Effect of Noise Spectrum on Cortical Evoked Auditory Potentials in Individuals with Normal Hearing And Invidual with Sensorineural Hearing Loss

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This Dissertation is submitted as part fullfillment for the Degree of Master of Science in Audiology University of Mysore, Mysore

May, 2016

CERTIFICATE

This is to certify that the dissertation entitled "**Effect of Noise Spectrum on Cortical Evoked Auditory Potentials in Individuals with Normal Hearing And Invidual with Sensorineural Hearing Loss** " is the bona fide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student (Registration No. 14AUD013). 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.

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CERTIFICATE

This is to certify that the dissertation entitled "**Effect of Noise Spectrum on Cortical Evoked Auditory Potentials in Individuals with Normal Hearing And Invidual with Sensorineural Hearing Loss**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "**Effect of Noise Spectrum on Cortical Evoked Auditory Potentials in Individuals with Normal Hearing And Invidual with Sensorineural Hearing Loss**" is the result of my own study under the guidance of Prof. Animesh Barman, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not submitted earlier in any other University for the award of any Diploma or Degree.

Mysuru
May, 2016

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Dedicated

To

my family,

teachers &

friends

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I would not be writing this part of my dissertation, had not my destiny been designed, to finish the right works at the right times. So let me first acknowledge the creator of my destiny to have not let me be too late in anything!!

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Abstract

The speech perception is poor in individuals with sensorineural hearing loss (SNHL) in quiet and in presence of noise compared to that of normal hearing individuals. This study was carried out to evaluate the differences in ALLR responses in quiet and different spectrum of noise between the SNHL and normal hearing individuals and see the differential effects of different spectrum of noise on the ALLR responses in the two groups. The study also aimed to study the correlation between behavioral speech in noise scores with the cortical responses elicited in quiet and noise conditions. The participants in the study included control group having normal hearing individuals and clinical group having individuals with SNHL in the age range of 18-50 years. ALLRs were evoked from all the participants to /ba/ and /da/ stimuli in quiet, high pass noise, low pass noise and speech noise conditions at 80 dB SPL. The absolute amplitudes and latency values of the peaks N1, P2 were marked and subjected to analysis. The results showed a significant increase in N1 amplitudes in SNHL individuals compared to the normal hearing individuals. The latencies between groups showed a trend towards increased latency of peaks N1 and P2 in SNHL group in all the conditions compared to the normal counterparts which could be due to the reduced neural processing in SNHL population. Results within conditions showed a significant increase in latency of the peaks N1, P2 and a decrease in amplitude of the peak N1 in the presence of noise which could be due to the effect of masking which reduces the audibility of speech sounds causing the increase of latency and decrease of amplitude. Also, P2 amplitude increased in the presence of noise

compared to the amplitudes elicited in quiet condition which could be due to the increase in neuronal firing due to the ambiguity in higher order processing of speech sound due to the presence of noise. There was a significant correlation of N1 latency in normal hearing individuals and P2 in SNHL individuals with behavioral speech in noise scores. It was concluded from the study that ALLR responses are different in both normal hearing and SNHL individuals indicating difference in neurophysiological processing for speech perception in both the populations and account for the affected speech perception in the SNHL population. The N1 amplitude is a better indicator of the differential processing present in the two groups as they showed a significant difference between the groups. There was a significant correlation of N1 latency in normal hearing individuals and P2 latency in SNHL individuals with behavioral speech in noise scores. Which could be due to the affected audibility that affects speech perception in noise in normal individuals that is correlated through N1 latency and the affected higher order processing that affects speech perception in noise in SNHL individuals that is correlated by P2 latencies.

Also, it could be concluded that the processing of speech is affected in the presence noise in both the groups. Though no significant differences between the different spectrums of noise could be seen, there was a trend towards differential effect of noises on ALLR responses where speech noise masked the most followed by the low pass masker and the high pass masker in the decreasing order. There can be a possible significant difference by taking larger samples for the study.

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Chapter 1

Introduction

Perception is how the brain decodes the information received through various senses. Therefore perception of speech is awareness of sound characteristics that are received at the cochlea and its recognition and interpretation done by making use of various cues that are present in speech like varied Voice Onset Time (VOT), burst and rapid formant transitions, closure interval of consonants etc. at the level of cortex.

The perception of speech is shown to be affected in individuals with cochlear hearing loss (Plomp, 1986; Zeng & Turner, 1990). This hampered perception is due to their inability to access speech cues mainly the place of articulation (Boothroyd, 1984; Bamford & Saunders, 1992; Turek, Dorman & Summerfield; 1980). According to Plomp (1986), place of articulation cues are affected in individuals with sensorineural hearing loss. He concludes that manner and voicing cues doesn’t play much role, regardless of the pattern of audiogram. The lack of audibility and ability to discriminate the varying transitions in consonants also add to the difficulty in speech perception (Zeng & Turner, 1990).

In general, the perception of speech deteriorates in the presence of noise. In individuals with sensorineural hearing loss (SNHL), speech perception in noise is affected more than in quiet. They are deprived of complete acoustical information of speech in the presence of background noise, reverberation or when more than one individual talks (Plomp, 1986; Moore, 2003). People with cochlear hearing loss seem less able than normally hearing people to take advantage of the temporal and spectral variations such as dips, in the presence of noise (Plomp, 1986). Needleman and Crandell, (1995) found a difference in speech perception, in normal individuals with simulated masking noise and individuals with SNHL. They found behavioural speech scores in noise, to be better in the normal individuals than individuals with SNHL. Since the testing was conducted at supra-threshold levels, they concluded that there were other factors other than reduced pure tone sensitivity that resulted in increased susceptibility to noise in SNHL individuals.

Electrophysiological methods (evoke potentials) are one of the measures to record the processing of speech in the brain. Auditory evoked potentials are the neural activity arising due to the acoustic stimulation that encodes the processing of sound beyond the level of the cochlea (Kraus & McGee, 1992). Auditory Late Latency Responses (ALLR) is one such auditory evoked response that occurs between 50 and 300ms and the major peaks being P1 (P60), N1 (N100), P2 (P160), and N2 (N200). They are mainly cortical in origin and reflect an individual's cortical auditory processing. ALLRs can be elicited through transient clicks, tone bursts and speech sounds. ALLR has been correlated to speech perception by various authors. Naatanan and Picton, (1987) indicated that, N1 in cortical event related potentials represent an obligatory response to audible stimuli and directly does not correspond to perception. Shtyrov et al., 1998; Hillyard and Picton, (1987), showed that acoustic features are encoded by P1 i.e. frequency and timing while a listener's ability to discriminate different stimuli and the attention towards the category of sound is reflected by the peaks N2 and P3 of ALLRs.

Sharma and Dorman, (1999), chose speech as stimulus for ALLRs and they increased the voice onset time of speech sounds from 0-30ms to 50-80ms and saw that the

LLR elicited for shorter VOT stimuli contained two negative peaks (N1 and N1'), instead of one N1 found and this was not to be seen in non-speech stimuli. They concluded that, speech processing was different from the non-speech processing. ALLR are thought to reflect the functional integrity of auditory pathways involved in processing of complex speech stimuli when speech sounds are used as stimulus. It has been found, that there are distinctive cortical response patterns for syllables that differed in their initial phoneme (Ostroff et al.,1998;Tremblay et al., 2003).Also, Purdy, McMahon and Newall (2006) noted that ALLR potentials have good correlation with behavioural speech scores. Rance, Cone-Wesson, Wunderlich and Dowell (2002) showed that speech evoked cortical potentials were better in amplitude and latency in subjects with auditory neuropathy having better speech identification scores compared to those with poorer scores . Cunningham, Nicol, Zecker, and Kraus, (2000) in their study, showed correlation between listening comprehension and amplitude of P1, N1 and N2 parameters of AALRs. Eggermont and Ponton, (2003) showed that the presence or absence of N1 component in ALLRs, could predict the ability of speech perception in noise in cochlear implantees. More recently Gutschalk, Michey and Oxenham (2008), researched that cortical potentials could be elicited when the speech signals were behaviourally detected and the cortical potentials being absent for absent behavioural detection of speech sounds. These studies show that ALLRs could be used to gain insight of speech perception of an individual and correlate with behavioural speech tests.

