ASSOCIATION BETWEEN SPEECH PERCEPTION MEASURES AND AUDITORY BRAINSTEM RESPONSE TO PAIRED CLICK STIMULATION IN ASSESSING TEMPORAL PROCESSING IN INDIVIDUALS WITH AND WITHOUT COCHLEAR HEARING LOSS

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P01II21S0087

This dissertation is submitted as part of fulfilment for the degree of

Masters of Science in Audiology

University of Mysore, Mysuru

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SEPTEMBER 2023

CERTIFICATE

This is to certify that this dissertation, entitled “**Association between Speech Perception Measures and Auditory Brainstem Response to Paired Click Stimulation in assessing temporal processing in Individuals with and without Cochlear Hearing Loss**” is a Bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student Registration numberP01II21S0087**.** 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
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CERTIFICATE

This is to certify that this dissertation entitled “**Association between Speech Perception Measures and Auditory Brainstem Response to Paired Click Stimulation in assessing temporal processing in Individuals with and without Cochlear Hearing Loss”** is a Bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student Registration numberP01II21S0087. This has been carried out under my supervision and guidance. It is also 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 "**Association between Speech Perception Measures and Auditory Brainstem Response to Paired Click Stimulation in assessing temporal processing in Individuals with and without Cochlear Hearing Loss**" is the result of my own study under the guidance of Mr. Saravanan P**,** Assistant professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier to any other University for award of any other Diploma or Degree.

Mysuru **Registration Number:**P01II21S0087

September, 2023

DEDICATED TO MY FAMILY

ACKNOWLEDGEMENT

First and foremost, I thank the Almighty, whose unwavering grace and blessings have illuminated my path and given me the strength and resilience to pursue my aspirations. The faith instilled in me helped me persevere in moments of doubt and challenge.

I sincerely thank my dissertation guide, ***Mr. Saravanan P****, whose unwavering guidance and expertise have completed this dissertation. Thank you for being such a great mentor from the beginning of my UG life through my PG. You were one of the reasons that I was interested towards audiology.*

I thank my parents for constantly supporting and encouraging me throughout my life. I dedicate this dissertation to you in honor of your enduring commitment to my dreams.

I express my heartfelt appreciation to my grandparents, whose stories and wisdom have enriched my life. You have instilled in me a love for learning. To my siblings, who have been my constant companions, thank you for your unwavering support.

I am deeply indebted to my teachers and staff of AIISH and JIPMER, who have dedicated their time, knowledge, and expertise to nurture my intellectual growth. Your guidance has been transformative, and I am profoundly grateful for the opportunities you have provided. I thank all the JRFs for helping me with data collection.

*Life at AIISH was easier with my friends beside me. I thank Juniya****, Anisha and Sruthi*** *for being there for me from day one at AIISH. I also thank* ***Hrishi, Anirban,Sneha, Joyline, Thejus, Rhea, Dhivagar, Abhishek,*** *my posting partners* ***Ashok, Dwijendra*** *and* ***Vasuki****and all other friends for making my two years of MSc life enjoyable. I also thank my dissertation partner,* ***Nutan,*** *for supporting, encouraging and helping me throughout this journey.*

Last but not least, I thank my batchmates, seniors and juniors for all the love and care

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ABSTRACT

Introduction:

Normal auditory processing is required to understand speech in quiet as well as in noise. Individuals with cochlear hearing loss have difficulty understanding speech in noise. Since speech is dynamic, normal temporal resolution abilities are essential for speech perception in noise. Auditory brainstem response (ABR) using paired click stimulation could be used to neurophysiologically assess the temporal resolution. Speech recognition at a higher sensation level also helps in assessing the temporal processing with respect to the low spontaneous rate fibres which is responsible for the speech encoding at higher intensities.

Aim of the study:

The aim of present study is to assess the temporal processing abilities measured using ABR with paired click stimulation and its relationship with speech perception measures in individuals with normal hearing and cochlear hearing loss.

Objectives:

The objective of the present study includes comparison of ABR with paired click stimulation, measures of speech perception and temporal processing measures in individuals with normal hearing sensitivity and cochlear hearing loss. This study also assesses the relationship between speech perception measures and temporal processing measures using paired click ABR in individuals with normal hearing sensitivity and cochlear hearing loss.

Materials and methods:

Paired click ABR, gap detection threshold(GDT), Speech recognition (SIS 90) at higher sensation levels (90dBSPL) and Quick SIN were measured in 30 participants, 15 normal hearing individuals (30 ears) under Group I and 15 individuals (20 ears) with mild to moderate sensorineural hearing loss under Group II, aged between 18 – 40 years.

Results:

The results showed a statistically significant difference between the recovery threshold of wave V, SIS 90, Quick SIN and GDT between the experimental and the control groups ($P<0.05$). In the control group, GDT and recovery thresholds showed statistically significant difference ($P<0.05$). There was a statistically significant difference between ABR wave V and wave I recovery thresholds in control group ($P<0.05$). The experimental group showed poorer responses in all the tests. In control group there was a statistically significant positive correlation between PTA and Quick SIN ($\rho=0.362$, $p<0.05$) and mild negative correlation between PTA and ABR recovery threshold for wave I ($\rho= -0.454$, $p<0.05$), all the other parameters do not show statistically significant correlation. In the experimental group there was no such relationship found between any of the parameters.

Conclusion:

Recovery thresholds of Paired click ABR responses can be used in assessing the auditory nerve integrity. Since the recovery threshold is a relative measure, it might overcome the limitations of the absolute measures in ABR. Paired click ABR a potential tool in assessing the temporal processing abilities in difficult-to-test population, adults as well as paediatric as is an objective measure.

CHAPTER 1

INTRODUCTION

Temporal processing is the ability of the auditory system to process the signal over time. Temporal processing refers to the time aspects of an auditory or acoustic signal. Because speech stimuli and other background noises change over time, temporal processing is a key component of understanding speech in quiet and in the presence of background noise. The auditory temporal processing is essential for detecting and distinguishing syllables, phonemes, stress patterns, and phonological awareness. Auditory temporal processing includes temporal resolution, the auditory system's ability to detect rapid changes in auditory stimuli (Shinn et al., 2009). Since speech is a dynamic stimulus, temporal resolution ability is essential for normal speech perception. The gap detection threshold is the commonly used test to evaluate the temporal resolution abilities of individuals. Temporal masking assesses how an auditory stimulus masks a preceding and following stimulus. Normal processing of all these aspects is necessary for understanding speech in quiet and adverse listening. Cochlear hearing loss is caused by damage to the inner ear or the auditory branch of the eighth cranial nerve, causing the speech recognition score to be poorer, and these individuals have difficulty understanding speech in background noise. Studies have shown that the ability to understand speech in noise deteriorates with peripheral hearing sensitivity and ageing (CHABA, 1988; Gates & Mills, 2005). In addition, hearing loss and age also affects the cognitive skills and the ability to encode temporal information (CHABA, 1988; Gates & Mills, 2005). According to Kujawa and Liberman, (2015), cochlear synaptic loss is related to hearing loss, including degeneration of the nerves, affecting the resolution of the auditory signals associated with difficulty understanding speech in noisy environments.

Animal studies on auditory brainstem response (ABR) demonstrated changes in ABR wave-I amplitude in animals exposed to noise, which correlates with the loss of synapses, affecting the temporal resolution of complex signals like speech. Among auditory nerve fibres, low spontaneous rate fibres have higher response thresholds, wider dynamic ranges, and are more noise resistant than high spontaneous rate fibres. Animal studies have suggested that low spontaneous rate fibres are more vulnerable to damage due to noise and age-related synaptopathy (Furman et al., 2013). High-spontaneous rate fibres most likely determine the capacity to hear sound in a quiet environment with response thresholds at or near the behavioural detection threshold. Their discharge rate, however, saturates about 20-30 dB over the threshold. Lower spontaneous rate fibres may be especially crucial for widening the dynamic range of hearing because of their greater thresholds and larger dynamic ranges. The preservation of high spontaneous rate fibres could be the reason for no change in the hearing threshold. Bharadwaj et al., (2015), studied envelope following response in individuals with normal hearing thresholds to study the suprathreshold deficits. The results of the study found that individuals with normal hearing thresholds show significant differences in behavioural measures of temporal coding, which correlates with the brainstem physiological measures. Several studies have investigated the relationship between speech perception and amplitude of the ABR wave-I and reported a relationship between speech perception and the ABR measures (Bramhall et al., 2015; Liberman et al., 2016; Ridley et al., 2018; Grant et al., 2020; Mepani et al., 2020) and others have found there is no such relationship between the both (Fulbright et al., 2017; Bramhall et al., 2018; Guest et al., 2018; Guest et al., 2019). Variability in findings could be due to variations in the study population, differences in speech perception tasks and differences in cognitive ability across participants (Bramhall, 2021).

ABR is measured with paired click stimuli, the response to two clicks separated in time by a brief inter-click interval. The response amplitude to the second click, or response recovery, is quantified as a percentage of the response amplitude measured with single click stimulation. At relatively small inter-click intervals (less than 5 ms), the connection between response recovery and inter-click interval offers a measure of temporal resolution. Paired click ABR is the auditory brain stem response elicited using two clicks with some inter-stimulus interval as the stimulus. While using paired click, we will get a wave with the response of click 1 and click 2, respectively. The latency of the later peaks depends on the inter-stimulus interval that is being set. The response amplitude to the second click, or response recovery, is quantified as a percentage of the response amplitude measured with single click stimulation. Studies have shown that the individual differences in ABR wave-I can be reduced using paired click ABR (Lee et al., 2021). The subtraction method separates the response to two clicks from the paired click response (Burkard & Deegan, 1984). Neural recovery is measured using the ABR recovery threshold which is the percentage of neural recovery in paired click ABR. Studies in the literature also showed that the ABR recovery threshold, along with the wave-I amplitude, provides information regarding the changes in hearing function and potentially assesses the temporal processing ability of an auditory system (Lee et al., 2021).

Using paired click stimulus, the presence of the first click affects the response of the second click due to the forward masking effect affecting the ABR wave's amplitude and latency. The preceding masker reduced the auditory nerve response but also caused prolongation of wave V latency. As the delay between the stimuli increased, more recovery from the forward masking was observed. A study done on normal-hearing individuals showed that with the increase in the masker-to-probe interval, the latency of ABR wave V decreased monotonously at 70 dB SPL. The change was very little at 35 dB SPL, which can be related to the level at which the low spontaneous rate fibres respond (Mehraei et al., 2017).

At a higher level, the low spontaneous rate fibres will fire, which is thought to be responsible for higher-level speech encoding. The reduced speech recognition score at a higher level can be associated with synaptic loss and affects middle ear muscle reflexes (Shehorn et al., 2020). According to Parker (2020), auditory nerve untuning occurs in subjects with mild–moderate sensorineural hearing loss, secondary to OHC dysfunction, and OHC function primarily governs the hearing in noise performance. In damaged ears, the compound action potential (CAP) amplitude was less than that of the CAP measured in normal ears. In another study, they found that the CAP amplitude in the hearing-impaired group diminished, and a proportional decrease in the latency of the CAP is seen in mild to moderate cochlear hearing loss (Hoben et al., 2017). Speech perception in noise is affected in cochlear hearing loss, and they exhibit better speech word discrimination in quiet at or near their audiometric thresholds when the stimulus was presented at equivalent sensation levels (Hoben et al., 2017). Individuals with cochlear hearing loss have difficulty in understanding speech, especially in the background noise, and one of the contributing factors, according to Lorenzi et al., (2006), is the reduction in the ability to resolve the frequency component in the complex signals.

