results obtained in the present study are reported under the following headings-

1. Descriptives of latency of V^{th} peak obtained using MFABR
2. Results of the test of normality
3. Comparison of aided thresholds obtained through behavioral method and ABR using MFTB
4. Correlation between the thresholds obtained through behavioral method and ABR using MFTB
5. Comparison of aided ABR thresholds obtained using MFTB across different degree of hearing impairment

4.1 Descriptive of latency of Vth peak obtained using MFABR

Descriptive statistics was done to obtain the mean latency of V^{th} peak, for the waveforms acquired using MFABR at all the test frequencies chained in the stimulus i.e., 500, 1000, 2000 and 4000 Hz for all degrees of hearing losses taken up in the study i.e., Group 1- Mild hearing loss, Group 2- Moderate hearing loss and Group 3- Severe hearing loss. The corresponding standard deviations and medians were also given after the analysis and are mentioned in Table 4.1. Refer Figure 4.1 for the waveform obtained using MFTB stimuli.

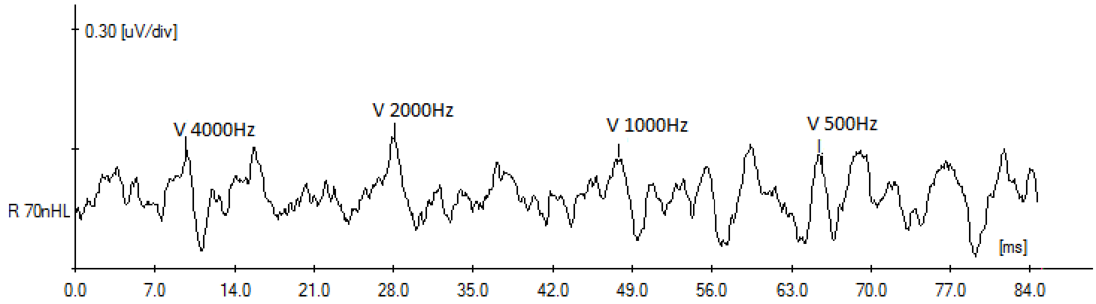

*Figure 4.1.*Waveform with V^{th} peak marked for all test frequencies of MFABR obtained at70 dB nHL

Table 4.1

Mean V^{th} peak latency obtained using MFABR, its standard deviation and median values at different test frequencies

Frequency (Hz)	Severity	Mean	Standard Deviation	Median
500	1	70.12	3.34	70.29
	2	70.96	2.99	71.91
	3	70.22	1.55	70.31
1000	1	49.85	2.73	49.00
	2	48.19	2.17	48.99
	3	48.74	2.32	48.07
2000	1	29.98	2.75	30.41
	2	29.34	2.44	28.57
	3	33.22	1.82	33.17
4000	1	6.36	0.76	6.33
	2	6.73	0.71	6.76
	3	7.07	0.55	7.03

*Note.*1 indicates Mild hearing loss group; 2 indicates Moderate hearing loss and 3 indicates Severe hearing loss

4.2 Results of Test of Normality

The group data was initially tested for its distribution across all the three groups (Group1: mild hearing loss, Group2: moderate hearing loss, Group3: severe hearing loss) and for the two threshold estimation methods using Shapiro-Wilks test of normality. Results showed that the data was not normally distributed ($p > 0.05$).

Hence, non-parametric tests were administered to analyze the data. The variability is accounted to the heterogeneity in the participants of the study. Following the normality test, the below mentioned statistical tests were administered to test the statistical significance of the objectives taken up in the present study.

1. Wilcoxon signed rank test was administered to compare the aided thresholds obtained using conventional behavioural method and electrophysiological method using MFABR.
2. Spearman’s rank correlation test was used to check whether there is any correlation between the thresholds obtained using conventional behavioural method and electrophysiological method using MFABR across frequencies.
3. Kruskal-Wallis test was administered to compare the aided thresholds obtained using MFABR across the three groups (severity of hearing loss).
4. Mann-Whitney U test was performed for parameters which exhibited a significant difference in Kruskal-Wallis test.