Similarly, Warrier , Johnson, Hayes, Nicol and Kraus (2004), have shown variations of speech perception in various clinical populations to be reflected in cortical potentials. Tremblay, Piskosz, and Souza (2004) showed that, N1 and P2 latencies prolong in older listeners to speech stimulus but no prolongation to pure tones indicating the distorted speech processing and not to non-speech processing in older individuals. Warrier et al., (2004) observed a decrease in amplitude and prolongation of latencies in children with learning disability. Similarly, Polen (1984); Gonzalez (2015); Polen, (1984) stated that late components of auditory ERP's might be altered in the presence of sensorineural hearing loss because of the loss of high frequency information causing decreased ability to discriminate phonemes. Also, he found reduced amplitude in all the components of LLR with N1 and P3 not significantly reduced, and P2 being drastically reduced. He implicated that P2 indicated reduction in sensitivity and the latency shift was more than just the intensity effect as the presentation level was well above the individual's puretone threshold. Oates, Kurtzberg, and Stapells, (2002), investigated systematically the effects of sensorineural hearing loss on cortical event-related potentials (ERPs) and behavioral discrimination scores. The results showed that, both ERP amplitudes and behavioral discrimination (d′) scores were lower for individuals with sensorineural hearing loss than for those with normal hearing. The latency changes that occurred with sensorineural hearing loss were significantly greater for the later ERP peaks (N2/P3) in comparison with earlier peaks like N1. As the presentation level was well above the individual's threshold, they concluded that sensorineural hearing loss has a greater impact on higher level or "nonsensory" cortical processing in comparison with lower level or "sensory" cortical processing that relates to audibility. Similarly, Martin and Stapells (1997, 1999, 2005); Anderson, Chandrasekaran, Han- Yi and Kraus (2010), have shown that the effects of noise that can affect behavioural speech tests can also affect cortical potentials. To study the central effects of noise on speech perception, Martin and Stapells (2005) investigated the effects of decreased audibility in low frequency spectral regions, produced by low pass masking noise on cortical ERP's. They showed that, decreased audibility from masking, affects N1 in differential manner compared to N2 and P3. Martin and Stapeles, (1997, 1999) also investigated decreased audibility produced by high pass masking noise and found that as the cutoff frequency of high pass masker was reduced to below 1000 Hz, latencies increased and amplitude decreased. Thus the studies showed that different types of noise produced different effects on different components of ALLR. Kaplan-Neeman, Kishon-Rabin, Henkin, and Muchnik, (2006) designed a study to characterize the effect of background noise on identification of syllables using behavioral and electrophysiological measures. They saw that performance accuracy and reaction time were prolonged due to noise. They concluded that the effects of noise on speech recognition occur at both physical and perceptual processing levels. Billings Penman, Mcmillan, and Ellis (2015) conducted a study encompassing cortical evoked potentials in noise on older hearing impaired and normal hearing older individuals. They found significant increase in N1 amplitude for older individuals with hearing impairment. Thus, there has been quite an amount of research that shows the effects of noise on speech processing at cortical level in different population.

Need for the study:

There have been studies comparing the speech perception of individuals with sensorineural hearing loss through auditory evoked potentials. Polen, (1984) reported longer N1, N2, P3 latencies and significantly reduced amplitudes in individuals with cochlear hearing loss when compared to normal hearing listeners. Oates et al., 2002 showed increased latency for N2 and P3 peaks in individuals with sensorinural hearing loss, associating it with deteriorated higher cortical processing. Thus, the studies have attributed difficulties of speech processing in SNHL population to variations in latencies and amplitudes of ALLRs. Martin et al., (1997, 1999, 2005) showed that the spectrum of noise differently affects spectrum of speech in normal individuals. Billings et al, (2015) studied the effect of continuous speech noise at different SNRs on elderly normal hearing population and elderly hearing impaired population through cortical potentials and found significant effects of different SNR noises in elderly individuals with hearing impairment. However, the effect of different types of noise on speech perception on clinical groups like sensorineural hearing loss has not been extensively investigated. The continuous noise used in the previous studies might have an effect of adaptation that might reduce the impact of noise on the stimulus. The differential effect of noise on different components of ALLRs in sensorineural hearing loss population has not been commented on, in the previous studies. Also, the effects of noise on ALLR has not been correlated with identification of behavioural speech in noise in sensorineural hearing loss population in most of the studies. As the speech in noise performance is poor in the SNHL population (Moore, 2003), it is necessary to know the effect of different noise on different components of ALLR to understand speech perception in the hearing impaired population. The current study investigates the stimulus environment dependent changes in LLR components – in quiet, in noise with high pass masking, noise with low pass masking and speech noise in a non-continuous paradigm in the clinical group and correlates them with behavioural speech scores.

Aim of the study:

The aim of the present study was to assess the effect of different types of noise on the various peaks of ALLR in individuals with normal hearing and individuals with SNHL and to investigate which component of ALLR correlates the best with the speech perception ability of the individual.

Objectives of the study:

The objectives of the study are as mentioned below:

1. To see the effect of different test environments like quiet, Low pass filtered noise (< 200Hz), high pass filtered noise (> 4000Hz) and speech noise on different components of ALLR in individuals with normal hearing.
2. To see the effect of Low pass filter, high pass filter and speech noise on different components of ALLR in individuals with sensorineural hearing loss.
3. To compare the effect of different spectrum of noise on different components of ALLR between the groups.
4. To find out the correlation between different components of ALLR and Speech Perception in noise scores.

Chapter 2

Literature Review

Perception of speech refers to a process wherein the speech signal that is incident at the level of ear undergoes processing at the cochlear, brainstem and cortical level leading to comprehension of the transmitted signal. The speech perception happens with the making use of various cues in speech that are decoded by the central auditory system. The cues that help in perception include fundamental and formant frequencies for vowels (Rakerd & Verbrugge, 1985) and transition duration, Voice Onset Time (Lisker, 1957), onset frequency of the burst (Stevens & Blumstein,1978), formant transitions (Cooper & Liberman, 1951) etc. for consonants.

The perception of speech is affected due to various subject related factors like age of the individual, presence of central auditory processing disorder, individuals with auditory neuropathy, individuals with sensorinural hearing loss. As the subjects in the current study are individuals with Sensorineural Hearing Loss (SNHL), information regarding speech perception in this population has been gathered from the literature and given under the following headings.

2.1 Speech perception in cochlear hearing loss:

The perception of speech is deteriorated in individuals with cochlear hearing loss (Moore, 1996). He provided an overview of the factors that might add to the poor speech perception in individuals with sensorineural hearing loss. The list of factors includes reduced absolute sensitivity, frequency selectivity, reduced pitch perception, affected temporal parameters which are among a few. He concludes that to all losses below 45 dB, it is the reduced audibility that acts as the main factor affecting speech perception.

According to a study by Moore (2003) the reduced speech perception is due to the broadened cochlear bandwidth that exist in individuals with SNHL, due to the damage of OHCs. This interrupts with the ability to separate different formants that are one of the cues for perception of speech. Also flattened cochlear tuning curves, might result in masking of second formants by the first, especially for the consonants having lower first formants, affecting the consonant perception in running speech.

In a study by Hood, (1989), the pattern of errors in patients with sensorineural hearing loss was examined. The monosyllabic CVC word identification was administered on 20 unilateral cochlear hearing loss individuals, 20 individuals with conductive hearing loss and 20 normal hearing individuals. It was seen that individuals with conductive impairment made twice more errors than the normal hearing individuals and individuals with cochlear impairment made twice more mistakes than the individuals with conductive impairment. They concluded stating that individuals with cochlear impairment had the most perception problems and the consonant errors were due to the loss of energy on the consonants by the spread of energy of the vowels.

Johnson, Whaley and Dorman, (1984) studied the Voice Onset Time (VOT) boundaries of place of articulation for stop consonants in normal hearing individuals and individuals with cochlear hearing loss of different degrees. The syllables used for the study were /pa/, /ta/, /ka/,/ba/, /da/ and /ga/ where, the VOT change was in a continuum. The results revealed that the VOT boundaries remained same for hearing losses up to mild degree, but the VOT boundaries were affected in moderate to severe cochlear losses leading to affected perception of place of articulation. They conclude that the affected VOT in the sensorineural hearing loss population play a role in affected speech perception.

In another study by Turner, Ling chi and Flock (1999), measured consonant recognition in normal individuals and individuals with moderate cochlear hearing loss by varying the spectral resolution of speech. The spectral resolution was decreased by processing speech information into 1, 2, 4 and 8 channels. More the channels, less was the resolution. It was seen that, the individuals with SNHL have a resolution of only one channel unlike an 8 channel resolution in their normal hearing counterparts. They conclude that the limitations in the speech performance in the clinical population are due to the reduced spectral resolution in the clinical population. Thus, from the review it can be noticed that the speech perception in SNHL individuals is poorer compared to their normal hearing counterparts.

Speech perception in adverse listening conditions is a taxing task for individuals with normal hearing as well as hearing impaired population. Speech can be perceived and comprehended in the presence of white noise when the SNR is as low as 0 dB. But the comprehension deteriorates at poorer SNRs (Fletcher 1953). The effect of noise on speech is depend on the spectrum of noise.