Need for the study:

Studies in the literature have reported that auditory brainstem responses (ABR) are used to assess temporal processing objectively in animal models and human participants. ABR waves are recorded in response to the synchronous firing of the auditory nerve fibres and correlate with the auditory system's synaptic integrity (Bramhall, 2021; Mehraei et al., 2016). According to Bramhall (2015), the relationship between ABR measures and speech perception is more apparent when there is associated outer hair cell dysfunction. OHC dysfunction is present in ears with cochlear hearing loss, even if the loss is minimal, and this damage leads to a decrease in the perception of speech in noise. Hearing in noise is affected by the OHC function, i.e., in normal hearing or minimal OHC dysfunction, as the damage to the OHC increases, the effect on hearing in noise diminishes (Parker, 2020). Auditory nerve dysfunction starts from mild hearing loss and exhibits lower CAP amplitude than normal listening individuals (Hoben et al., 2017). When there is damage to OHC or auditory nerve, temporal processing of the signal is affected. Studies in the literature have reported that the ABR wave V latency changes with masking significantly predictor temporal processing measures in animal models(Mehraei et al., 2016). Using animal models, investigators have reported the role of the amplitude of the ABR wave I in identifying damages to cochlear synapses. The amplitude of ABR wave 1 shows huge variability among different human studies. The considerable variations in the amplitude of ABR wave-I among different individuals could be the reason for this debate (Lauter & Loomis, 2009; Bramhall et al., 2015; Bramhall, 2021). The variability can be due to the variability in the background noise during the testing (Suresh & Krishnan, 2021), the testing environment, and differences in head circumference (Bramhall, 2021). Using the relative ABR metrics (Wave I/V amplitude ratio, ABR wave V recovery from forward masking) during paired click stimulation will help reduce the high variability of ABR wave-I in human participants.

Paired click stimulation in ABR assessed temporal processing in humans (Ohashi et al., 2005) and animals (Lee et al., 2021). The amplitude of the ABR wave-I and the ABR recovery threshold in paired click ABR help identify the ear's temporal processing properties. The amplitude of wave I is reported to be reduced in ears with OHC dysfunction and/or auditory nerve damage (Parker, 2020). ABR recovery threshold is reported to be correlated with auditory nerve integrity, confirmed by histopathological findings in an animal study (Lee et al., 2021). Forward masking in paired click ABR assesses the neural recovery of the auditory nerve. Hence, forward masking can identify the deafferentation of auditory nerve fibres (Mehraei et al., 2017). Little is known about the influence of pre-neural cochlear functions, such as outer hair cell function, on these relative ABR metrics. Studying the effect of intact or impaired outer hair cell functioning (in individuals with cochlear hearing loss) on relative ABR metrics will elucidate the relative contribution of outer hair cell functions and auditory nerve functions in speech perception in noise.

A study in the literature has shown that speech recognition at higher sensation levels is degraded for the ears exposed to noise and the reduction in middle ear muscle reflexes. The underlying factor for this reduction is synaptic loss (Shehorn et al., 2020). At higher levels, signals are coded by low spontaneous rate fibres with a high threshold and wide dynamic range. These fibres could be essential in higher-level speech perception (Carney, 2018). In cochlear hearing loss, with mild to moderate degrees, where there is no neural component, it is a confirmed condition that the sensory structures are affected; studying cochlear hearing loss will help us to retrospectively study the effect of sensory loss on the temporal processing using paired click ABR, behavioural measures and speech perception measures.

AIM OF THE STUDY:

The present study aimed to assess the temporal processing abilities measured using auditory brainstem response with paired click stimulation and its relationship with speech perception measures in individuals with normal hearing and cochlear hearing loss.

OBJECTIVES OF THE STUDY:

1. To assess and compare the auditory brainstem response recovery of wave V with paired click stimulation between individuals with normal hearing sensitivity and cochlear hearing loss.
2. To assess the relationship between the speech perception measures and temporal processing measured using auditory brainstem responses in individuals with normal hearing

3. To assess the relationship between the speech perception measures and temporal processing measured using auditory brainstem responses in individuals with cochlear hearing loss.

CHAPTER-II

REVIEW OF LITERATURE

Temporal processing refers to the temporal aspects of an auditory or acoustic signal. Because speech stimuli and other background noises change over time, temporal processing is a key component of understanding speech in quiet and in the presence of background noise. Auditory temporal processing is essential for detecting and distinguishing syllables, phonemes, stress patterns, and phonological awareness. Gates and Mills (2005) said that the ability to understand speech in noise deteriorates with peripheral hearing sensitivity.

Understanding difficulties in the presence of background noises are the major complaints in individuals with cochlear hearing loss. OHC and auditory nerve function plays a major role in hearing in noise and if any of these structures are affected that individuals will have speech understanding in noise problems even if the conventional audiometric studies show normal hearing thresholds. According to Parker (2020), there are 2 major contributing factors to speech understanding problems in normal hearing individuals are the operational cochlear synaptopathy and OHC dysfunction. In individuals with mild to moderate sensorineural hearing loss (SNHL) the AN untuning occurs secondary to the OHC dysfunction which is the third contributing factor for the speech perception in noise difficulties. OHC is the major governing factor for speech in noise difficulties rather than AN (Parker, 2020).

Leigh-Paffenroth & Elangovan (2011) studied the effect of age and hearing loss in middle-aged listeners on temporal processing in eleven normal-hearing young adults, eight normal-hearing middle-aged adults, and nine middle-aged adults with high-frequency sensorineural hearing loss (HFSNHL). The results showed a significant increase in the gap detection thresholds of individuals with HFSNHL compared to their age or pure-tone average (PTA) matched individuals. They concluded that cochlear hearing loss might have an off-channel impact on auditory processing since it significantly increased the gap detection threshold (GDT) for stimulus presented in regions with normal hearing sensitivity.

Liberman and Kujawa (2015) reported that cochlear synaptic loss is related to hearing loss. It can lead to degeneration of the nerves, affecting the resolution of the auditory signals associated with difficulty understanding speech in noisy environments. They also said that the hair cells are the primary targets in cases with acquired SNHL, by far the most frequent kind of SNHL and that the degeneration of sensory neurons happens primarily as a subsequent effect of the loss of their hair cell targets.

Moore (1985) studied frequency selectivity and temporal resolution in normal-hearing listeners and hearing-impaired listeners, and they summarised that speech interpretation problems, especially in noisy situations, are primarily caused by poor frequency selectivity and temporal resolution found in people with cochlear hearing loss.

Electrophysiological measure of temporal processing

Bharadwaj et al., (2015) studied the pattern of individual differences in suprathreshold temporal coding in a cohort of young, normal-hearing adult listeners, consistent with cochlear neuropathy. They examined peripheral cochlear mechanics and hair cell function to see where the problem arose in 26 subjects. They measured envelope-following responses (EFRs), EEGs and 40Hz ASSR as the electrophysiological measures for measuring temporal coding. In addition to these tests, they also did other behavioural tests for temporal coding and tests to see cochlear mechanical function. The results showed that EFR slope metrics strongly correlated with the binaural measures of temporal coding. Cortical EEG correlates of binaural temporal processing showed that the sub-cortical temporal coding fidelity varies across NH listeners, affecting both behaviour and cortical physiology. Analysis of the 40 Hz cortical ASSR, in contrast to the 100 Hz EFR, showed significant between-subject variations in the background cortical activity in the 40 Hz region. They also found that individuals with normal hearing thresholds show substantial individual differences in behavioural measures of temporal coding, which correlates with the brainstem physiological measures.

Mehraei et al., (2016) conducted a study on auditory brainstem response latency in noise in detecting cochlear synaptopathy in both human and animal subjects. They studied 32 human subjects aged between 20 and 40 years and 63 CBA/CaJ male mice for the study. The purpose of their research was to determine (1) whether noise-induced cochlear synaptopathy in animals affects the ABR wave-V latency shifts with the background noise level and (2) whether these shifts are correlated with individual differences in suprathreshold temporal coding in young normal-hearing listeners. The results showed a more significant wave V latency shift with increasing masker levels in normal hearing groups. In mice and humans, ABR wave I amplitude and the masking noise latency shift correlated with the stimulus level and were not correlated with cochlear mechanics. With the help of histopathological examination, animals confirmed a loss of low spontaneous rate fibre before and after the noise exposure. It is assumed that the shift in the latency was due to the loss of these fibres. The authors concluded that differences in the Wave-V latency shift with the noise level and perceptual abilities among normal hearing listeners reflect varying degrees of ANF loss. They also said that ABR wave V latency shift could be used to predict temporal processing in individuals.

ABR and speech recognition

Bramhall et al., (2015) studied 101 ears of 57 adults, ages 19 to 90 years, with a 45 dBHL or better PTA. The study aimed to test the correlation between wave 1 of ABR and speech in noise performance. They analysed the age and relationships between wave I amplitude and speech perception ability in human participants. Speech perception was measured in quiet and in noise. To test in quiet, they used NU-6 wordlist, and in noise testing, they used Quick SIN. ABR was recorded using ear canal electrodes to measure ABR waveforms from each ear. Wave 1 amplitude was measured as the absolute voltage between the peak and the following wave trough. The results showed that as the age increases, the amplitude of the ABR wave I decrease. Reduced amplitude of wave I is associated with decreased performance in speech in noise; the greatest effects were observed in individuals with poorer pure-tone averages. They also found that ABR wave I amplitude is not correlated with speech perception in quiet. They concluded that reduced ABR wave I is an indicator of cochlear degeneration.

Liberman et al., (2016) recruited young adults and divided them into high-risk and low-risk groups based on their exposure history to noise. The subjects were recruited from local colleges and universities who are good in health, have no history of ear or hearing problems or neurological issues and are aged between 18 to 41 years of age. All subjects completed a questionnaire based on which they were divided into groups. They administered pure tone audiometry speech recognition, DPOAEs and electrocochleography. Word recognition was recorded under 5 conditions: in quiet or in the presence of ipsilateral noise at an SNR of 5 dB or 0 dB or after 45% or 65%

digital time compression of original duration, with a reverberation of 0.3 sec added. Cochlear functions were recorded using click evoke auditory brainstem response using a tip-trode electrode. Results showed that wave I was reduced with the damage, and the SP/AP ratio was larger in the high-risk group, nearly twice that of the low-risk group. Results of word recognition tests showed no significant difference between the groups in quiet conditions. In contrast, the high-risk group performed poorer when the test was conducted in ipsilateral noise conditions and SNR of 5dB and 3 dB. Similarly, the high-risk group showed poorer performance in the time-compressed and reverberation conditions than the low-risk group. They concluded that these tests would help us detect the cochlear neural and hair cell damage early.

Ridley et al., (2018) studied 13 normal-hearing adults and 20 adults with sensorineural hearing loss at 4 kHz. This study aimed to construct a statistical model for estimating hidden hearing loss in humans using thresholds in noise as the outcome variable and several experimental measurements, including ABR, which represent the integrity of sites along the auditory pathway as predictor variables. They used outcome measures and experimental measures to test. Outcome measures included thresholds in noise using the TEN test and noise exposure questionnaire (NEQ). Experimental measures included distortion-product otoacoustic emissions, auditory brainstem response (ABR), Electrocochleographic (ECochG) action potential (AP) summating potential (SP) and categorical loudness scaling (CLS). All tests were done at 1 kHz and 4 kHz. ABR and ECochG were done at 80- and 100-dB SPL and DPOAE and CLS were measured at several levels. The ABR and ECochG were measured simultaneously using a tip-trode electrode and surface electrodes. The results of the study showed that speech recognition in quiet was not correlated with OHC function, but speech recognition in noise was correlated with measures that reflect OHC function. Wave I of ABR showed reduced amplitude at 4 kHz at 100 dB PeSPL, which correlated with noise thresholds. More neuronal loss at 4 kHz is suggested by an increase in thresholds-in-noise residual with wave I amplitude ratio. The authors concluded that the prediction of hair-cell degeneration in humans might benefit from considering thresholds in noise, the SP/AP ratio and ABR waves I and V. Their findings support the hypothesis that suprathreshold auditory performance may be caused by inner hair cells and auditory nerve pathology.