4.3 Comparison of aided thresholds obtained through behavioral method and ABR using MFTB.

Descriptive statistics were carried out to find the median of aided behavioral and aided MFABR thresholds. Results of the statistical analysis are given in Table 4.2 and Figure 4.2.

Table 4.2

Median of aided behavioral and aided MFABR thresholds across severity (1- Mild, 2- Moderate, 3- Severe hearing loss) at four test frequencies- 500, 1000, 2000 and 4000 Hz

Frequency (Hz)	Mode	Severity	Median
500	Behavioural	1	21
		2	20
		3	33.5
	MFABR	1	18
		2	19
		3	32
1000	Behavioural	1	24
		2	21
		3	35.5
	MFABR	1	19
		2	19
		3	32
2000	Behavioural	1	26
		2	29
		3	40.5
	MFABR	1	22
		2	20
		3	37
4000	Behavioural	1	32
		2	25
		3	48.5
	MFABR	1	24
		2	22
		3	44

Further, Figure 4.2 depicts the median of unaided, aided behavioral and aided MFABR thresholds obtained for the three groups with mild, moderate and severe hearing loss at the four test frequencies: 500, 1000, 2000 and 4000 Hz.

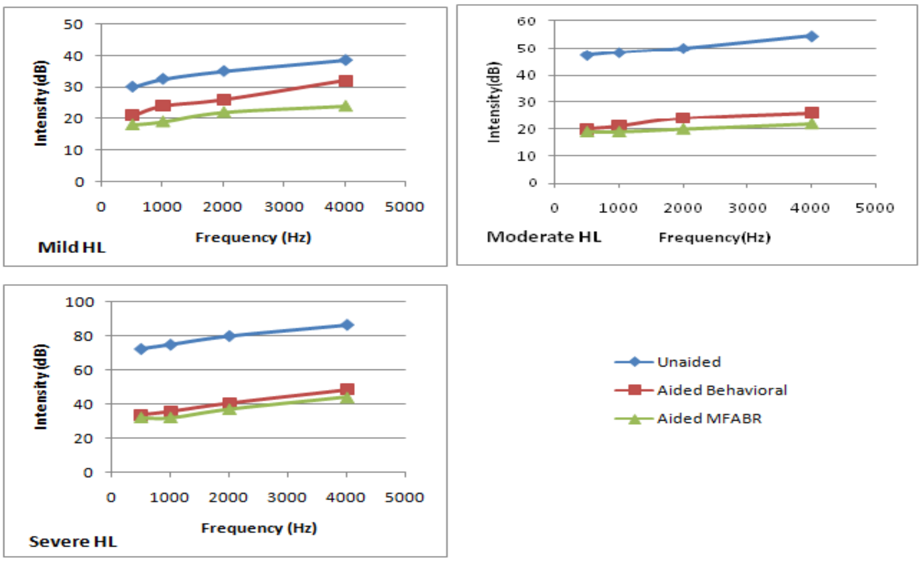

Fig 4.2. Median of unaided, aided behavioral and aided MFABR thresholds obtained for the three groups with mild, moderate and severe hearing loss at the four test frequencies.

On visual inspection of Figure 4.2, it is clear that the aided behavioral and aided MFABR thresholds are comparable in all the test frequencies across the three degree of hearing losses except 4000 Hz. Aided MFABR thresholds are better (1 to 9 dB range) than aided behavioral thresholds across all the three degrees of hearing losses at all the test frequencies.

Aided behavioral threshold was obtained by asking the individual to indicate when there is presence of a pure tone and aided MFABR threshold was defined as the lowest intensity at which ABR V^{th} peak was present in the waveform starting from 70 dB nHL. It is compared across the three groups; Group 1 (Mild hearing loss), Group 2 (Moderate hearing loss), Group 3 (Severe hearing loss) and the same are provided in Table 4.3.