The effects of white noise on the identification of consonants were examined in normal individuals by Miller and Nicely (1955). The consonants were classified based on their manner and place of articulation. The results revealed that place of articulation were affected the most and the voicing, frication and nasality were the least affected. They concluded that white noise affects speech perception in normal hearing individuals due to masking of high frequency portion of speech spectrum.

Miller (1947) examined the effect of different type of maskers that affects speech perception in normal.it was seen that the speech noise concentrated between 0.1 to 6 kHz was the most effective masker and affected speech perception the most, and low frequencies were more effective maskers than the high frequencies. Thus the studies reveal that presence of noise hampers perception of speech and the effect of noise varies with its spectrum.

2.2 Speech perception in noise in Cochlear Hearing loss:

The perception of speech in adverse conditions in SNHL population is more affected than normal hearing individuals. The presence of noise poses a negative impact on perception of speech in sensorinural population and there is a differential effect of various spectrum of noise on speech perception (Miller & Nialy, 1955).

Moore (1996), summarizes from of the studies on speech in noise, that an individual with cochlear hearing loss requires an SNR of 16 dB more than their normal hearing counterparts. He reasoned that this may be due to the fact that they fail to take advantage of the spatial separation that persists between speech and background noise.

Judy, Dubno, Dirks, and Morgan (1984) studied the effect of mild cochlear hearing loss on speech recognition ability in the presence of speech babble. The participants included young normal and hearing impaired adults and old normal hearing and hearing impaired adults. The speech in noise test using sentences was performed and the thresholds for 50% scores were noted. It was found that the older individuals with cochlear hearing loss had the highest thresholds whereas the thresholds for young hearing impaired individuals were minimally affected. They concluded that the age and cochlear damage had a combined effect on decreased speech perception.

Eisenberg, Dirks and Bell, (1995), studied the effect of amplitude modulated noise on the normal individuals and individuals with cochlear hearing loss. A spectrally shaped broadband noise equivalent to the puretone thresholds of the individuals was given to both the groups along with the non-sense syllable. The results showed lesser release of masking from the amplitude modulated noise in cochlear loss population suggesting higher susceptibility to presence of noise in speech perception in the population.

Needleman and Crandell, (1995) compared speech perception of normal individuals with simulated hearing loss done through noise masking and individuals with natural cochlear hearing loss to study the speech perception in noise. The study was done to see if the deteriorated speech in cochlear hearing loss was due to the secondary distortions in the cochlea or due to the reduced puretone sensitivity. The normal subjects were simulated with hearing loss equal to mild and moderated degree matched with cochlear hearing loss group, and speech stimuli in the presence of speech spectrum noise was presented to both the groups. The results indicated that the group with cochlear hearing loss obtained poorer scores in sentence recognition. It was concluded that reduced speech in noise in the clinical group was due to factors other than just reduced puretone sensitivity and that secondary distortions in the cochlea could be one of the other factors.

To establish the factors affecting the perception of speech in noise, Hrost (1987), studied the frequency selectivity, frequency discrimination and speech perception in noise. There was a significant correlation found between frequency selectivity and perception in noise among the subjects. The correlation was also significant between frequency discrimination and speech in noise. They concluded that the impaired frequency resolution and discrimination abilities in individuals with cochlear hearing loss are some of the important factors for their poor perception in noise.

Lorenzi, Gilbert, Carn, Garnier and Moore (2006), studied the effect of temporal fine structure (TFS) processing in perception of speech in noise in individuals with SNHL and normal hearing individuals. They filtered the speech into 16 adjacent frequency bands where the envelope of speech was preserved and TFS was varied. Also stimulus where envelope was preserved and varied TFS was created and was administered on the two groups. The results showed that the scores of individuals with SNHL matched with that of normal individuals in the condition where envelope was varied but was significantly poor when the TFS as varied. Also, they found the sores of TFS to correlate with the speech in noise scores of individuals. Thus they suggested that the reduced ability to use temporal fine structures could be responsible for poor speech in noise abilities in SNHL individuals.

Cooper and Cutts, (1971) studied the effect of SNR of cafeteria noise on speech perception in normal hearing and SNHL population with adiometric thresholds of 20-60 dB HL using NU-6 wordlist. It was found that the performance to noise was poorer in SNHL population at all SNRs, i.e. (0, 4, 8 and 12 dB) and had a larger variability at poorer

SNRs. They concluded that the increased variability was due to increased perception problems in some of the individuals with SNHL than the normal hearing individuals.

2.3 Speech perception and auditory evoked potentials:

One of the measures to study auditory speech perception is through recording Cortical Auditory Evoked Potentials (CAEP). They measure the amount of information transfer that has happened from the cochlea to the cortex (Naatanen et al., 1987; Giard et al ., 1995). Auditory Late Latency Responses is a slow cortical response extending from 50 to 230 ms, after the presentation of stimulus. These potentials are exogenous in nature and depend on the characteristics of the stimulus (Hall, 2007). The LLRs elicited from a normal adult individual include components-a positive P1 that occurs at 50 ms, a negative N1 occuring at 80-100 ms, a second positive peak P2 occuring at 180-200 ms and a second negative peak N2 occuring at 250 ms (Stapelles, 2008). The component N2 may or may not be present in normal individuals (Hall, 2007). The most prominent peak in majority of the individuals is N1-P2 and has a large inter subject variability (Hyde 1997).

According to a study Naatanen and Picton (1987), P1 is generated by the thalamic projections into the auditory cortex and N1 is generated by supra temporal auditory cortex. They also pointed out that in normal hearing individuals, N1 signifies the physical energy of the stimulus and is most sensitive to the changes in the signal. They conclude that the presence or absence of a stimulus at the cortical level is determined by the presence of N1. The later peaks like P2, N2 and P3 signify the ability of the individual to detect and discriminate the sounds.

The LLRs can be elicited to clicks, tonebursts, chirps and speech stimulus. As non-speech stimuli do not give information on the processing of speech at the cortical level, speech stimulus is used to study speech perception. Speech evoked auditory potentials provide an insight to the neural coding that underlie speech processing (Aaltonen, Niemi, Nyrke, Tuhkanen, 1987, Sharma et al., 1992). Thus evoked potentials using speech stimulus could be useful to see the effect of hearing loss on the neural encoding of speech (Martin, Tremblay & Korczak, 2008).

Hayes, Warrier, Nicol, Zecker and Kraus (2002), studied the effect of speech training in the learning disorder population using cortical potentials. They also studied the correlation of behavioral responses to cortical potentials after the training. It was found that there was an enhancement in amplitude of cortical responses as well as an improvement in behavioral scores. Thus showing a good correlation in improved amplitude of peaks in LLR to improved behavioral speech scores.

Anderson, Chandrasekaran, Yi and Kraus (2010) investigated the relation between behavioral speech in noise scores and cortical potentials elicited to the /da/ consonant in noise in children with learning disability. It was seen that the effects of noise on cortical potentials were evident only in the group having poorer behavioral scores and the cortical measures were minimally changed in the population having good speech in noise scores. They suggested that the improvement in amplitudes of cortical potentials to have a good correlation with the improved behavioral speech scores.

Rance, Cone-Wesson, Wunderlich, and Dowell (2002), investigated the presence of cortical potentials in children with auditory neuropathy (AN) and the correlation between presence of LLRs and speech perception. The children were divided based on the behavioral scores on PBK word list as the group with no open set recognition of speech and the group who had speech recognition similar to their SNHL counterparts. The results showed that the cortical responses were present only in the group having open set recognition of the speech word list. They concluded that speech evoked cortical potentials are the indicators of behavioral speech perception abilities in individuals with AN and are helpful to predict the usefulness of amplification in this population.

Cunningham, Nicol, Zecker, and Kraus (2000) evaluated the maturation pattern of the central auditory system and their correlation with the behavioral speech perception by measuring cortical potentials in normal children and children with learning disability. It was seen that there was a significant correlation between P1/N1/N2 parameters and auditory processing, listening comprehension abilities in the LD group. It was also shown that there was a predictive relation between N2 latency and auditory processing in the same group.

Thus, from the mentioned review of literatures it can be seen that LLRs have a good correlation with the behavioral speech processing of an individual.

2.4 Factors affecting LLR:

Late latency responses can be affected by various factors. Hyde, 1997 delineated the factors that affect the LLRs which include:

1. Level of the stimulus, where N1-P2 amplitude increases with stimulus level.
2. Repetition rate, where N1-P2 amplitude increases with increase in inter stimulus interval up to 10 s, with little change in latency.
3. Number of sweeps, where the response amplitude decreases over repeated stimuli which suggest an active habituation process.

Thus decrements in the number of sweeps will cause SNR enhancement.

The subjective factors include attention of the subject, age of the individual, state of arousal etc.