Grant et al., (2020) conducted a study on 124 native English-speaking individuals aged between 18- 63 years having good health and no history of any ear or hearing problems and no history. All of their participants had normal audiometric thresholds. The pure tone audiometry, DPOAE, word recognition thresholds and ECochG were measured. Word recognition thresholds were measured in the presence and absence of ipsilateral speech-noise masker, time-compressed 45% or 65% with added reverberation. They measured modified Quick SIN in the presence of a four-talker babble noise at decreasing SNR from 10 to 5, 3, 2, 1, and 0 dB. Masking effects were analyzed by averaging the responses of both ears, and differences between masked and unmasked were computed. Results of word-recognition performance showed excellent scores in all the subjects. However, when present in speech-shaped noise at 0 dB SNR or time compressed and reverberation, the word recognition scores were observed to be poorer. The Quick SIN test also showed comparably large variability. Behavioral thresholds at standard and EHFs were correlated with word recognition scores on some tests, further the age and sex did not correlate to any of these tests. DPOAEs showed a significant correlation between 65% time-compressed scores and DPOAEs at EHFs. In individuals with poorer performance in word scores, SP was larger than AP and AP-P1, and the AP was wider in these individuals. The possible reason for the increase in SP is unclear, and the reduction in AP amplitude and increase in width of AP are consistent with the cochlear nerve deficits in the worst performance group. The authors concluded that word recognition has a strong cochlear component and, along with SP, can be used to measure and track the neural deficits of the cochlear nerve.

Fulbright et al., (2017) studied to assess if the history of recreational noise exposure causes ABR wave I to be smaller and poorer performance in suprathreshold auditory tests. They collected noise exposure history from participants aged between 18 and 30 with hearing thresholds ≤25 dB in octave and mid-octave frequencies. Each individual was administered an otoscopic evaluation, audiometric testing, words in noise, words in broadband noise, DPOAE, ABR, and temporal summation in quiet and noise and noise exposure questionnaire. At 4 kHz, ABR wave I, and audiometric thresholds showed no significant relationship. The relationship between noise exposure and ABR wave I amplitude for click and tone bursts do not show any significant relationship to wave I of both men and women. They found no significant relationship between ABR wave I word in quiet. They concluded that the non-significant results may be due to the participants not being exposed to the noise continuously and frequently for longer durations.

Guest et al., (2018) studied impairment of speech perception measures in noise in individuals with normal audiograms. The study population includes participants aged between 18 and 40 years, with normal audiometric thresholds and no otological or neurological problems. The participants were divided into two groups: the experimental group included individuals with impaired speech in noise scores, and the control group had normal SPiN scores. This study aimed to measure the association between audiometric threshold, ABR measures and noise exposure.

They administered both perceptual and electrophysiological measures. Perceptual measures included audiometry, speech perception in noise: the coordinate response measure (CRM), educational level and cognitive ability and lifetime noise exposure using the noise exposure structured interview (NESI). Electrophysiological measures include ABR and envelope-following responses (EFR). Results showed no significant difference in ABR wave I amplitude for the control and experimental groups. The amplitude ratios of wave I and V showed no association with verified SPiN deficiencies. They concluded that increased lifetime noise exposure and decreased brainstem response amplitudes were absent in people with impaired SPiN and normal audiograms. In humans with normal audiograms, synaptopathy alone does not significantly impact perception.

Bramhall (2021) conducted a review study and summarized studies that used ABR to measure cochlear synaptic function in animal and human models. Several studies have demonstrated that animals with synaptopathy, IHC loss, or spiral ganglion cell loss perform less well than controls on tasks requiring temporal processing and signal-in-noise detection. The authors concluded that ABR wave I amplitude measurement may benefit future clinical evaluation of cochlear synaptopathy/deafferentation.

Sherhorn et al., (2020) studied the association of speech recognition at higher thresholds, middle ear muscle reflex (MEMR) and noise exposure in normal-hearing individuals. Forty-three adults aged 21-54 years were grouped into two groups. They conducted pure-tone audiometry in octave and inter-octave frequencies from 125-8000 Hz and at 10,000, 12,500, and 14,000 Hz. DPOAEs were measured from 2000 Hz to 6000 Hz. Ipsilateral and contralateral wideband MEMR were measured along with ABR, IPD, the Maryland CNC test, The speech subscale of SSQ hearing scale, lifetime noise exposure, tinnitus in the sound booth, Cognitive Trail Making Tests part A and B and total noise exposure were measured. The results showed that the average CNC scores decreased for both groups with increasing presentation levels. They also found that the ipsilateral MEMR was a predictor for CNC scores. They concluded that speech recognition performance in reverberation and noise decreased with increasing presentation levels. The lifetime noise exposure reduces MEMR magnitude, associated with degraded speech recognition at high presentation levels, possibly due to synaptic loss.

Verhulst et al., (2016) conducted a study to assess the individual differences in the characteristics of the ABR waves and their relation to the different aspects of peripheral hearing loss. They simulated ABR wave I and wave V using functional model of auditory periphery and auditory brain stem. The study was conducted on 30 participants with different degrees of sloping audiograms in the high frequency region. They further divided the participants on the basis of their audiogram configurations. They recorded ABR for different levels of 70, 80, 90 and 100 peSPL. The average waveforms for Wave I, III, and V were analyzed to calculate the ABR peak latency, amplitude, and peak-to-peak amplitudes and measured amplitude and latency growth. They found that the more severe the cochlear gain loss, the curves of amplitude and latency became steeper. They also found that in high frequency configuration, the amplitude growth function affects the latency growth function. They also found that in listeners with ABR growth ratio within normal limits, reduced wave V/I ratio showed AN fiber loss and increased wave V/I shows a high frequency sloping configuration. At 100 dB peSPL, in both the individuals with normal hearing as well as the individuals with high frequency audiometric configuration, ABR wave I amplitudes does not show any relationship. The conclusion that they arrived at was that the high-frequency cochlear gain loss aspect of hearing loss has a significant impact on the ABR latency growth metric, ABR level growth may both reflect a steepening due to cochlear gain loss and become shallower due to a lack of high-threshold AN fibres contributing to the suprathreshold ABR amplitude.

Paired click ABR

Mai et al. (2014) conducted a study on infants of 6 weeks and 9 months to investigate the development of temporal processing abilities at the two ages. They also attempted to provide normative values of forward masking using ABR in healthy infants. They took 125 infants 6 weeks old and 104 infants 9 months old who were healthy and had no risk factors or acute or chronic illness. Before starting the testing, they did a hearing screening evaluation using 30 dB nHL click stimuli in both ears and proceeded to the forward masking paradigm, where the initial click was presented at 0.1ms presented at 80 dB nHL, followed by identical stimuli separated by 8 ms, 16 ms or 54 ms. The results showed that the ABR data for 9 months was positively correlated with the ABR data for 6 weeks, suggesting that in 1st year of life, temporal processing development is stable. They investigated ABR differences as a function of the masker-probe interval and found that the latency decreased as the probe-masker interval increased. The authors concluded that 64 ms forward masking interval is a more sensitive interval for developmental assessments in the first year of life.

Davis-Gunter et al. (2001) conducted a study to investigate the successful recording of the summating potential(SP) using a paired click paradigm and to determine if the excitatory postsynaptic potential is reflected in ABR wave I’ potential. The ABR was recorded in three normal hearing subjects aged 7 to 23 years using a standard click followed by seven paired click stimulus intervals of 4 ms, 2 ms, 1 ms, 0.8 ms, 0.4 ms, 0.2 ms and 0.1 ms. Electronic subtraction of the responses was done to yield seven derived responses. They recorded the amplitude and latencies of wave I and wave I’. The generation sites of these peaks are wave I from the distal part of AN; wave I’’s anatomical generator is unknown but hypothesised to be the unmyelinated afferent VIII nerve dendrites. The results showed that wave I’ had a slightly higher latency and smaller amplitude than wave I. They observed specific morphological changes for derived ABRs characterised by splitting major and minor peaks. The latencies of Wave I showed a positive moderate correlation for wave I (0.70), wave I’ showed a positive but low correlation (0.30), and wave I showed a low negative correlation of - 0.30. The amplitude of waves I° and I’ showed zero correlation, while Wave I showed a moderate positive correlation for wave I (0.70). They hypothesised that Wave I° represents the cochlear SP wave I’ represents the summation of neural EPSPs and waves I through V remain same in the derived ABRs.

Bidelman & Syed Khaja (2014) assessed the spectro-temporal tradeoffs of auditory processing by investigating how the neurophysiological encoding of fast temporal events may predict behavioral spectral acuity. They conducted the study on ten normal-hearing individuals using behavioral and electrophysiological measures. Behavioral measures included frequency difference limen (FDL) measured using a three alternative forced choice (3AFC) discrimination task, psychophysical tuning curves (PTCs) were used to assess the frequency selectivity and filter sharpness was quantified using the quality (Q) factor of the auditory filter. The electrophysiological measure included ABR measurement at 91.8 peSPL. ABR recovery was calculated. The results of behavioral FDL were on the order of ∼1–2%, PTCs showed a typical V-shaped with a low-frequency tail, highly selective tip frequency, and steep high-frequency skirt. ABR temporal recovery showed a monotonic increase in the recovery as the ICI increased. The recovery in the longest and shortest intervals showed a significant difference. The 50% ABR recovery showed a reliable threshold of ～4 ms. Behavioral FDLs and ABR temporal measures showed no correlation, whereas ABR response recovery negatively correlated with behavioral Q10. The strong correlation between behavioural measures and ABR temporal thresholds suggests a sharper, more selective frequency tuning indicating poorer auditory temporal resolution. They concluded that the temporal resolution of ABR correlates well with the psychophysical measure.

Mehrai et al., (2017) on twenty subjects aged between 20-40 years with pure-tone thresholds better than 20 dB hearing level (HL) in the tested ear at octave frequencies between 0.25 and 8 kHz. They studied ABR latency in forward-making as a marker of sensory deficits in normal-hearing individuals. They did a forward masking behavioural experiment using an AFC package using a 100ms broadband noise as the masker and chirp as the probe tone. The masker was presented at two different intensities, 35dB SPL and 70dB SPL. Forward masking ABR was recorded using the same stimulus for behavioural measures but presented at 90dB peSPL and three MPI intervals of 20 ms, 40 ms and 201 ms. They also measured forwarding masking recovery and forward masking simulation in the auditory nerve. The results showed that in forward masking ABR, the latency of ABR wave V changed very little when the masker was presented at 35 dB SPL and a monotonic decrease in the wave V latency was seen with increasing MPI at 70 dB SPL. A strong effect of forward masking in the ABR and detection thresholds was observed when the masker level was increased to 70 dB SPL, at which low-SR contributions to the response should be relatively high. They also found that the AN probe response increase is comparatively faster when low-SR fibres are selectively lost than when both low- and high-SR fibres are included in the combined response. The study concluded that young NHT listeners' sensitivity to temporal structure in forward masking, both perceptually and in the ABR, varies significantly from that of the general population. They also saw that changes in the ABR wave V latency in forward masking are related to individual differences in forward masking detection thresholds, correlating speech intelligibility in noise.