Table 4.3

Results of Wilcoxon signed rank test comparing thresholds obtained using aided behavioral and aided MFABR measurements across three groups (1=Mild HL, 2=Moderate HL, 3=Severe HL)

Frequency	Severity	/Z/	*p*
500 Hz	1	1.730	>0.05
	2	1.000	>0.05
	3	0.647	>0.05
1000 Hz	1	2.232	<0.05*
	2	1.633	>0.05
	3	1.725	>0.05
2000 Hz	1	1.841	>0.05
	2	2.640	<0.05*
	3	1.897	>0.05
4000 Hz	1	2.388	<0.05*
	2	2.699	<0.05*
	3	1.611	>0.05

Note. *indicates $p < 0.05$

Wilcoxon Signed Rank test showed that there was no significant difference ($p > 0.05$) seen between the aided thresholds obtained using behavioral and MFABR at 500 and 2000 Hz; whereas significant difference ($p < 0.05$) was observed at 1000 and 4000 Hz in group 1 (mild hearing loss). In group 2 with moderate hearing loss, there was significant difference seen at 2000 and 4000 Hz, whereas no statistical significance was seen at 500 and 1000 Hz between the aided thresholds obtained using behavioral and MFABR. In severe hearing loss group, there was no significant difference seen in any of the test frequencies.

4.4 Correlation between the thresholds obtained through behavioral method and ABR using MFABR

To test whether the observed relationship between the two thresholds is statistically significant, Spearman’s rank correlation test was used as the data was not normally distributed. The correlation was tested separately at all the four test stimulus frequencies; 4000Hz, 2000Hz, 1000Hz and 500Hz. Table 4.4 gives an insight on the test results.

Table 4.4

Results of Spearman's rank correlation test for correlating thresholds obtained using aided behavioral and aided MFABR measurements across three groups (1=Mild HL, 2=Moderate HL, 3=Severe HL) at all four test frequencies

Frequency	Severity	ρ	*p*
500 Hz	1	0.659	<0.05*
	2	0.770	<0.05*
	3	0.448	>0.05
1000 Hz	1	0.401	>0.05
	2	0.746	<0.05*
	3	0.668	<0.05*
2000 Hz	1	0.727	<0.05*
	2	0.610	>0.05
	3	0.720	<0.05*
4000 Hz	1	0.161	>0.05
	2	0.464	>0.05
	3	0.574	>0.05

Note. *indicates $p < 0.05$

There was significant ($p < 0.05$) correlation between the thresholds obtained using both the methods in group 1 and 2 (mild and moderate HL respectively) whereas no significant correlation ($p > 0.05$) was seen for the 3rd group (severe HL) at 500Hz. At 1000Hz, significance ($p < 0.05$) was seen in group 2 and 3 (moderate and severe HL) and was not seen in group 1 (mild HL). Significant correlation was present between the two methods in group 1 and 3 (mild HL and severe HL) and was absent in group 2 (moderate HL) at 2000Hz. Interestingly, none of the groups showed correlation at 4000 Hz statistically.

4.5 Comparison of aided ABR thresholds obtained using MFTB across different degree of hearing impairment

Kruskal-Wallis test was administered to compare the three independent groups for aided MFABR thresholds. This test indicated a significant effect for MFABR thresholds across all the three groups; mild, moderate and severe hearing impaired individuals for all test frequencies (500, 1000, 2000 and 4000 Hz).The Kruskal-Wallis test results are depicted in Table 4.5.

Table 4.5

Results of Kruskal-Wallis test for comparing the three hearing impaired groups for aided MFABR thresholds

Threshold Frequencies (Hz)	χ^2	*p*
500	18.725	$<0.05^*$
1000	16.382	$<0.05^*$
2000	16.574	$<0.05^*$
4000	20.694	$<0.05^*$

Note. *indicates $p < 0.05$

Further, Mann-Whitney U test was administered to compare between the three groups at all test frequencies (500, 1000, 2000 and 4000 Hz) since the results showed significant difference in Kruskal-Wallis test for all the three groups. Results are depicted in Table 4.6 for the same.

Table 4.6.