Picton and Hillyard (1974) studied the effect of attention on the auditory evoked potentials. The normal individuals were asked to count the number of click presented at 60 dB HL in active attention task and were asked to ignore the clicks in passive attention task. There was a significant increase in amplitudes of the peaks N1 and P2, for active attention and no effects of latencies were seen.

Tremblay, Billings and Rohila, (2004) investigated the effect of age and stimulus rate on LLRs using tonal and speech stimuli. The test was carried out with fast and slow inter- stimulus intervals. The results revealed that the N1-P2 latencies were prolonged in older individuals compared to young adults only for the speech stimulus and not to the tonal stimulus. They concluded that the prolongation of latencies only with the faster inter stimulus rates but not with the slower rates reflect the slow neural processing in older adults.

2.5 Effect of SNHL on Late latency responses:

Polen (1984) compared the speech evoked LLRs of normal hearing and moderate to severe SNHL individuals for phonemic stimuli. He found a prolongation in N1, P2, N2 and P3 latencies and a reduced P2 and N2 amplitudes in individuals with moderate to severe SNHL. There was no reduction in the N1 amplitude and a trend for reduced amplitudes only for the later peaks majorly for P2. He reported that P2 was an indicator of reduced sensitivity and reduced input to cortical areas in the SNHL population. He also suggested that there was a cortical deficit present in this population which led to increased latencies, which cannot be attributed to reduced audibility, as the stimulus presentation was at supra-threshold levels.

In a study by Wall, Delebout, Davidson and Fox, (1995) speech AEPs were elicited in five normal and five symmetrical moderate SNHL individuals with matched age range of 32 years. The speech stimuli consisted of two stop consonant contrasts /be-de/ and /be-pe/, where the first contrast differed in VOT and the other, differed in the place of articulation. The results revealed that there was no difference for later peaks like P3 and P2 between the groups. There was a reduction in the N1 amplitude for the stimulus with VOT contrasts, which has been attributed to the reduced audibility in the SNHL population. Thus the authors suggest N1 to be an indicator of audibility of the stimulus at the level of cortex.

In a study by Oates, Kurtzberg and Stapells (2002), they recorded AEPs to speech stimuli /ba/ and /da/ at 65 and 80 dBSPL in normal and individuals with SNHL mild to profound degree. The stimuli were presented in an oddball paradigm. The results showed a significant decrease in amplitude and increased latency of hearing impaired population for both the stimulus levels. There was an increase in amplitude for N1 in SNHL population at 80 dBSPL, which was attributed to the process of recruitment in these individuals. They also saw that the effects of amplitude were stable till 55 dB of hearing loss whereas the effect of latency was seen as early as for mild hearing loss. They concluded that the AEP latencies act as a sensitive measure than amplitude and they reflect the increased neuronal processing time taken in the SNHL population, due to which speech perception is affected.

A study on 10 individuals with cochlear pathology was conducted by Anirban (2007) in age group of 18-50 yrs. He performed behavioral speech in noise at 40 dBSL, for quiet and in noise and also speech evoked ABR and LLR to the transition portion of /pa/, /ta/ and /ka/ consonants. Results revealed no significant difference between groups for latency and amplitude measures in cortical potentials. Also there was no correlation between the behavioral speech in noise and cortical responses but a correlation of the same to ABR was seen. The author concluded that poor encoding in noise might be present at the level of brainstem but not at the cortical levels.

Sumitha (2008), it was aimed to study the effect of different speech sounds on the normal and SNHL population through cortical potentials. The speech stimuli /ba/,/da/ and /ga/ were used as stimulus at 70 dBnHL and 40 dBSL . It was seen that at 40 dBSL latencies were lesser in the SNHL population which was explained by the recruitment phenomenon that happens in cochlear pathology at higher SLs. At 70 dBnHL, latencies were more for the SNHL population along with increased amplitudes. This has been attributed to slow transmission due to reduced energy at the cochlea, when compared to the normal individuals. Thus, it can be seen that the LLRs are deviant in the population with SNHL and the changes in perception can be reflected by the cortical potentials.

As it was seen from the behavioral studies, there was deteriorated speech perception in the presence of noise. This deterioration in processing is also evident from the cortical studies.

2.6 Effect of noise on late latency responses:

Martin and Stapells (2005) investigated the effects of decreased audibility in low frequency spectral regions, produced by low pass masking on cortical ERP’s. The speech sounds used were /ba/ and /da/ and the low pass cutoff noise with frequency of 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. The testing was done at 65 dB SPL and 80 dB SPL in both active and passive conditions. It was shown that with increase in the cutoff frequency of lowpass noise, ERP latencies increased and amplitudes decreased. N1 had different changes than the other peaks and had a little effect for latency and amplitude at 80 dB SPL. Also, when lowpass masker was raised to 4000 Hz, there was reduction in amplitude of N1 where as N2 and P3 did not change until lowpass masker was raised to 2000 Hz.They concluded that, decreased audibility from masking affects N1 in differential manner compared to N2 and P3. Also N1 indexes the presence of audible stimulus energy, as N1 was present when the signal was heard but the peaks N2 and P3 were present only when the signals were discriminable, hence indexes behavioral discrimination of speech sounds.

Martin, Sigal, Kurtzberg and Stapells (1997, 99) did a similar study with the use of same procedure but with high pass masking noise. The results showed that with the lowering of cutoff frequency, the latencies of peaks N1, P2, N2 and P3 increased and amplitudes decreased where N1 was the first to get affected by the changes starting from a cut off of 4000 Hz . The changes in LLR included gradual increase as the cut off frequency was reduced below 4000 Hz. The changes in the peaks N2 and P3 were drastic and marked, below a cutoff of 2000 Hz and no effect of noise was seen above the cut off of 2 KHz, unlike the peak N1.

Billings, Tremblay, Stecker, and Tolin (2009), studied the effect of noise on normal hearing individuals with different SNRs and different stimulus levels. The stimulus consisted of 1000 Hz tone presented at 60 and 75 dB SPL, in quiet and in presence of noise. the SNR of noise was varied in five consecutive steps and SNR was matched with each signal level. They observed an increase in N1, P2 and N2 amplitudes and a decrease in P1, N1, P2 and N2 latencies with increase in SNR. There was no significant difference in amplitude or latency when two different signal levels were used. They suggested that the effect of SNR was more than the signal increment on the perception of stimuli.

Billings, Bennett, Molis, and Leek (2011) investigated the effect of type of signal, type of noise and evoking paradigm on P1-N1-P2 complex in normal individuals. The evoked potentials were elicited to various types of noise like continuous speech noise, interrupted speech noise and four talker babble at an SNR of -3 dB. The stimuli consisted of /ba-da/ contrast as well as a tonal contrast of 1000-500 Hz stimulus. The result showed longer latency for the speech stimulus than the tonal stimulus. Also, the four talker babble resulted in the longest latencies and smallest amplitudes and the interrupted noise had the least effects on the latency and amplitude. It was seen that the N1 had minimal effects for latency and highest effect for amplitude in the presence of noise. They concluded that CAEPs may be a useful tool in understanding the underlying causes for deficits of speech perception in the presence of noise.

Kaplan and Neeman, (2006) designed a study to characterize the effect of background noise on identification of syllables using behavioral and electrophysiological measures in normal hearing individuals. The speech sounds /da/ and /ga/ were embedded in white noise at +15, +3 ,0, -3 and -6dB SNRs, where the onset of noise was 1000 ms before the onset of the speech stimulus in order to separate the speech LLRs from the noise one . It was seen that performance accuracy and reaction time were prolonged due to noise. N1 latency was increased in both /ga/ and /da/ context whereas P3 latencies were increased only in /ga/ context. /ga/ was better identified than /da/ in all noisy conditions behaviorally, but there was no significant difference for /ba/ and /da/ in cortical potentials. They concluded that the effects of noise on speech recognition could be shown to be occurring at perceptual processing levels in the cortex through AEPs.

Similarly, the effects of noise on individuals with cochlear hearing loss were shown through LLRs by Billings, Penman, McMillan and Ellis (2015). The subjects included younger normal hearing individuals, older normal hearing adults and older adults with SNHL. The speech stimulus consisted of sentences presented at different SNR and signal levels. The results of the study indicated that as the SNR increased, the latencies decreased and amplitudes increased and the effect of SNR was more than that of the signal level. Also, no significant difference in latency was seen between the three groups, but the N1 amplitude was increased in older SNHL population when compared to the younger and older normal hearing individuals.This enhanced N1 amplitude was associated with the recruitment phenomena in SNHL individuals.