Lee et al., (2021) conducted a study on twenty-two male Sprague Dawley rats (6 weeks old). They investigated the significance of recording auditory evoked potentials in response to paired click stimuli to evaluate the function of ribbon synapses in temporal processing in noise-induced cochlear synaptopathy. The recording was done using needle electrodes placed in each animal under anaesthesia. The ABR recording was done before and at 1, 3, 7 and 14 days after noise exposure for tone burst stimuli, and ABR recovery was measured before and at 7 and 14 days after noise exposure. The results showed a significant difference in the averaged peak I amplitude at all frequencies before and after noise exposure. The recovery happened for averaged peak 1 amplitude at 8 and 12 kHz after 14 days of noise exposure, and at 16 and 32 kHz didn't recover even after 14 days post-exposure. Paired click stimuli was used to investigate the temporal processing abilities after the noise exposure and found 100% recovery at ICI 20 ms and decreased at shorter ICI. They also found that the ABR recovery threshold and amplitude of peak 1 were significantly correlated with the number of synapses at 16 kHz and 32 kHz. The study concluded that for diagnosing synaptic health in NICS, measuring ABRs to paired click stimuli may be helpful in addition to ABR peak I amplitude. Furthermore, using the paired click paradigm in the clinic, the individual difference of ABR wave I amplitude can also be decreased.

Burkard and Deegan (1984) studied the use of digital response subtraction of auditory brainstem response to paired click stimuli. They took 6 subjects with normal hearing sensitivity without otological and neurological complaints. They recorded ABR sessions for control single-click stimuli and experimental paired click stimuli. The results showed that at the shortest (0.5-2 ms) inter-click interval (ICI), only single clicks were apparent; as the ICI increases, the identification of wave V becomes easier. Digital subtraction improved the resolution of paired clicks, and they could identify responses below 3 ms. They found a latency shift in the click 1 response at longer ICIs. Paired t-test at each interval showed a significant difference ($p<0.01$) at 9.8, 8, 4 and 2 ms ICIs. Only 2 out of 6 subjects could identify wave V of click 2 responses for ICI 3 ms and not below 3 ms; therefore, the responses were shown down to 4 ms. In derived responses, they could identify till 1 ms. They also found that as ICI increases, the amplitude of the click 2 responses increases in the digital subtraction method down to 4ms and for derived responses to 1 ms.

Paired click ABR was used to measure temporal processing, AN fiber loss as well as to see I the excitatory post synaptic potential has an effect on the ABR wave I. paired click ABR of inter click interval 64 ms was observed to be more sensitive to developmental changes (Mai et al., 2014). There was strong correlation between the behavioural measures and ABR temporal thresholds in normal hearing individuals which shows the relationship between temporal resolution of ABR and psychophysical measure (Bidelman & Syed Khaja, 2014). Forward masking in the ABR is helpful in assessing the AN fiber loss, when the stimulus is presented at a higher presentation level low spontaneous rate fibers are responsible for the responses and loss of this fibers are indicated by a faster increase in the AN probe response. (Mehraei et al., 2017). ABR recovery thresholds were used to assess the temporal resolution abilities. Exposure to noise for longer duration causes the synaptic loss which can be persistent at high frequency regions even after 14 days of exposure. This was studied by Lee et al., (2021) where they correlated the recovery thresholds and amplitude of ABR wave I with the number of synapses. The ABR recovery thresholds and amplitude of wave I correlated with no of synapses was correlating at high frequencies, at 16 and 32 kHz (Lee et al., 2021).

CHAPTER - 3

METHOD

The present study was aimed to assess the association between speech perception, paired click auditory brainstem response in assessing temporal processing abilities, temporal resolutions abilities across individuals with normal hearing and cochlear hearing loss.

3.1. Participants

The subjects were divided into two groups viz Group I and Group II. Each group will consist of 15 participants.

Group I- Individuals with normal hearing sensitivity.

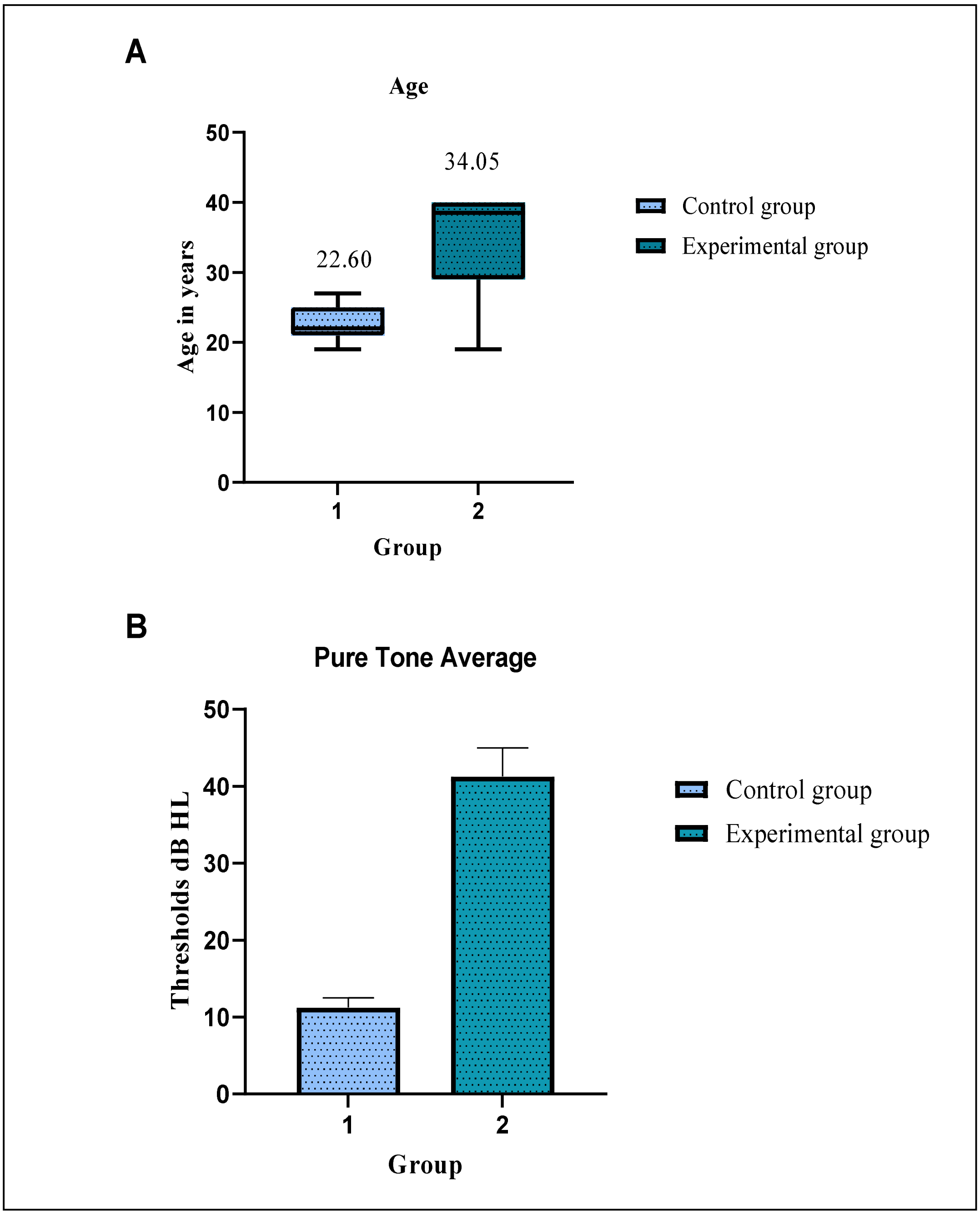
Group II - Individuals with cochlear hearing loss.

Group I included a sample of 15 normal-hearing individuals aged between 18-40 years. Each of the participants within the group had behavioural pure-tone thresholds of ≤15dB HL in all the octave frequencies, i.e., 250 to 8000 Hz on air conduction and in frequencies from 250 to 4k Hz on bone conduction testing and an air-bone gap of ≤10dB HL. The participants in this group also had normal cochlear, middle ear and outer hair cell functions.

Group II included 15 individuals aged 18-40 years who had mild to moderate sensorineural hearing loss. Each of the participants within the group had behavioural pure-tone thresholds with high-frequency average (hfPTA) within 26 dB HL to 50 dB HL with normal middle ear functioning.

Figure 3.1:

Figure shows the mean and standard deviation of the age and conventional four frequency pure tone average of the subjects in the control and experimental group



3.1.1. Participant inclusion criteria:

Group I: Individuals with normal hearing sensitivity

- Participants had hearing thresholds of ≤15dB HL in all the octave frequencies, i.e., 250 to 8000 Hz, on air conduction and in frequencies from 250 to 4000 Hz on bone conduction testing, with an air-bone gap of ≤ 10dB HL.
- Participants had normal middle ear functioning confirmed using immittance audiometry. The participants had an 'A' or 'As' type tympanogram in single-frequency tympanometry and had both ipsilateral and contralateral reflexes present.
- Participants had normal outer hair cells (OHC) functioning, confirmed by distortion product otoacoustic emissions (DPOAEs) responses at conventional frequencies in both ears.
- Participants did not have any retro-cochlear pathology.
- Participants did not have any neurological or otological problems during testing.
- Participants were not exposed to higher levels of noise.

Group II: Individuals with mild to moderate sensorineural hearing loss

- Participants' hearing thresholds with high-frequency average (hfPTA) which is the average pure tone thresholds at 1000, 2000, and 4000 Hz. The hfPTA ranged from 26 dB HL to 50 dB HL.
- Participants had normal middle ear functioning, which was confirmed by immittance audiometry. All the participants had a tympanogram of 'A' or 'As' type tympanogram and had the presence of ipsilateral and contralateral acoustic reflexes correlated with the severity of the hearing loss.

- Participants had no history of any neurological or otological problems during testing.
- Participants had no history of high-level noise exposure**.**

3.2. Instrumentation:

3.2.1. Pure tone audiometry:

A calibrated diagnostic audiometer GSI-61(Grason-Stadler, Eden Prairie, MN, USA) with TDH-39 supra-aural headphones was used for estimating air conduction thresholds, speech audiometry and Radioear B-71 bone vibrator was used for the estimation of bone conduction thresholds.

3.2.2. Immittance audiometry:

A calibrated diagnostic immittance meter GSI-Tympstar Pro was used to measure tympanometry, ipsilateral and contralateral acoustic reflex thresholds (ARTs).

3.2.3. Otoacoustic Emissions:

Distortion product otoacoustic emissions (DPOAEs) were measured using a calibrated Otodynamics DP ILO-V6 DP Echoport version 6.0(United Kingdom) instrument.

3.2.4. Auditory Brainstem Response with Paired Click Stimuli:

Calibrated Biologic Navigator Pro EP system (Natus Medical Inc., Mundelein, USA) was used to record paired click auditory brainstem responses.

3.2.5. Speech perception tests and gap detection tests:

A calibrated dual channel diagnostic audiometer GSI- 61(Grason-Stadler, Eden Prairie, MN, USA) connected to a computer to route the stimulus to the TDH-39 headphones were used to test speech perception in noise tests and speech recognition at higher presentation levels. The gap detection test was done using the same instruments, and the test was administered through the psychoacoustics toolbox implemented in MATLAB using MLP, which was loaded onto a Hewlett-Packard computer desktop computer with Intel i7 and 16 RAM running Windows 10.

3.3. Test environment:

All the tests will be done in a sound-treated room according to the ANSI S3.1-1999 (R2008). All the experiments were conducted in an acoustically treated and electrically shielded room.