Results of Mann- Whitney U test for comparing the three hearing impaired groups for aided MFABR thresholds

Frequency	Severity	/Z/	*p*
500 Hz	1 v/s 2	0.404	>0.05
	1 v/s 3	3.707	$<0.05^*$
	2 v/s 3	3.736	$<0.05^*$
1000 Hz	1 v/s 2	0.000	>0.05
	1 v/s 3	3.404	$<0.05^*$
	2 v/s 3	3.404	$<0.05^*$
2000 Hz	1 v/s 2	0.659	>0.05
	1 v/s 3	3.322	$<0.05^*$
	2 v/s 3	3.603	$<0.05^*$
4000 Hz	1 v/s 2	0.659	>0.05
	1 v/s 3	3.902	$<0.05^*$
	2 v/s 3	3.877	$<0.05^*$

Note. *indicates $p < 0.05$

When Group 1 (mild hearing loss) and 2 (moderate hearing loss) were compared across all the test frequencies no significant difference was seen. All the test frequencies showed significant difference when group 1 (mild hearing loss) and 3 (severe hearing loss) were compared and similar results were seen when group 2 (moderate hearing loss) and 3 (severe hearing loss) were compared.

To summarize, when aided threshold obtained through behavioral and ABR using MFTB were compared across frequencies in each hearing impaired groups it was found that thresholds were comparable at 500 and 2000 Hz and was not comparable at 1000 and 4000 Hz in mild hearing loss group whereas in moderate hearing impaired group, thresholds were comparable at 500 and 1000 Hz and not comparable at 2000 and 4000 Hz. However, thresholds were comparable at all test frequencies in severe hearing loss group.

When aided threshold obtained through ABR using MFTB were compared across mild and moderate hearing impaired groups the thresholds were comparable at all the test frequencies and this was absent when mild v/s severe and moderate v/s severe hearing loss groups were compared.

Chapter 5

Discussion

The research topic was taken up to study whether aided ABRs elicited by multi frequency chain of tone burst (MFTB) can be used as a clinical tool for obtaining aided hearing thresholds. The study also focused on the relation between aided behavioral thresholds and aided MFABR thresholds. The findings of the present study are discussed under the following headings.

1. Comparison between aided behavioral and aided MFABR thresholds
2. Correlation between aided behavioral and aided MFABR thresholds
3. Comparison between MFABR thresholds across three degrees of hearing losses and
4. Utility of the MFABR as a clinical tool.

5.1 Comparison between aided behavioral and aided MFABR thresholds

The present study compared the aided thresholds obtained through behavioral and aided MFABR methods across three degrees of severity; mild, moderate and severe hearing loss at four test frequencies; 500, 1000, 2000 and 4000 Hz.

In mild hearing impaired individuals, there was significant difference in the aided thresholds obtained using behavioral and MFABR at 1000 and 4000 Hz indicating the thresholds were not comparable at these two frequencies whereas at 500 and 2000 Hz there was no significant difference. In moderate impaired individuals, there was significant difference in the aided thresholds obtained using behavioral and MFABR at 2000 and 4000 Hz indicating the thresholds were not comparable at these two frequencies whereas at 500 and 1000 Hz there was no significant difference seen. In severe impaired individuals, there was no significant difference in the aided thresholds obtained using behavioral and MFABR at all test frequencies indicating the thresholds were comparable at these frequencies.

These results suggest that when all the hearing impaired groups are combined, the thresholds were comparable at more than 50% of the test frequencies. Research done by Maruthy and Mamatha (2016) suggested that there was a better agreement between the pure tone thresholds and the MFABR thresholds in SNHL compared to the normal hearing individuals.

The findings are in concordance with Dündar, Kulduk, Soy, Kilavuz, Sakarya, Yazici, & Eren (2014). They studied eighty patients with advanced and very advanced SNHL. Comparison of pure-tone air conduction thresholds of advanced, and very advanced SNHL patients with tone-burst ABR thresholds were made at 500, 2000 and 4000 Hz. They found the differences between tone-burst ABR thresholds and pure-tone thresholds in normal hearing group to be 13 dB, 7 dB, 8 dB for 500, 2000, and 4000 Hz respectively, while the corresponding differences in patients with SNHL were 4.75 dB, 6.25 dB, and 4.87 dB respectively. The better agreement between tone burst ABR thresholds and pure tone thresholds in SNHL group has been often attributed to the steeper loudness growth and larger spread of excitation in SNHL (Dündar et al., 2014).