From the literature review, it is evident that the changes in perception in noise can be reflected through LLR. However, there is a dearth of studies that correlate the difficulty in the perception of speech with different components of LLR. Also the results have been variable across the studies. Further, there is a lack of literature on the effects of noise in SNHL population alone, without the interference from age related factors as variables. Finally, most of the studies use a continuous noise for the assessment of noise effects, which may add adaptation as another variable. In this study, we aim to control on the age effects, continuous noise adaptation effects by using interrupted noise and try to correlate effect of different spectrum noise on different components of ALLR and relate the same with behavioral speech in noise perception normal hearing individuals and individuals with SNHL.

Chapter 3

Method

The method of the study involves examination of cortical potentials (ALLR) in quiet as well as in different type of noises. These tests are performed on normal individuals and individuals with SNHL to see the electrophysiological variations in the normal individual and clinical population in quiet and noisy situations and correlate the same with the behavioural speech perception problems in noisy conditions. To achieve the goal, following method was adopted.

3.1 Participants:

Two groups of participants participated in the study

I. Clinical group: included 15 individuals with cochlear hearing loss in the age range of 18-50 years.

II. Control group: consisted of 15 age matched normal hearing individuals.

3.1.1 Clinical Group:

Participants Selection Criteria:

The participants considered for the clinical group met the following criteria:

1. All the participants had bilateral mild to moderate flat sensorineural hearing loss (30-50 dB loss) based on pure tone threshold (approximately equal degree of hearing in all frequencies with 5-10 dB variation, Clark, 1981).

2. All of them had “A” or “As” type tympanogram with present/elevated/absent acoustic reflexes in both ears indicating normal middle ear structure.
3. All the participants had absent Transient Evoked Oto Acoustic Emissions.
4. All of them were native speakers of Kannada with Speech identification scores proportionate to their degree of hearing loss.
5. All the participants did not have any evidence of retrocochlear pathology which was evaluated using ABR.
6. Uncomfortable Level for speech was greater than 100dB HL in both ears for all participants.
7. Participants had no history or presence of any other neurological problems.
8. None of them had history of presence of ear pain, ear discharge, and exposure to loud levels of noise.

3.1.2 Control Group:

Participants Selection Criteria:

The participants considered for the control group met the following criteria:

1. All the participants had their air conduction pure tone hearing thresholds within 15 dB HL for frequencies between 250 Hz to 8000 Hz.
2. They were native speakers of Kannada with speech identification scores above 90%.
3. Their Speech in noise scores were above 60% at 0dB SNR in the presence of speech noise. Phonemically Balanced Word List in Kannada developed by Yathiraj and Vijayalakshmi, (2005) were used for the same.

4. Their uncomfortable level (UCL) for speech was greater than 100 dB HL in both ears.
5. They had “A” type tympanogram with presence of acoustic reflexes in both ears.
6. All of them had presence of TE OAE’s in both ears with an SNR above 6dB SPL.
7. There was no history or presence of any otological problems (like ear discharge and ear pain).
8. There was no history or presence of any neurological problems which was evaluated using ABR.

3.2 Instrumentation:

1. A calibrated two channel GSI-61 diagnostic audiometer with Telephonics TDH 50 supra aural headphones and Radio ear B-71 bone vibrator, were used for behavioural threshold estimation and also to obtain speech recognition scores, UCL and speech in noise (SPIN) scores.
2. A calibrated GSI TYMPSTAR Immittance meter was used for conducting tympanometry and reflexometry.
3. ILO 292 DPEcho port system (otodynamics Inc, UK) was used to assess Transient Evoked Oto Acoustic Emissions.
4. An intelligent Hearing system (IHS version 4.3.02) was used for recording auditory brainstem responses and cortical responses. Calibrated Eartone 3A insert earphone was used to deliver the air conduction noise and speech stimulus ipsilaterally.
5. A personal computer with Adobe Audition software version-3 was used for stimulus generation and mixing of signal with noise.

3.3 Stimulus preparation

Two naturally recorded speech syllables /da/ and /ba / were used for the study. These syllables were recorded from an adult native male speaker on to a computer at 16 bits and 44100/sec sampling frequency using Adobe Audition software version 3.0. The stimulus was recorded by a male speaker as Kiliç, and Ogüt (2004); Robinson,(2011), has shown that speech from a female speaker is significantly difficult to discriminate than male speakers, for individuals with sensorineural hearing loss. The sounds were recorded in an omnidirectional microphone that was kept 6 inches away from the speaker's mouth. The sounds were recorded 5 times out of which middle 3 were selected and given to 5 audiologists/speech language pathologists to obtain the best stimulus using Goodness test.

Stimulus /ba/ and /da/ were considered for the study since they occur frequently in Kannada, (Sreedevi, Smitha & Vikas, 2012) and differ in terms of F2, which is an important cue for speech perception. Also Martin and Stappels (1997, 99, 05) have taken these two sounds to see the effects of different types of noise on ALLR. Hence by taking the same speech stimuli /ba/ and /da/, it would be possible to discuss the results in reference to their findings .

3.4 Signal processing:

The stimulus was prepared for four different conditions. The first condition consisted of stimulus /ba/ and /da/ of 100 ms duration without having any noise to it. In the next three conditions the stimuli /ba/ and /da/ was embedded in three different types of noise: low pass noise (<200Hz), high pass noise (>4000Hz) and spectrum of speech noise to obtain 0 dB SNR with respect to the signal. The stimuli with noise consisted of 500 ms of noise onto which, a 100 ms stop consonant was added at 300 ms and that extended till 400 ms .The noise continued post speech stimulus till 500 ms to avoid the offset response of the noise overlapping with the response of the speech stimulus ending at 400 ms. The noise of different spectrum of 500 ms were generated using Aux Viewer 1.37 and mixed with /ba/ and /da/ to obtain 0 dB SNR. The figures below show the representation of the stimuli in quiet as well as in the presence of noise.

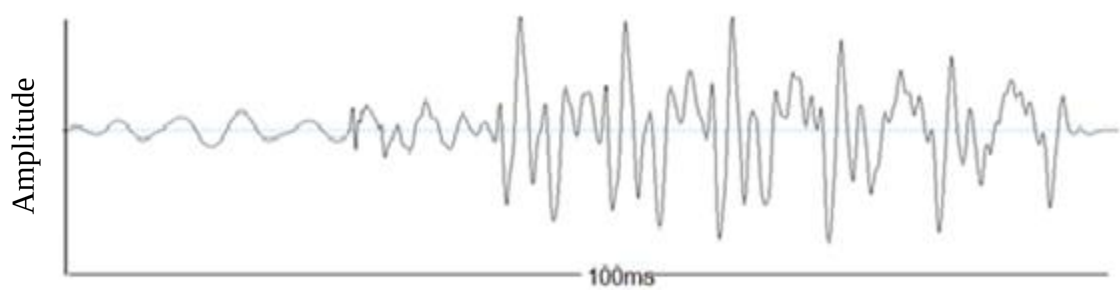


Fig 3.1: Syllable /ba/ of 100 ms.

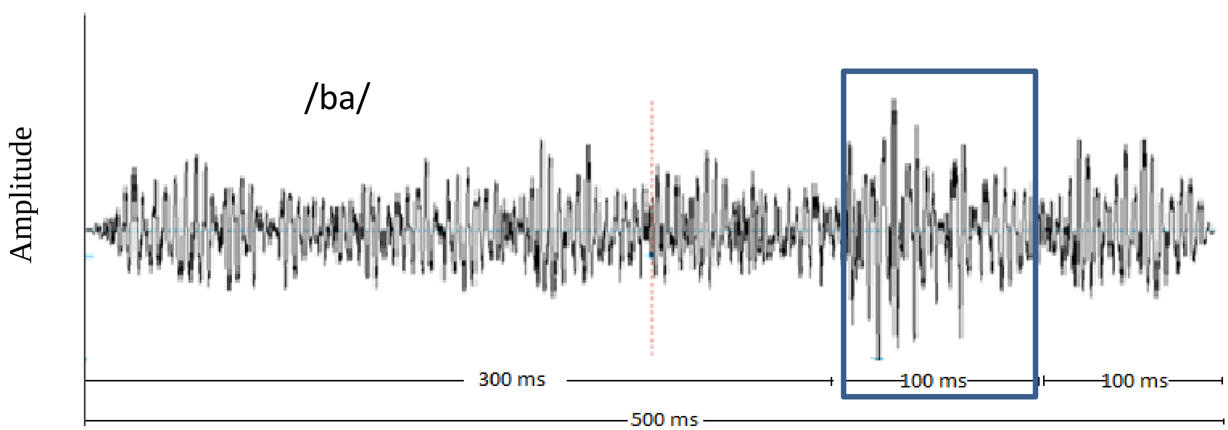


Fig 3.2: Speech noise of 500 ms with /ba/ of 100 ms embedded at 300ms

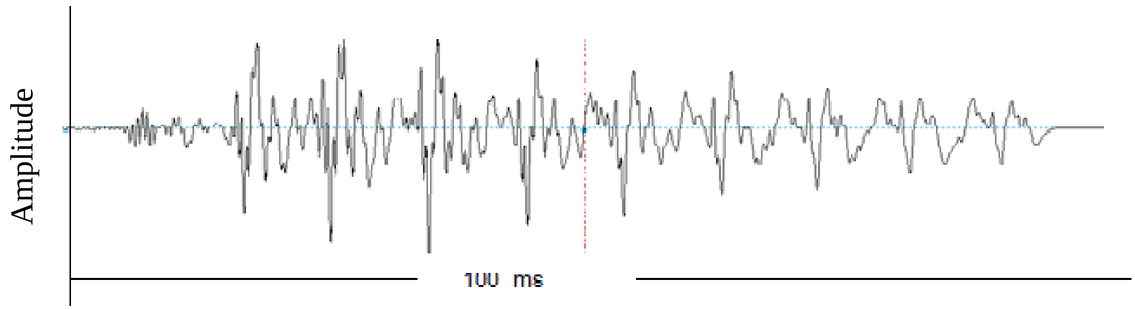


Fig 3.3: Syllable /da/ of 100 ms.