3.4. Procedure:

The testing was done in the following steps:

3.4.1 Case history:

A detailed case history was taken to ensure that the participants do not have any history of middle ear infection, noise trauma and other otological diseases.

3.4.2 Otoscopic examination:

Otoscopic examination was done to examine the external ear canal and tympanic membrane.

3.4.3 Pure tone audiometry testing:

Pure tone thresholds were obtained in octave intervals between 250Hz to 8000Hz for air conduction and between 250Hz and 4000Hz for bone conduction using modified Hughson-Westlake procedure (Carhart and Jerger, 1959). Participants who had thresholds within the normal limits, i.e., hearing thresholds of ≤15dB HL in all the octave frequencies, i.e., 250 to 8000 Hz on air conduction and in frequencies from 250 to 4000 Hz on bone conduction testing and an air-bone gap of < 10dB HL where considered for group I and participants who were diagnosed under categories mild to moderate sensorineural hearing loss with the hfPTA between 26 dB HL to 50 dB HL were considered for the group II.

3.4.4 Immittance audiometry testing:

Tympanometry and reflectometry were carried out to rule out any middle ear pathology. The subjects who had tympanogram of ‘A’ or ‘As’ type tympanogram and had the presence of ipsilateral and contralateral acoustic reflexes correlated with the severity of the hearing loss were taken for the study.

3.4.5 DPOAE measurement:

Distortion product otoacoustic emissions (DPOAEs) were recorded using a calibrated ILO V6 DP Echoport instrument. Measurements were done at different frequencies, i.e., 1 kHz, 1.5 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, and 8 kHz, using f1/f2 ratio of 1.22 for the intensities L1= 65 and L2 =55 dB SPL. The distortion product was measured at 2f1-f2.

3.4.6 Paired click ABR measurements:

Participants were asked to sit on an incline chair comfortably. Electrode placement sites were cleaned by applying cleaning gel on cotton. Three Ag-AgCl cup-size electrodes was used for recording the far-field data from the scalp using vertical montage, and placement was fixed with the help of adhesive tapes. An appropriate amount of conduction gel was used to make good contact between the electrode and the skin. Absolute electrode impedance was kept at less than 5kΩ and inter-electrode impedances were less the 2 kΩ. Etymyotic 3A- research insert receivers were used to deliver the stimuli. The paired click stimulus was generated using MATLAB software (R 2014). The stimulus was delivered at 90 dBnHL at ten different inter-click intervals (ICI). Participants were instructed to relax to reduce the possible muscular artefacts. After obtaining the waveform from different ICIs, the response of click 1 from click 2 of paired click was isolated using subtraction from the response of single click. The recovery threshold was calculated after isolating the responses using the formula given by Henry et al. (2011). ABR recovery threshold is determined as the shortest ICI, which exceeds 50% ABR recovery.

$$\text{ABR recovery (\%)} = \frac{\text{Peak of paired click} - \text{Peak of single click}}{\text{Peak of single click}} \text{ X } 100$$

The detailed protocol for the ABR recording is shown in Table1.Amplitude changes were measured as the ratio of the ABR peak at each inter-click interval condition relative to the single-click condition. Wave V latency shift with paired click stimulation compared to single click stimulation was calculated across different inter-click intervals in both groups of participants. The analysis of ABR recovery was carried out for both ABR wave I and wave V in control group and for wave V in experimental group as there was absence of ABR wave I response for participants in this group.

Table 3.1:

The table shows the recording parameters of click-evoked ABR

Stimulus parameters		Acquisition parameters	
Stimulus	paired -click	Analysis window	32 ms
Polarity	Rarefaction	Amplification	100000
Intensity	90 dBnHL	Artifact rejection	23µV
Repetition rate	11.1/sec	Filtering	LPF:100 Hz
Transducer	Etymyotic 3-A Research insert receiver		HPF:3000 Hz
Inter-stimulus interval	0,0.7,1,1.5,2,4,5,7,10 and 20ms	Electrode placement	Inverting: Test ear mastoid Non-inverting: Forehead (Fz) Ground: Non-test ear mastoid
		No: of channels	1
		No: of sweeps	1500
		No: of replications	2

3.4.7. Speech recognition at high presentation levels:

Speech recognition scores were assessed using phonetically balanced monosyllabic words (Yathiraj & Vijayalakshmi, 2005). A list of 25 recorded monosyllabic words was routed through an audiometer and presented monaurally using TDH 39 headphones at higher sensation levels. The signal was presented at 90 dB SPL from the speech recognition threshold of the client. Recognition scores were calculated as no: of correct responses divided by the total number of words multiplied by 100.

3.4.8. Speech perception in noise test:

Speech perception in noise was measured using SNR-50, which is the signal-to-noise ratio (SNR) required to understand 50% of the speech presented in the presence of a competing signal. The test stimuli developed by Avinash, Methi and Kumar (2010) were used with 3 dB steps (Hijas & Kumar, 2013). The audiometer was connected to the computer, and the stimulus was presented through calibrated headphones. SNR 50 was measured using four-talker babble. Each list contains seven Kannada sentences with five keywords each. For every following sentence from 1 to 7 in each list, the signal-to-noise ratio was decreased in 3 dB steps from +8 dB SNR to -10 dB SNR. These sentences were presented at 70dB HL. The participants were asked to listen to the sentences and repeat the target sentences heard in the presence of multi-talker babble at different SNRs. At each SNR, the number of correct keywords identified was counted. Scores were calculated using the Spearman-Karber equation (Finney, 1978) as

$$\text{SNR-50} = I + \tfrac{1}{2}(d) - (d)(\#\ \text{correct}) / (w)$$

Where I= initial level of presentation (dB S/B)

d= step size of attenuation (decrement)

correct= total no: of keywords correct

w= no: of keywords per decrement

3.4.9. Gap detection threshold:

Gap Detection Threshold (GDT) was assessed through the psychoacoustics toolbox implemented in MATLAB (R 2014) (Grassi & Soranzo, 2014), at 40 dB SL w.r.t the pure-tone average thresholds, through maximum likelihood procedure (MLP) loaded in a laptop computer. The signal was routed through a calibrated audiometer and was presented through calibrated Sennheiser HDA 200 headphones. The gap duration was varied, and a three-interval alternative forced choice procedure (3AFC) was used to estimate the minimum gap the participant can detect. Every presentation level had three intervals with noise bursts. A noise burst with a gap served as the target, and the participants were instructed to specify the interval with a gap to estimate GDT. A band of 750 ms Gaussian noise with a gap in its centre was used. According to the listener's performance, the gap duration was varied. At the beginning and end of the gap, the noise had 0.5ms cosine ramps. In the 3AFC task, the standard stimulus was kept at 750 ms broadband noise with no gap, whereas the variable stimulus contained the gap.

CHAPTER IV

RESULTS

The present study examined the differences between measures of auditory brainstem response to paired click stimulation, speech perception measures, and temporal processing measures in individuals with and without cochlear hearing loss.

Shapiro Wilk test was performed and results revealed that the data was not normally distributed ($p < 0.05$). Hence, an appropriate non-parametric test was chosen for further statistical analysis.

The statistical analysis was carried out using IBM Statistical Package for the Social Sciences (SPSS) version 20 software. Descriptive statistics were used to summarise and describe the main features of the dataset, such as mean, median, standard deviation, and interquartile range, as shown in Table 4.1.

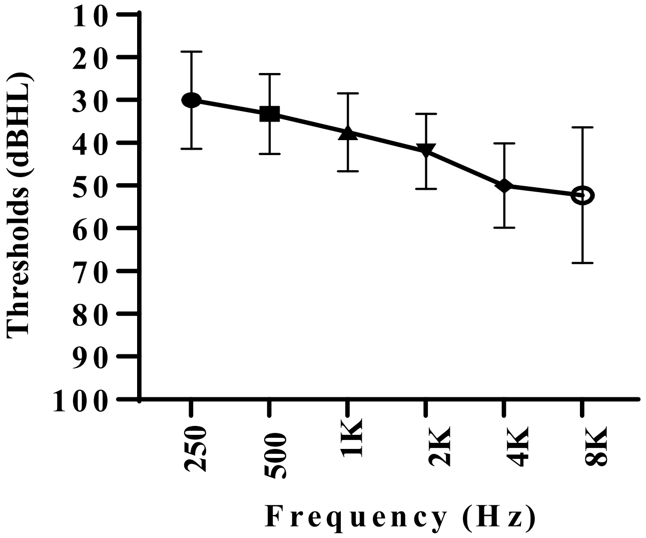
Table 4.1

Descriptive statistics of Age, PTA, GDT, Quick SIN, SIS90 and recovery 50 % for both the groups.

Variables	Group	Statistic			
		Mean	Std. Dev	Median	Interquartile Range
Age	control	22.60	2.28	22	4.00
	experimental	34.05	7.52	38.5	11.00
PTA	control	11.45	2.20	11.25	2.50
	experimental	40.25	6.85	41.25	10.00
SIS90	control	99.86	.73	100	0.00
	experimental	86.2	6.01	86	11.00
GDT	control	2.48	0.47	2.27	0.91
	experimental	14.69	9.42	10.79	15.71
Quick SIN	control	-5.08	1.22	-4.9	1.80
	experimental	.015	1.63	-0.40	2.40
Recovery 50 %(ms)- Wave V	control	3.34	.93	3.29	0.86
	experimental	5.29	1.25	5.34	2.31
Recovery 50 % Wave I	Control	4.94	1.66	4.70	2.29

Figure 4.1

Figure shows the mean and standard deviation of the pure tone thresholds for experimental group



4.1. Between-group analysis

4.1.1. ABR recovery threshold

The recovery thresholds for wave V in the experimental group were significantly higher than that of the control group ($|z| = 4.614$, $p<0.05$) as identified using the Mann Whitney U test. The percentage of recovery and recovery thresholds of both groups are shown in Figure 4.2.

Figure 4.2

Figure shows the percentage of ABR recovery for wave V A) Averaged percentage of recovery for wave V for control and experimental groups, B) recovery threshold for wave V for the control group and C) recovery threshold for the experimental group.