Since thresholds are comparable across majority of the test frequencies across the three different degrees of hearing losses, the null hypothesis is partially accepted.

5.2 Correlation between aided behavioral and aided MFABR thresholds

In this study, correlation between aided behavioral and aided MFABR thresholds were checked across the four test frequencies viz. 500, 1000, 2000 and 4000 Hz in all three severity of hearing losses.

At 500 Hz, there was correlation between aided behavioral and aided MFABR in mild and moderate hearing impaired groups and there was no correlation between the two methods of aided threshold estimation in severe hearing impaired group. At 1000 Hz, there was correlation between aided behavioral and aided MFABR in moderate and severe hearing impaired groups and there was no correlation between the two methods of aided threshold estimation in mild hearing impaired group. At 2000 Hz, there was correlation between aided behavioral and aided MFABR in mild and severe hearing impaired groups and there was no correlation between the two methods of aided threshold estimation in moderate hearing impaired group. At 4000 Hz, there was no correlation between aided behavioral and aided MFABR in all the three groups: mild, moderate, and severe hearing impaired.

These results correlate with the findings of a study done by Picton et al (1998) in which the physiologic thresholds were quite closely related to the behavioral thresholds except at 4000 Hz where there was significantly greater variability in the relation between the behavioral and physiologic thresholds. In several of the aided subjects, they found that the response at 4000 Hz was not recognized even when the stimuli were significantly above behavioral thresholds. This problem at the high frequencies might be explained on the basis of the abnormal tuning curves for the auditory nerve fibres in cochlea-damaged ears (Kiang, Liberman, & Levine, 1976; Dallos & Harris, 1978). These tuning curves lack the normal high-sensitivity "tip" at the characteristic frequency and have a shape similar to the Bekesy travelling wave with a relatively greater sensitivity to low frequencies than to high. The distorted tuning curves usually maintain their high-frequency cut-off slopes. When multiple stimuli are presented simultaneously, the low-frequency stimuli might interfere with the response to the high-frequency stimulus because of these distorted tuning curves. Although this might occur at high intensities in normal subjects, it occurs close to threshold in subjects with sensori-neural hearing loss.

5.3 Comparison between MFABR thresholds across three degrees of hearing losses- mild, moderate and severe

To find whether the MFABR thresholds are comparable across severity of hearing losses, two groups were compared at a time (mild v/s moderate, mild v/s severe and moderate v/s severe) at all test frequencies: 500, 1000, 2000 and 4000 Hz.

When Mild v/s Moderate hearing impaired groups were compared, there was no significant difference between MFABR thresholds at any frequencies. When Mild v/s Severe and Moderate v/s Severe hearing impaired groups were compared, there was a significant difference between MFABR thresholds at all test frequencies between the groups. The possible reason for this could be ABR thresholds tend to underestimate behavioral thresholds for moderate or greater hearing losses (Rance et al. 2005). Hence, the difference between the aided MFABR thresholds and behavioral thresholds could be lesser for higher degree of losses. Even in another study, similar results were seen when ASSR thresholds tend to agree more closely with behavioral thresholds when severe hearing loss exists (Rance et al. 2005).

Since there is a significant difference in aided MFABR threshold across majority of the hearing impairment groups, the null hypothesis is partially rejected.

5.4 Utility of the MFABR as a clinical tool

During infant hearing screening and hearing aid fitting and in cases of difficult- to- test population, objective measures play a major role. Conventional click evoked ABR has several drawbacks while doing aided electrophysiological testing mainly due to its short duration. The recommended hearing aid fitting process for individuals with hearing impairment is by using real ear insertion gain measurements. The pre-requisite for which is frequency specific hearing thresholds and cooperation of these individuals.