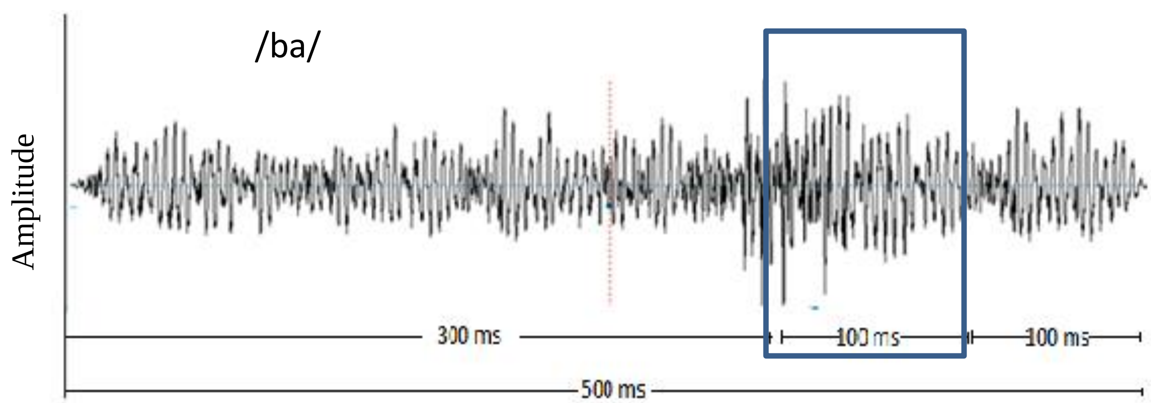


Fig 3.4: Speech noise of 500 ms with /da/ of 100 ms embedded at 300ms.

The high pass and low pass noise maskers were taken with cut offs as mentioned above because the second formant transitions of /ba/ and /da/ that are important for speech perception, do not come in the 200 Hz to 4000 Hz range, which preserves the speech perception of the speech sounds /ba/ and /da/ . Speech noise was used to study the waveforms which have undergone total masking of the speech sounds and perception of the speech stimuli is degraded. Thus the maskers that contrast between intact perception of speech sounds for high pass and low pass noises and total loss of perception of speech stimuli in the presence of speech noise were taken.

The initial and final 10 ms was ramped with a cosine window to ensure smooth onset and offset of the stimuli. All the above was carried out with the Adobe Audition software, version 3. The RMS of all the types of noise was kept constant. This was ensured by calculating the RMS value of noise using Adobe audition software version 3.0. These stimuli were converted into a wave file and were loaded into IHS instrument.

3.5 Procedure:

1. Pure-tone thresholds were obtained using modified version of Hughson and Westlak procedure (Carhart & Jerger, 1959) at octave frequencies between 250 Hz to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction.
2. Ascending method was used to determine participant's UCL for both ears using speech stimuli that was presented through headphones.
3. Speech Recognition Scores were obtained using GSI-61 audiometer presented through TDH 50 headphones at most comfortable level using PB wordlist developed by Yathiraj and Vijayalakshmi, (2005).
4. SPIN scores were obtained at 0 dB SNR. SPIN was done using phonemically balanced word list in Kannada, developed by Yathiraj, and Vijayalakshmi, (2005).
5. Immittance evaluation was carried out with a probe tone frequency of 226 Hz. Ipsilateral and contralateral acoustic reflex thresholds were measured for 500, 1000, 2000, and 4000 Hz pure tones.

6. TE-OAE was using otodynamics software.
7. ABR was carried out using standard ABR protocol for clicks, to rule out the presence of retrocochlear pathology.

3.6 Recording and Analysis of evoked potentials

The patients were seated in an electrically and acoustically shielded room. A skin abrasive was used to clean the electrode sites (Cz: Non inverting; Tip of the nose: Inverting electrode and Fpz: Ground) in accordance with the 10-20 International system (Jasper, 1958). The disc electrodes dipped in a conduction paste were placed on their respective sites using a surgical tape. The electrode impedance was maintained at ≤ 5 k Ω and inter-electrode impedance at $\leq 2k\Omega$. They were asked to relax and were made to watch a film with the soundtrack turned off. They were asked not to pay attention to the stimulus and to avoid excessive blinking.

A baseline LLR was taken without noise for /ba/ and /da/ stimulus i.e. in quiet and in noise that has been mentioned above. Thus LLRs were recorded in 8 different stimulus conditions i.e. /ba/ consonant in quiet, in highpass, lowpass and speech noise, /da/ consonant in quiet, highpass, lowpass and speech noise conditions both in normal and SNHL individuals. The SNR for the speech in noise stimulus was 0 dB. The stimuli were presented at a level of 80 dB SPL. The speech stimulus was presented in 5 sets of 30 sweeps, in all 8 conditions, where the recordings with less noise are considered for the averaging. Protocol followed for recording ALLR is as follows:

Table 3.1: *stimulus and acquisition parameters used for ALLR recordings*

<table>
<tr><th colspan="2">Stimulus Parameters</th><th colspan="2">Acquisition Parameters</th></tr>
<tr><td>Speech stimulus</td><td>/da / and /ba/</td><td>Transducer</td><td>Insert earphones ER-3A</td></tr>
<tr><td>Duration of stimulus</td><td>1. 100 ms speech stimulus without noise.
2. 300 ms noise+100ms speech in noise+100 ms of post stimulus noise for noise conditions.</td><td>Analysis Time</td><td>-100ms to 900ms</td></tr>
<tr><td>Stimulus level</td><td>80 dB SPL</td><td>Band pass filter</td><td>1Hz-30Hz</td></tr>
<tr><td>Polarity</td><td>Alternating</td><td>Electrode placement</td><td>Cz,:Non inverting
Tip of the nose: Inverting electrode
Fpz: Ground</td></tr>
<tr><td rowspan="4">Mode of presentation</td><td rowspan="4">Ipsilateral presentation of speech stimulus in quiet and in the presence of noise monaurally.</td><td>Sweeps</td><td>150 that are averaged from 5 trials of 30 sweeps</td></tr>
<tr><td>Line filter</td><td>Off</td></tr>
<tr><td>Artefact rejection</td><td>±100 micro Volt</td></tr>
<tr><td>Gain</td><td>50000</td></tr>
<tr><td rowspan="3">Repetition rate</td><td rowspan="3">0.9/sec</td><td>Electrode Impedance</td><td>≤ 5 kΩ</td></tr>
<tr><td>Inter Electrode Impedance</td><td>≤ 2 kΩ</td></tr>
<tr><td>Number of recordings</td><td>2</td></tr>
</table>

The peaks N1 and P2 thus obtained were marked by three experienced Audiologists. The latency and absolute amplitude was obtained for all their peaks.

3.7 Response Analysis:

Initially the waveform analysis of LLR in quiet was done for /ba/ and /da/ and the same was done in noise conditions. For the noise conditions, there were two LLRs present, one for the onset of noise and other for the onset of speech in noise. The LLR obtained from the portion of speech in noise was considered for the analysis. The latency and absolute amplitude of the N1 and P2 of the LLR were measured with respect to the baseline and subjected to analysis. The peaks N1 and P2 were considered for analysis, as in the majority of individuals N1and P2 are the prominent peaks (Hyde, 1997). Mean and standard deviation of amplitude and latency were calculated. Grand-average waveform that consisted of average of all the participants for a single condition was done to all the 8 conditions. The grand average analysis as well as individual subject analysis was done keeping in mind the individual variability among participants.