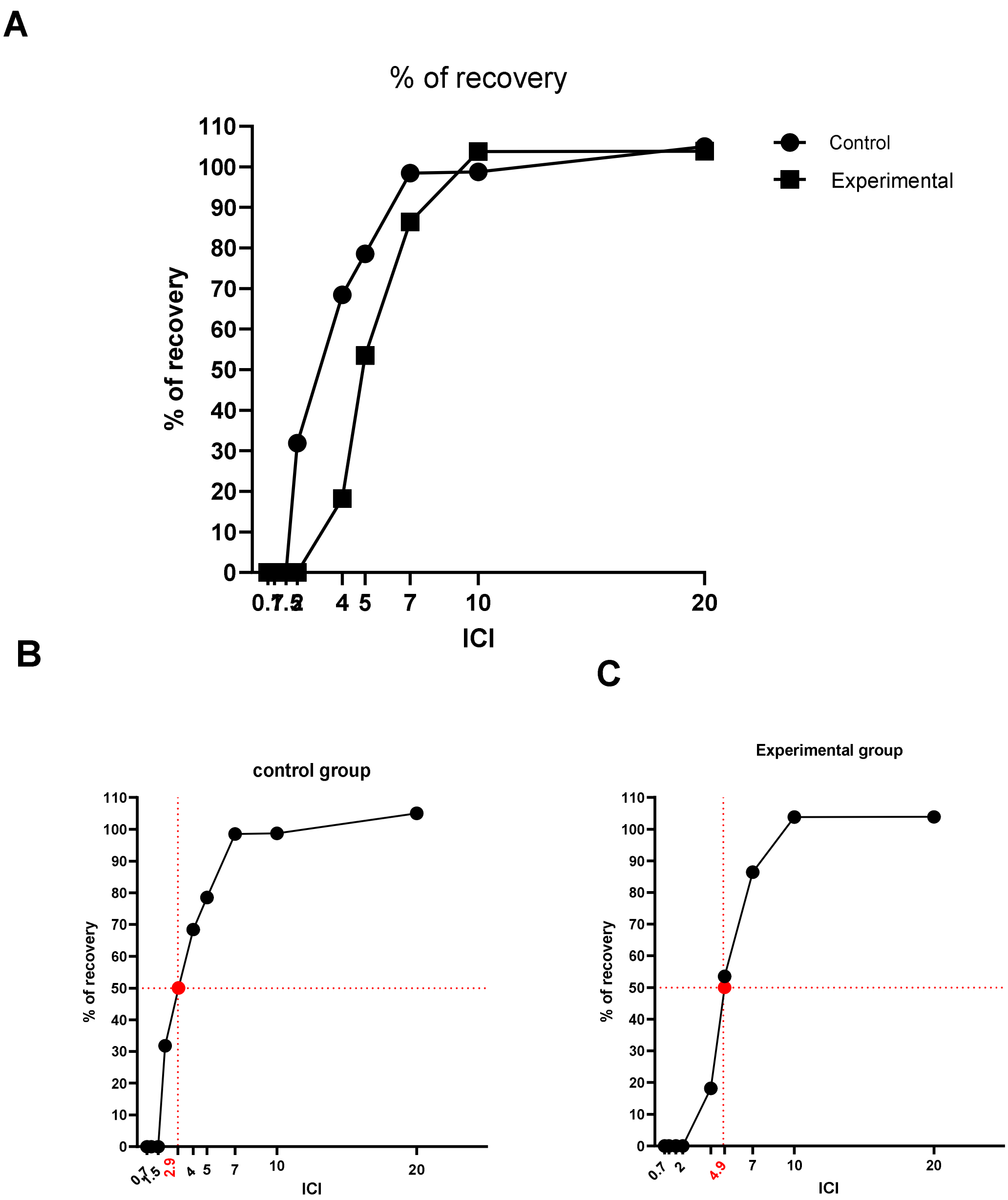


Figure 4.3

Figure shows the representative waveform of the recorded and its respective derived ABR waveform. for ICI 10 ms a) the top waveform (blue) shows the recorded waveform b) the bottom waveform(black) shows the derived waveform, i.e., the recorded waveform of any ICI 10 subtracted from the response of the ICI 0.

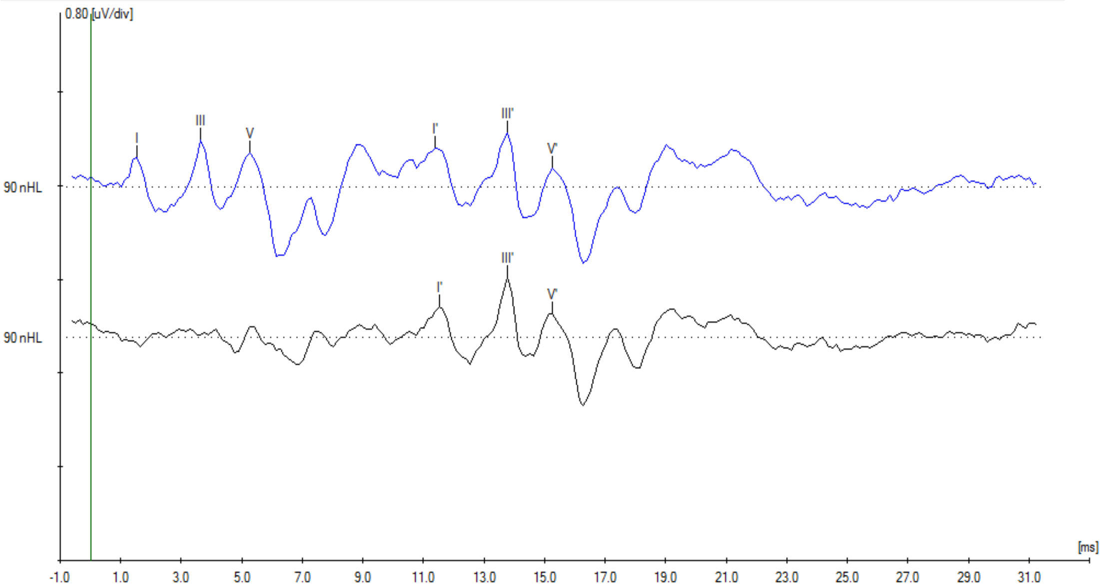
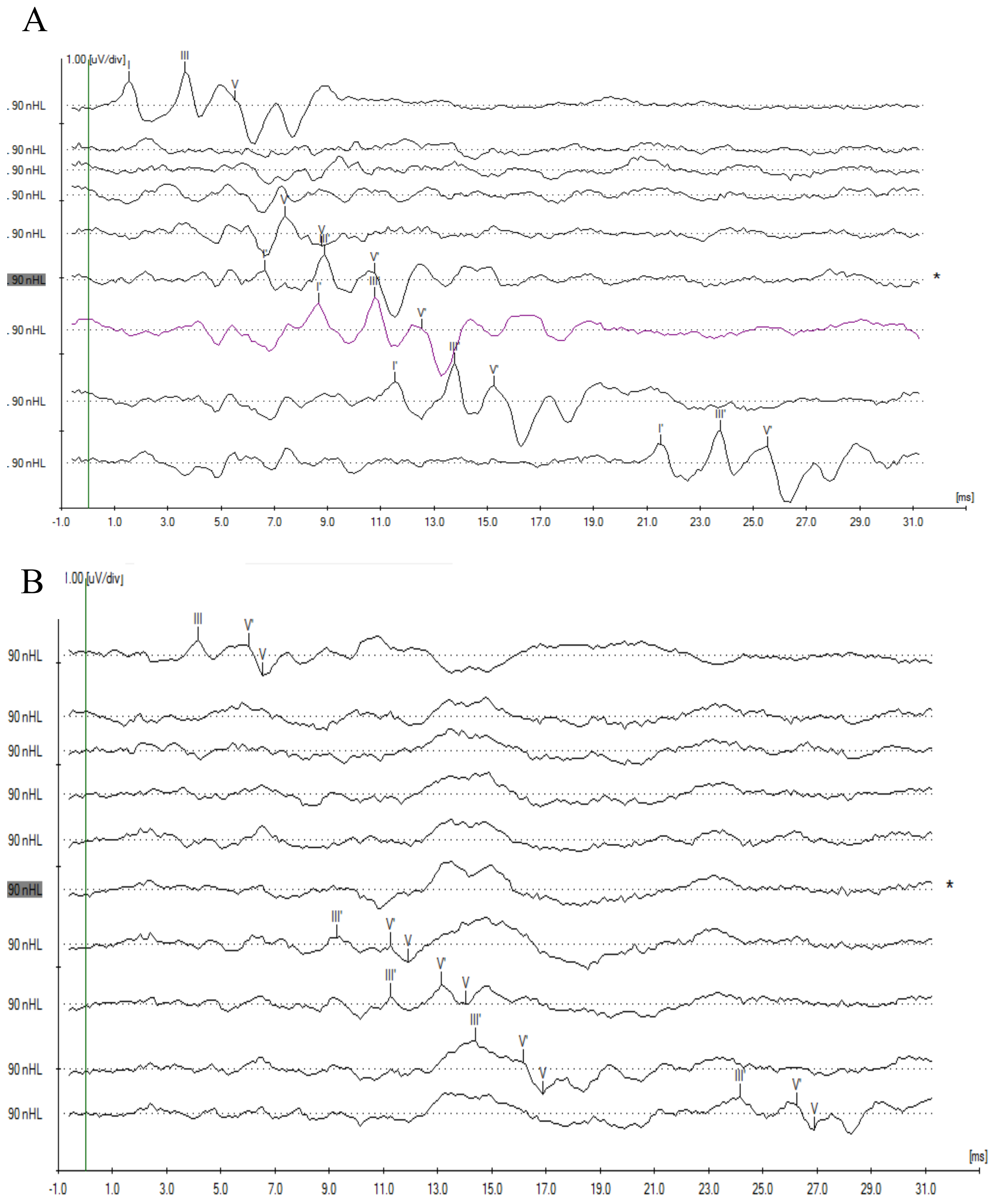


Figure 4.4

Figure shows the representative derived waveforms of control and experimental groups. A) Shows the derived waveform of the control group of ICI 0,0.7,1,1.5, 2, 4, 5, 7, 10 and 20, respectively, and B) shows the derived waveform of the experimental group of ICI 0, 0.7, 1, 1.5, 2, 4, 5, 7, 10 and 20, respectively.



4.1.2. Comparison of wave V amplitude for shorter (2, 4 and 5 msec) and for longer (7, 10 and 20 msec) inter-click intervals between control and experimental groups

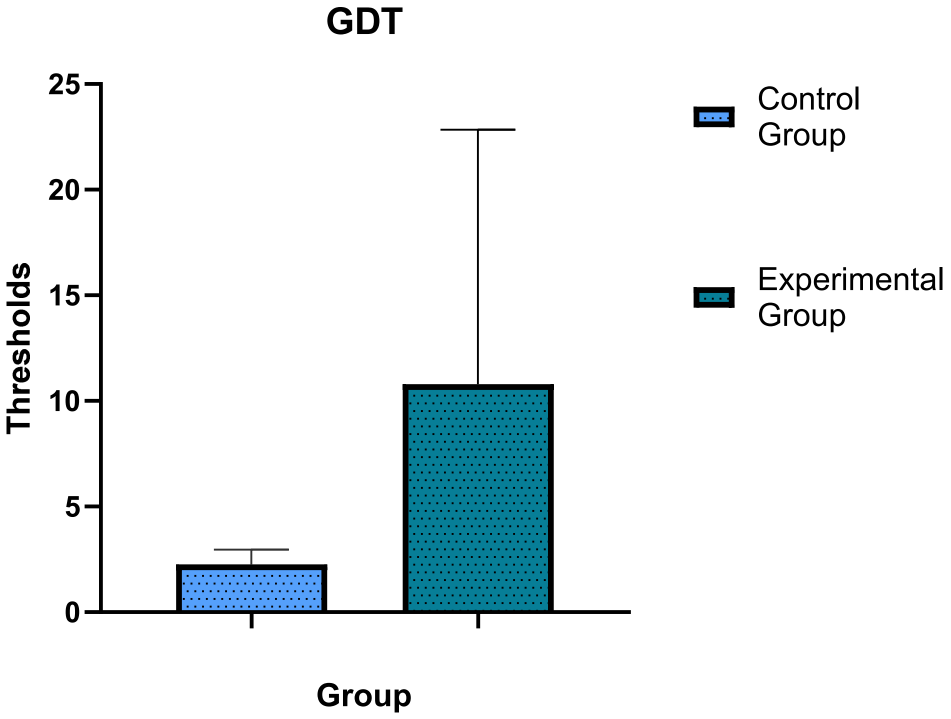
Mann Whitney U test was administered to compare the wave V amplitude for shorter (2, 4 and 5 msec) and longer (7, 10 and 20 msec) inter-click intervals. The results showed a statistically significant difference between shorter ($|z| = 2.57$, $P < 0.05$) and longer ($|z| = 2.37$, $P < 0.05$) inter-click intervals in the control group and experimental groups. We also compared the wave V amplitude of the second click between the control and experimental groups. The results revealed that there was no significant difference between the amplitude of the wave V in the control and experimental groups ($|z| = 1.43$, $P > 0.05$). We also intended to compare the amplitude of the wave V response to single click (ICI 0) between control and experimental groups. The results showed no statistically significant difference between the amplitude of wave V response to single click between control and experimental groups ($|z| = 1.67$, $P > 0.05$). Whereas the wave V latency to single click response showed a statistically significant difference ($|z| = 3.63$, $P < 0.05$).