MFABR is a potential time efficient objective tool to acquire frequency specific thresholds for hearing aid fitting as the time taken by it is only $1/4^{th}$ of that of conventional tone burst ABR. The results of the current study successfully validate the use of MFABR as a viable tool for aided threshold estimation and is comparable with behavioral thresholds except at higher frequencies, the reason for this is stated above. This could be the limitation of this stimulus and further research should take care of the same.

Chapter 6

Summary and Conclusions

Estimating reliable behavioral thresholds in infants and non-cooperative (malingering) adults is always a challenge for audiologists. In such instances, obtaining aided behavioral thresholds will become even more difficult and this will hinder the process of rehabilitating the hearing impaired. Then objective techniques play a major role in threshold estimation. Auditory brainstem responses (ABRs) are the widely used auditory evoked potential to estimate unaided hearing thresholds. Aided hearing thresholds are obtained using ALLRs, ASSRs and electro- acoustic measurements when behavioral measurements are unreliable but they all have limitations and are all time consuming.

Therefore, the present study tried to explore the use of ABR in the estimation of aided hearing thresholds with the use of multi-frequency ABR (MFABR) which gives frequency specific ABRs of multiple frequencies simultaneously. The aim of this study is to check whether aided ABRs elicited by multi frequency chain of tone burst (MFTB) can be used as a clinical tool for obtaining aided hearing thresholds, which is likely to take lesser time than all the other methods.

The study was done in 30 male new hearing aid users with mild, moderate and severe flat hearing losses in the age group of 18 to 50 years. Aided behavioral and aided MFABR thresholds were recorded with a strong class BTE hearing aid of a particular brand in the following test frequencies 500, 1000, 2000 and 4000 Hz in all the three groups. The four channel hearing aid was programmed in first fit with NAL-NL2 prescription formula and acclimatization level two based on their individual hearing sensitivity. The compression settings in the device were turned off, giving linear amplification. The MFABR stimulus was given at 70 dB SPL and was decreased in 10dB steps till the threshold was obtained. The threshold in MFABR was defined as the lowest intensity at which ABR Vth peak is present in the waveform.

The data obtained was entered in IBM SPSS statistics (version 21) for analysis. Initially the data were tested for its distribution using Shapiro-Wilks test of normality. Accordingly, Wilcoxon singed rank test was used for comparison between aided thresholds procured through behavioral and MFABR across the three groups- mild, moderate and severe. Further, Spearman's rank correlation test was used to test the relation between aided thresholds of behavioral and MFABR at each frequency across the three degrees of hearing losses. Kruskal-Wallis test for comparison among the three groups were done. To verify the statistical significance of the comparison Mann-Whitney U test was administered.

The results obtained showed that when aided thresholds obtained through behavioral and ABR using MFTB were compared across the three hearing impaired groups; the thresholds were correlating in all frequencies except 4000 Hz. When aided threshold obtained through ABR using MFTB were compared across different groups, significant difference was seen between all the groups except mild v/s moderate.

In conclusion this electrophysiological method using MFABR is a promising procedure to find aided hearing thresholds in pediatrics and difficult- to- test population.

6.1 Implications of the study

1. The aided thresholds obtained using behavioral and MFABR are correlating at all frequencies except for 4000 Hz across all degrees of hearing losses. This indicates the implication of this tool in obtaining aided hearing thresholds when behavioral thresholds are not reliable in paediatric and difficult- to- test population.

2. This can be used in deciding amplification device for individuals with different degrees of hearing losses.

6.2 Limitations of the study

1. The study population should be larger in order to generalize the findings.
2. The programming parameters were all put off in the hearing aid used for the testing which is not the case when we prescribe hearing aids to individuals with hearing impairment.

6.3 Future directions

1. Future studies can focus on using different hearing aid characteristics such as noise reduction algorithms and so on while using MFABR.
2. Studies should be done using MFABR in different configuration of hearing losses.
3. In order to generalize the results in paediatric population, similar study needs to be replicated in the target group.

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