Chapter 4

Results

The aim of the study was to investigate the effect of different types of noise on Auditory Late Latency Responses in individuals with Sensorineural Hearing Loss and normal individuals. Attempts were also made to see the correlation between behavioral speech perception scores and components of ALLR in both the groups.

A test of normality distribution was done for latency and amplitude measures of both the groups, obtained across different conditions for the syllable /ba/ and /da/ using Shapiro wilk test. A descriptive statistics was done to all the parameters. All the conditions were compared between groups and within groups, the following statistical tests were administered for the inferential analysis:

- To compare the latency and amplitude of ALLR peaks between the groups and across conditions, Mixed ANOVA was used where the values followed normal distribution. For the values that lay out of the normal distribution, Mann Whitney U test was used.
- To find the significant difference in latency and amplitude, between conditions within a group, Repeated Measures ANOVA was done for values falling in normal distribution. For the values lying out of the normality curve, Friedman test was used.

- For pairwise comparison between conditions, Bonferroni test and paired t test was done and the non-parametric counterpart for the same, Wilcoxon signed rank test was used for values falling outside the normality curve.
- To see the correlation between the latency and amplitude measures across conditions, between the groups, with the speech scores, Pearson's correlation was done.
- For better understanding, the results have been given under the following headings:

  1) Latencies of N1 between groups and across conditions.

  2) Amplitude of N1 between groups and across conditions.

  3) Latencies of P2 between groups and across conditions.

  4) Amplitude of P2 between groups and across conditions.

4.1 Latency of N1 between groups and across conditions:

The descriptive statistics was done for the latency of the peak N1 elicited by the syllables /ba/ and /da/ at 80 dB SPL. This was done across different conditions for the control and clinical group. The mean and standard deviation values for the same have been given in the Table 4.1.

Table 4.1: *Mean and standard deviation for latency of N1 elicited by /ba/ and /da/ stimulus across conditions in clinical and control group*

Parameters	Syllable	Control group		Clinical group	
		Mean (ms)	**SD**	**Mean (ms)**	**SD**
	/ba/	105.07	13.64	113.33	15.37
N1 (Quiet)	/da/	95.20	13.07	100.47	14.06
N1 (HPN)	/ba/	122.80	18.25	132.53	17.41
	/da/	113.47	11.68	113.07	15.75
N1 (LPN)	/ba/	129.33	18.50	133.33	27.52
	/da/	114.67	20.25	114.80	17.53
N1 (SPN)	/ba/	138.40	17.09	136.53	17.54
	/da/	126.60	31.79	118.93	17.00

For the pictorial representation, bar graph representing the mean N1 latency along with standard error obtained for the syllables /ba/ and /da/ in two groups is given below figure 4.1.

/ba/

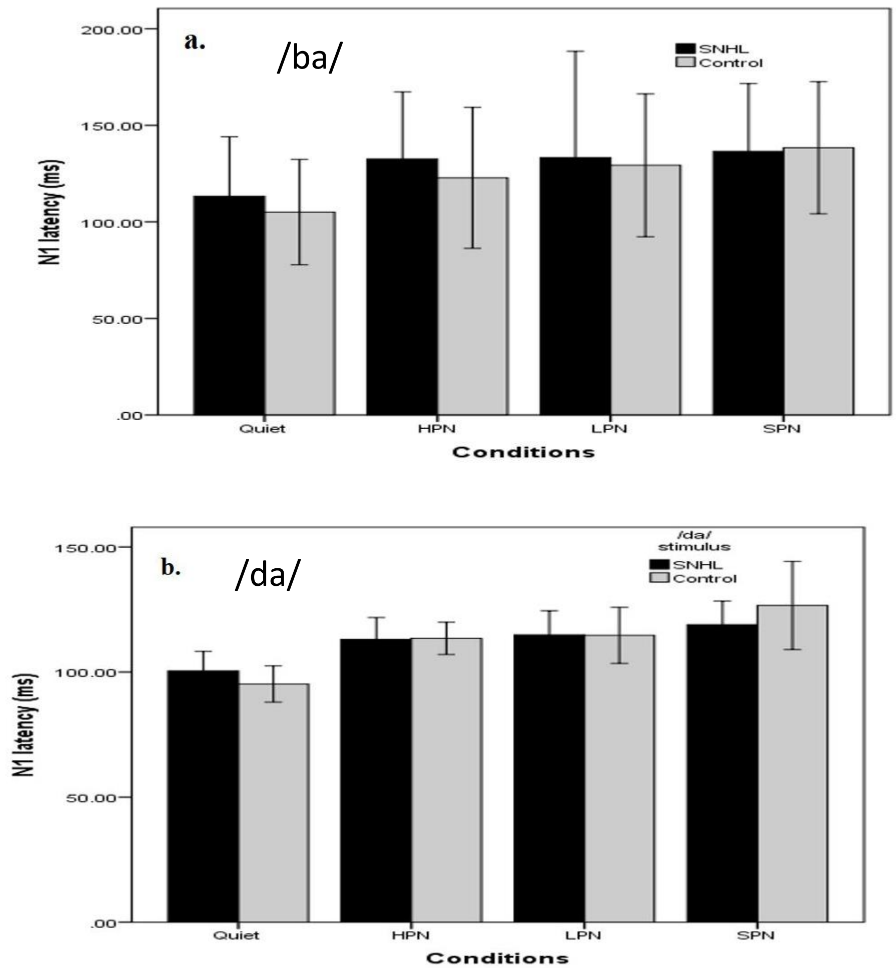


Fig 4.1.**a & b**: Mean and error bar of N1 latency obtained across conditions for stimuli /ba/ and /da/ in both the groups.

From the above Table 4.1 and Fig 4.1, it can be noted that the N1 latencies obtained in quiet stimulus condition occurred much earlier than the latencies elicited from high pass, low pass and speech noise conditions in both the groups, for stimulus /ba/ and /da/. It can also be seen that the N1 latencies of clinical group is slightly higher than the control group, except for that obtained in the speech noise condition. The changes across the conditions follow a similar pattern in both the groups for both /ba/ and /da/ stimuli.

Inferential statistics was done to see significant main effects of different stimulus conditions i.e. (in the presence of quiet, in high pass, in low pass and in speech noise) and groups on N1 latency using Mixed ANOVA. The mixed ANOVA revealed no significant main effect of groups for /ba/ stimulus, [$F (1, 28) = 1.01, p > 0.05$], and for /da/ stimulus [$F (1,28) = 0.02, p > 0.05$]. There was a significant main effect of conditions [$F (3, 84) = 21.28, p < 0.05$.] and [$F (3,84) = 11.91, p < 0.05$] for /ba/ and /da/ stimulus respectively. There was no significant interaction effect seen between the groups and conditions, [$F (3, 84) = 0.97, p > 0.05$] and [$F (3,84= 0.024, p > 0.05$] for /ba/ and /da/ stimulus respectively. To see the pairwise comparison between conditions, Bonferroni Pairwise comparison was done as the condition showed significant main effect. The below Table 4.2 represents pairwise comparison between different conditions for the stimulus /ba/ and /da/.

Table 4.2: ***pairwise comparison for between conditions for N1 latency obtained for stimulus /ba/ and /da/.***

Stimulus		**/ba/**		**/da/**	
Combination pair		**Std. Error**	**Significance Level.**	**Std. Error**	**Significance Level.**
Quiet	HPN	3.66	**0.000**	5.91	**0.058**
	LPN	3.79	**0.000**	5.20	**0.002**
	SPN	3.20	**0.000**	5.53	**0.000**
HPN	LPN	4.23	1.000	6.86	1.000
	SPN	3.63	0.071	5.50	0.079
LPN	SPN	3.77	0.692	5.40	0.695

It can be seen from the Table 4.2 that the N1 latencies obtained in quiet condition is significantly less compared to any other noise conditions i.e. in the presence of high pass, low pass and speech noise. There is no significant difference between N1 latency obtained in any two noise conditions for both /ba/ and /da/ stimulus.

4.2 Within group across condition comparison:

As the conditions have shown significant main effects, Repeated Measures ANOVA was administered for each group for stimulus /ba/ to see which group has significant main effect of conditions. The results showed that there was significant main effect of conditions for SNHL [F (3, 42) = 9.89, p<0.05] and for control group [F (3,42)= 11.95, p<0.05]. To see between which two conditions there was a significant difference, Bonferroni pair wise comparison was done and the Table 4.3 shows the details.