4.1.3. Gap detection threshold (GDT)

Mann Whitney U test was performed to compare the GDT between the control and experimental groups. The results showed the GDT scores of the experimental group were significantly higher than that of the control group ($|z| = 5.963$, $p < 0.05$). The median and interquartile ranges for both groups are shown in Figure 4.5.

Figure 4.5

Median and interquartile range of gap detection thresholds for control and experimental group

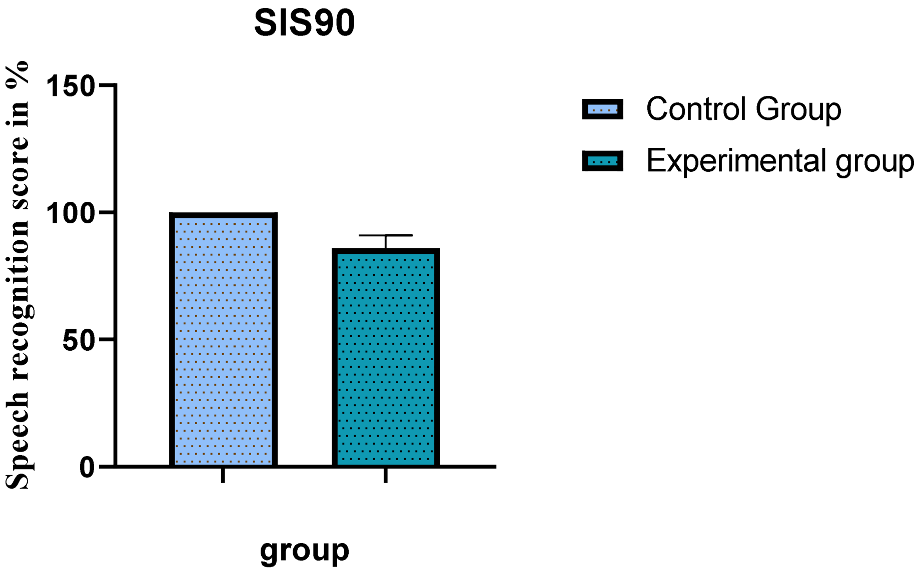


4.1.4. Speech recognition at higher sensation level (90dB SPL)

The SIS 90 scores were compared between the groups using Mann Whitney U test. The results depicted that the SIS 90 scores were significantly higher for the experimental group than the control group (│z│= 6.6, P<0.05). The median and interquartile range for speech recognition scores at higher sensation levels are shown in Figure 4.6.

Figure 4.6

Median with interquartile range for speech recognition scores at higher sensation level 90dB SPL

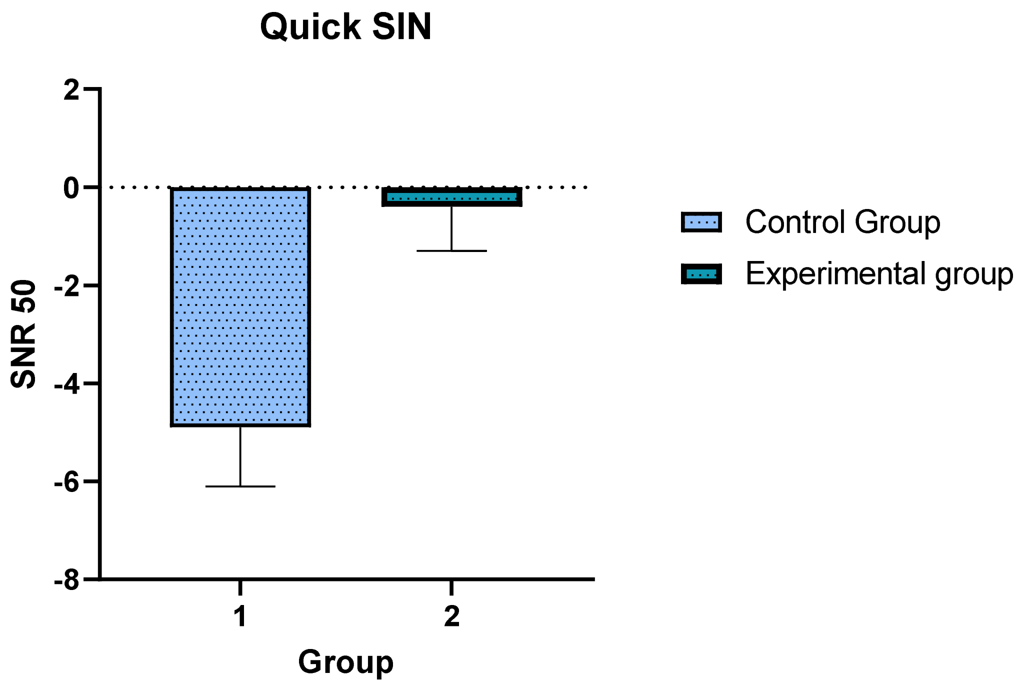


4.1.5. Quick SIN

Mann Whitney U test was administered to compare the Quick SIN values between the groups. The results revealed that the SNR 50 of the experimental group was higher than that of the control group ($|z|=5.944$, $p < 0.05$). The median and interquartile range for this test is shown in Figure 4.7.

Figure 4.7

Median with interquartile range of SNR 50 of Quick SIN for control and experimental groups.



4.2. Within-group analysis

4.2.1. Correlation across GDT, SIS90, Quick SIN, PTA, ABR recovery threshold of wave V and wave 1 for the control group.

Spearman's correlation was done to investigate the correlation across GDT, SIS90, Quick SIN, PTA and ABR recovery thresholds in individuals with normal hearing sensitivity and cochlear hearing loss. The results revealed a statistically significant positive correlation between PTA and Quick SIN ($\rho=0.362$, $p<0.05$) and a statistically significant negative correlation between PTA and ABR recovery threshold for wave 1 ($\rho= -0.454$, $p<0.05$)in individuals with normal hearing sensitivity. However, there was no statistically significant correlation between other parameters, i.e., GDT, SIS90 and ABR recovery thresholds in the control group (p>0.05). The results of the correlation test for the control group are shown in Table 4.2.

Table 4.2

Correlation between. GDT, SIS90, Quick SIN, PTA and ABR recovery thresholds of wave 1and wave V in individuals with normal hearing sensitivity

		PTA	SIS90	GDT	Quick SIN	Recovery50 _wave_V
PTA	Rho ρ	-	-	-	-	-
	Sig. (2-tailed)	-	-	-	-	-
SIS90	Rho ρ	-.133	-	-	-	-
	Sig. (2-tailed)	.483	-	-	-	-
GDT	Rho ρ	-.024	-.284	-	-	-
	Sig. (2-tailed)	.899	.129	-	-	-
Quick SIN	Rho ρ	.362*	-.315	.000	-	-
	Sig. (2-tailed)	.049	.089	.999	-	-
Recovery50 % wave V	Rho ρ	.295	.139	-.115	.176	-
	Sig. (2-tailed)	.113	.462	.547	.352	-
Recovery50 % wave I	Rho ρ	-.454*	-.054	-.036	.076	-.112
	Sig. (2-tailed)	.012	.778	.850	.691	.556

4.2.2. Correlation across GDT, SIS90, Quick SIN, PTA and ABR recovery threshold of wave V for the experimental group

In the experimental group, there was no statistically significant correlation between GDT, SIS90, Quick SIN, PTA and ABR recovery thresholds (p > 0.05). Table 4.3 shows the results of the correlation test for the experimental group.

Table 4.3

Correlation between GDT, SIS90, Quick SIN, PTA and ABR recovery thresholds in individuals with cochlear hearing loss

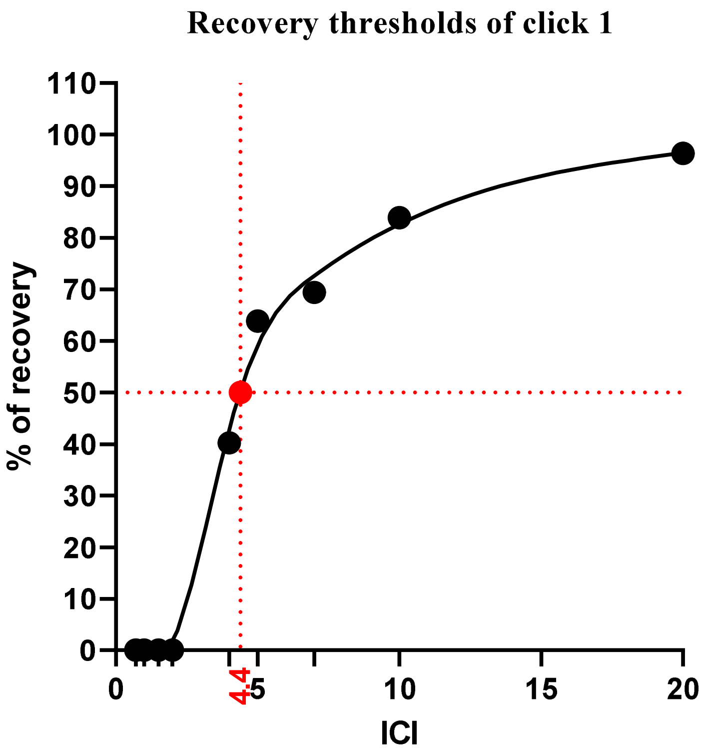
		GDT	**SIS90**	**PTA**	**Quick SIN**
GDT	Rho ρ	-	-	-	-
	Sig. (2-tailed)	-	-	-	-
SIS90	Rho ρ	.013	-	-	-
	Sig. (2-tailed)	.958	-	-	-
PTA	Rho ρ	.215	.112	-	-
	Sig. (2-tailed)	.364	.639	-	-
Quick SIN	Rho ρ	-.225	-.243	-.011	-
	Sig. (2-tailed)	.341	.302	.962	-
Recovery50	Rho ρ	-.012	.386	.031	-.201
	Sig. (2-tailed)	.960	.093	.897	.395

4.2.3. Comparison of Recovery thresholds of ABR wave I and recovery thresholds of wave V in the control group.

Wilcoxon signed rank test was performed to assess whether the recovery pattern for wave I and wave V were similar. The results showed a statistically significant difference between recovery of wave 1 and the recovery of wave V in the control group ($|z|=3.671$, $p < 0.05$). The recovery threshold of the ABR wave I is shown in figure 4.8

Figure 4.8

Figure 4.9 shows the ABR recovery percentages for the ICI 0.7, 1, 1.5, 2, 4, 5, 7, 10 and 20ms and the recovery threshold i.e., 50 % recovery (red dot), of ABR wave 1.



4.2.4. Comparison of GDT and recovery threshold of wave V

Differences between GDT and ABR recovery thresholds in the mean were observed for both control and experimental groups. Hence, the Wilcoxon Signed rank test was performed to check the significant difference between GDT and ABR recovery thresholds in both groups. The results of the control group showed (│z│= 3.569, p<0.05)a statistically significant difference between GDT and ABR recovery threshold of wave V in the control group. The results of the experimental group also showed a statistically significant difference between GDT and the recovery threshold of wave V in the experimental group (│z│= 3.584, p<0.05).

CHAPTER 5

DISCUSSION

The aim of the present study was to assess the temporal processing abilities measured using auditory brainstem response with paired click stimulation and its relationship with speech perception measures in individuals with normal hearing and cochlear hearing loss. It was also of interest to compare the measurements between both groups. The results of the comparison showed there was a significant difference between the two groups in pure tone thresholds, auditory brainstem response (ABR) recovery threshold, gap detection thresholds (GDT) and SIS 90 ($p < 0.05$). Further, the within-group analysis was also done to assess the relationship across various measures in both groups of participants. The results showed a statistically significant positive correlation between PTA and Quick SIN in the control group; no significant correlation was observed in all the other parameters in the control group. In experimental group none of the parameters showed a statistically significant correlation.

5.1. Comparison between the control and experimental group

ABR responses to the paired click stimulation were recorded at 10 ICI (0, 0.7, 1, 1.5, 2, 4, 5, 7, 10 and 20 msec). The response of the second click was obtained using the subtraction of the paired click responses at different inter-click intervals from the response of the single click. The recovery threshold, i.e., 50 % recovery of the amplitude of the wave V of the second click of the paired click, was then calculated. The recovery threshold was compared between the normal hearing and cochlear hearing loss groups. The recovery thresholds of the individuals with cochlear hearing loss were significantly higher than that of the normal hearing individuals. In individuals with normal hearing sensitivity, at shorter inter-click intervals, i.e., 0.7, 1, 1.5, the responses to the second click were not present in any of the subjects. In contrast, few of the subjects showed responses at 2 ms, and most of the subjects had responses at 4 ms. Similar results were reported by Burkard and Deegan (1984). They found no wave V responses for click two below 3 ms, and only a few subjects showed responses at 3 ms for unsubstracted conditions. However, authors could track wave V response to 1 ms in at least 4 of 6 subjects in the derived condition. This is due to the adaptation caused by the forward masking effect in shorter ICI, as the nerves do not get enough time to recover and respond for the second click in the paired click. As the ICI increases, the auditory nerve recover, the second click response becomes evident, and the amplitude of the second click response increases. Forward masking may be significantly aided by inhibitory networks in the brainstem. Efferent inhibitory mechanisms, for example, influence the cochlear nucleus response to forward masking. Increased inhibition at the level of the inferior colliculus might reduce the response to the second click due to the masking effect of the first click. The inhibition can lead to reduced amplitude and prolonged latency to the response of the second click (Mehraei et al., 2017).

Psychophysical studies report that the listeners can perceive two clicks when the paired click is presented with an inter-click interval as low as 1-2 msec (Hirsh, 1975). In the present study, individuals with normal hearing showed a mean 50 % recovery threshold for wave V of 2.9 msec, whereas individuals with cochlear hearing loss showed a mean recovery threshold of 4.9 msec. The recovery thresholds between the groups were differed significantly ($p > 0.05$). Three mechanisms are thought to contribute to ABR adaptation and recovery in general: (1) auditory nerve refractoriness, (2) presynaptic neurotransmitter depletion, and (3) postsynaptic-membrane mechanisms (Ohashi et al., 2005).

Comparison of wave V amplitude for shorter ICI (2, 4 and 5 msec) and longer ICI (7, 10 and 20 msec) inter-click intervals between the control and experimental groups showed statistically significant differences between the groups ($p<0.05$). The recovery patterns were entirely different in individuals with cochlear hearing loss than with normal hearing individuals, as both the shorter ICI and longer ICI were affected in individuals with cochlear hearing loss. We also compared the wave V amplitude of the second click between the control and the experimental groups. The results revealed no significant difference between the amplitude of the wave V in the control and experimental groups. We also intended to compare the amplitude of the wave V response to a single click (ICI 0) between control and experimental groups. The results showed no significant difference in wave V amplitude for single click ABR between the two groups, which could be due to the compensatory central gain in response to cochlear damage by the central auditory system could maintain the wave V amplitude (Mehraei et al., 2016). The latencies of the absolute wave V response to a single click between the control and experimental groups were compared. The results showed a statistically significant difference between the groups. Burkard and Sims (2002) studied the effect of broad-band masking noise on the ABR peaks and reported that as the masker increased, the wave V latency was significantly prolonged. The possible reason for latency shift could be neural desynchronisation and loss of OHC dysfunction in individuals with cochlear hearing loss.

GDT was measured at 60dB SPL for both groups. The results revealed that the gap detection thresholds of the cochlear hearing loss group were significantly higher than those of the individuals with normal hearing. The mean value of GDT was 2.48 msec for the normal hearing group and 14.69 msec for the cochlear hearing loss. The results of our study were similar to the findings reported in the literature (Leigh-

Paffenroth & Elangovan, 2011; Fitzgibbons & Wightman, 1982; Glasberg et al., 1987; Florentine & Buus, 1984; Nelson & Thomas, 1997). The individuals with cochlear hearing loss have poor temporal resolution abilities compared to the normal hearing individual, which can be attributed to the loss of outer hair cells (affecting compressive non-linearity and active process), inner hair cells (reducing the amount of information that is conveyed through the AN) and auditory nerve fibres in cochlear hearing loss group (Moore,. 2007). Even at equal sensation levels (SLs), gap detection thresholds were typically higher in the impaired ears. The scatter of gap thresholds was significant for a given degree of hearing loss, but it tended to increase with increasing absolute threshold (Glasberg et al., 1987).

A comparison of SNR 50 between the cochlear hearing loss and normal hearing groups showed that the hearing-impaired group had a higher SNR 50 than the normal hearing individual group. The mean value for the normal hearing group was -5.02, and 0.15 in the group with cochlear hearing loss. These results suggest that individuals with cochlear hearing loss require higher SNRs or positive SNRs to understand better speech in the presence of background noise. These results were similar to the results of studies in literature, where they found that speech perception is poorer in hearing-impaired individuals compared to the normal hearing individuals (Dubno et al., 1984; Killion et al., 2004; Wilson et al., 2007; Sultan et al., 2020).

The speech recognition score was tested at a higher sensation level, 90dB SPL. The results showed that the scores were significantly higher for the group with cochlear hearing loss compared to the normal hearing group. The results suggest that individuals with cochlear damage tend to have difficulties in understanding speech at higher intensities. This can be due to the loss of low spontaneous rate fibre. The low spontaneous rate fibres are responsible for carrying the information to the auditory cortex at higher intensities (Shehorn et al., 2020)

5.2. Within-group analysis

5.2.1. Correlation across GDT, SIS90, Quick SIN, PTA and ABR recovery threshold

Correlation across GDT, SIS90, Quick SIN, PTA and ABR recovery threshold was studied within control, and results revealed that PTA and Quick SIN were positively correlated. However, GDT, SIS90 and ABR recovery of wave I and wave V thresholds did not show any statistically significant correlation among each other. There was a ceiling effect for SIS90 in the control group, which could be why SIS90 did not correlate with any of the other parameters in this group.

Within the experimental group, there was no statistically significant correlation between GDT, SIS90, Quick SIN, PTA and ABR recovery thresholds of wave V. The possible explanation for no correlation between GDT and ABR recovery function could be the variable level of neural adaptation across the different regions of the auditory neural pathway. Differences are reported in neural adaptation measured with cortical auditory evoked potentials and the ABR (Bidelman et al., 2014). Where GDT measures the ability of the listener to identify the minimum gap in the stimulus, which assesses the integrity of the entire auditory system, the difference in presentation level between the GDT measure and paired click ABR also could have led to no relationship between the two measures in the control group.

5.2.2. Comparison of Recovery thresholds of ABR wave -I and recovery thresholds of wave V in the control group.

Comparison of recovery thresholds of wave I and wave V showed a statistically significant difference between each other. The difference in the wave I recovery and wave V recovery can be due to the difference in the anatomical generation site where wave I was generated from the AN and wave V from the brainstem. There could be a different recovery pattern at different level of auditory system. Moreover, the forward masking effect in shorter ICIs is greater compared to the longer ICIs, in the shorter inter-click interval, where both the signals are reaching within the neural recovery of the AN, the response of the second click get masked by the response of the first click. The masking effects are more pronounced for wave I than for wave V. The possible reason for this difference can the contribution of low-spontaneous rate fibres to the forward masking. This contribution slows down the recovery of the recovery of the ABR wave I amplitude in normal-hearing individuals and the deafferentation causes the faster recovery of the ABR wave I amplitude (Mehraei et al., 2017).

5.2.4. Comparison between GDT and recovery threshold within the group

GDT and recovery thresholds were compared within the control group and experimental group. The results showed significant differences between GDT and the recovery thresholds in both groups. The psychoacoustic measurement of the recovery rate from forward masking shows that normal hearing individuals show more rapid recovery from forward masking than individuals with cochlear hearing loss when compared to equal SPL (Glasberg et al., 1987). However, these differences were less if the comparison was made in comparable sensation levels. The present study did not equalise the presentation levels in terms of equal sensation levels. The slow recovery from the forward masking found in individuals with cochlear hearing loss could be partially due to reduced compressive non-linearity in the basilar membrane.

Limitations of the study:

In the present study, we did not analyse other relative measures such as ABR wave V latency recovery, wave V/I ratio, and wave I-V latency interval. The ABR was only recorded at 90 dBnHL and did not use different intensity levels; hence, it is not clear on the effect of intensity on the wave recovery function. The present study did not control hearing loss in the experimental group, including a range of mild to moderate sensorineural hearing loss. The present study did not control for the age and gender of participants in both groups. The participants in the control groups are younger compared to the participants in the experimental group. The present study measured GDT at equal sound pressure levels (SPLs) and not at equal sensation levels (SLs) in the control and experimental groups.

CHAPTER VI

SUMMARY AND CONCLUSION

Normal auditory processing is essential to understand speech in quiet as well as in the presence of noise. Individuals with cochlear hearing loss have difficulty understanding speech in noise. Studies have investigated temporal processing abilities using auditory brainstem responses to paired click stimulation and found that recovery thresholds and wave I amplitude help in identifying temporal processing deficits. The relation between recovery threshold and inter click interval provides a measure of temporal resolution. Speech recognition at a higher sensation level also helps in assessing the temporal processing with respect to the low spontaneous rate fibres which is responsible for speech encoding at higher intensities.

The current study aimed to assess the temporal processing abilities measured using auditory brainstem response with paired click stimulation and its relationship with speech perception measures in individuals with normal hearing and cochlear hearing loss. Appropriate statistical analysis was carried out, and the results revealed the following

1. A statistically significant difference between the recovery threshold of wave V SIS 90, Quick SIN and GDT between experimental and control groups.

2. GDT and recovery thresholds showed statistically significant differences in both the groups.

3. A statistically significant difference between ABR wave V and wave I recovery thresholds in control group.

4. Correlation of parameters within the control group showed a statistically significant positive correlation between PTA and Quick SIN.
5. No statistically significant correlation between GDT, SIS90 and ABR recovery thresholds in the control group.

The results obtained indicated that the experimental group showed poorer scores in all the parameters when compared with the normal-hearing individuals which are attributed to the damage to the cochlea. The loss of OHC, IHC and auditory nerve fibre shows a major contributing factor for the temporal processing as well as the speech perception in noise.

Clinical Implications:

Paired click ABR can be a potential tool in assessing the temporal processing abilities in difficult-to-test population, adults as well as paediatric as is an objective measure. Since the recovery threshold is a relative measure, it might overcome the limitations of the absolute measures in ABR. The paired click ABR may be useful measure while assessing the cochlear synaptopathy since it’s a relative measure.

Future Directions

1) Recovery thresholds can be compared with other psychoacoustic measures of forward masking
2) Analysis can be done for other relative measures such as ABR wave V latency recovery, wave V/I ratio, and wave I-V latency interval.
3) Paired click ABR can be measured at different intensity levels to see the effect of intensity on the wave recovery function.

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