Table ***4.3: pairwise comparison between any two conditions of N1 latency for stimulus /ba/ in SNHL group and control group.***

Groups		SNHL		CONTROL	
Condition pairs		**Std. Error**	**Significance level**	**Std. Error**	**Significance level**
Quiet	HPN	4.31	**0.003**	4.31	**0.003**
	LPN	5.53	**0.017**	5.53	**0.017**
	SPN	3.22	**0.000**	3.22	**0.000**
HPN	LPN	4.97	1.000	4.97	1.000
	SPN	4.75	1.000	4.75	1.000
LPN	SPN	5.26	1.000	5.26	1.000

From the above table it can be seen that N1 latencies obtained in quiet condition is significantly less compared to the noise conditions i.e. high pass, low pass and speech noise. There is no significant difference between any two noise conditions in SNHL and control group for /ba/ stimulus.

As the Mixed ANOVA has shown significant main effects of conditions on N1 latency elicited by /da/ stimulus, Repeated Measures ANOVA was administered for each group to see which group has significant main effect of conditions. The results showed that there was significant main effect of conditions for SNHL group [$F(3, 42) = 5.48$, $p<0.05$] and for control group [$F(3,42) = 6.72$, $p<0.05$]. To see between which two conditions there was a significant difference, Bonferroni pair wise comparison was done for each group separately and the Table 4.4 shows the details.

Table 4.4***: Pairwise comparison between any two conditions of N1 latency obtained for stimulus /da/ within the SNHL and control group.***

Groups		**SNHL**		**CONTROL**	
Condition pairs		**Std. Error**	**Significance level**	**Std. Error**	**Significance level**
Quiet	HPN	2.66	**0.002**	2.65	**0.000**
	LPN	4.16	**0.024**	5.15	**0.012**
	SPN	5.76	**0.038**	8.16	**0.011**
HPN	LPN	4.84	1.000	4.53	1.000
	SPN	5.82	1.000	9.13	1.000
LPN	SPN	4.85	1.000	9.71	1.000

From the above table it can be seen that N1 latencies obtained in quiet condition is significantly less compared to the noise conditions i.e. high pass, low pass and speech noise. There is no significant difference between any two noise conditions in SNHL and control group for N1 latency elicited by /da/ stimulus.

4.3 N1 Amplitude across conditions and groups:

The descriptive statistics was done for the N1 amplitude elicited by syllables /ba/ and /da/ at 80 dB SPL. This was done across different conditions for the control and clinical group. The mean and standard deviation values for the same have been given in the Table 4.5

Table 4.5*: Mean and standard deviation for N1 amplitude elicited by /ba/ and /da/ stimulus across conditions in clinical and control group.*

Parameters	**Syllable**	**Control group**		**Clinical group**	
		Mean (µV)	**SD**	**Mean (µV)**	**SD**
N1 Quiet	/ba/	- 2.48	1.56	-3.41	1.37
	/da/	-2.85	1.49	-3.10	1.58
N1 HPN	/ba/	-0.91	0.89	-1.57	1.08
	/da/	-1.54	0.71	-2.15	1.45
N1 LPN	/ba/	-0.82	1.18	-1.25	0.87
	/da/	-1.35	1.53	-1.36	0.82
N1 SPN	/ba/	-0.50	0.83	-0.78	1.68
	/da/	-0.42	0.95	-0.94	1.40

For the pictorial representation, bar graph representing mean N1 amplitude along with standard error obtained for syllable /ba/ and /da/ in two groups is given in Figure 4.2.

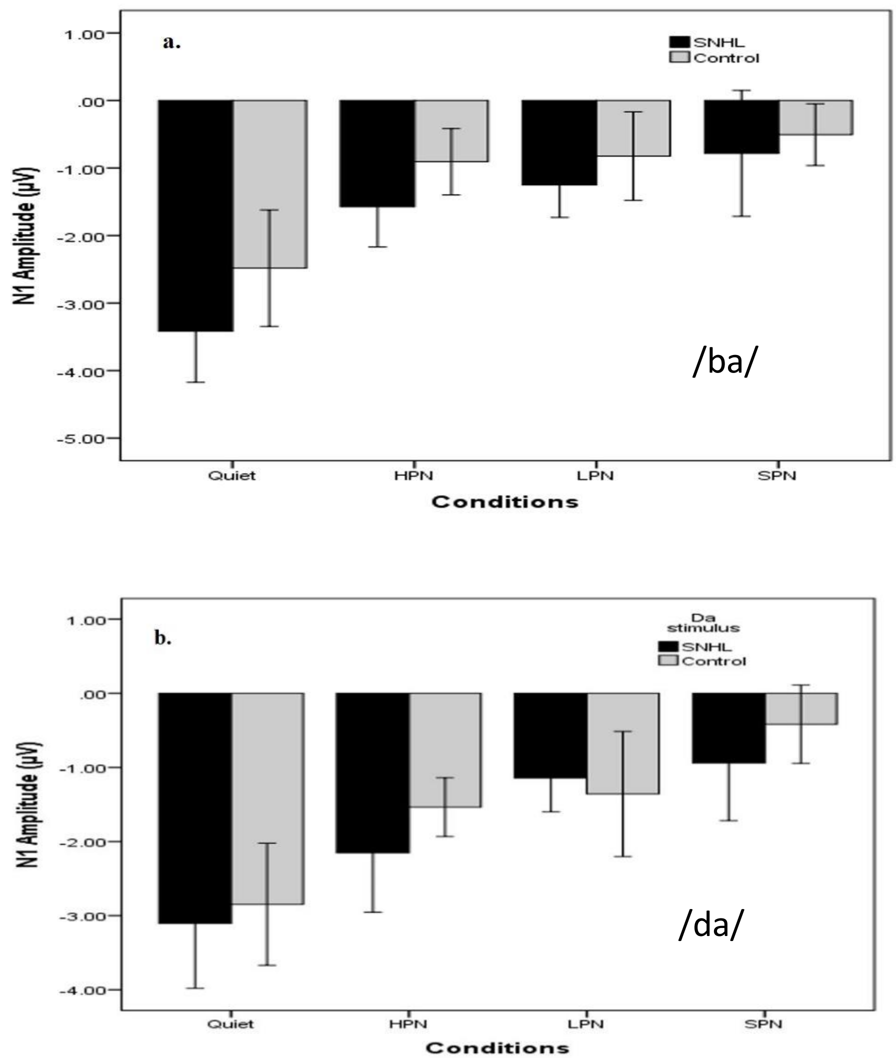


***Fig 4.2**:* a and b shows the Mean and error bar of N1 amplitude obtained across conditions for stimuli /ba/ and /da/ in both the groups

From the above Table 4.5 and Fig 4.2, it can be noted that the N1 amplitudes obtained in quiet stimulus condition had much more amplitude than the amplitudes elicited from high pass, low pass and speech noise conditions in both the groups, for stimulus /ba/ and /da/. It can also be seen that the amplitudes of clinical group is higher than the control group, except for that was obtained in the low pass noise condition for /da/ stimulus. The changes across the conditions follow a similar pattern in both the groups for both /ba/ and /da/ stimuli, i.e. highest amplitudes in the order of quiet, high pass, low pass and speech noise.

The amplitudes of the N1 was different at different conditions (quiet, high pass noise and speech noise) and were normally distributed; Mixed ANOVA was carried out to see the main effects of groups, conditions and interaction effect between groups and conditions for N1 amplitude elicited by stimulus /ba/. N1 amplitude obtained for low pass noise condition were not normally distributed and hence were not considered for Mixed ANOVA. The mixed ANOVA showed significant main effect of groups [$F(1,28) = 5.41$, $P<0.05$]. There was a significant main effect of conditions [$F(2,56) = 26.42$, $p< 0.05$]. However, there was no significant interaction effect seen between the groups and conditions, [$F(2, 56) =0.5$, $p> 0.05$]. To see the pairwise comparison between conditions, Bonferroni Pairwise comparison was done. The below Table 4.6 represents pairwise comparison between different conditions for N1 amplitude obtained in quiet, highpass and speech noises obtained for the stimulus /ba/.

Table 4.6: *Pairwise comparison for different conditions of quiet, high pass noise and speech noise, for amplitude of N1 obtained for stimulus /ba/*

(I) N1A	(J) N1A	Std. Error	Significance level
Quiet	HPN	0.31	**0.000**
	SPN	0.38	**0.000**
HPN	SPN	0.28	0.135

From the Table 4.6 it can be seen that N1 amplitude obtained in quiet condition is significantly more in amplitude than highpass and speech noise conditions, but there is no significant difference between highpass and speech noise conditions.

4.4 Within group across condition comparison of N1 amplitude

As the conditions (quiet, high pass and speech noise) have shown significant main effects, Repeated Measures ANOVA was administered for each group to see which group has significant main effect of conditions.The results showed that there was a significant main effect of conditions (quiet, high pass and speech noise) for SNHL group,[$F (2, 28) = 12.6, p<0.05$] and for control group[$F(2,28)= 15.18, p< 0.05$]. To see between which two conditions there was a significant difference, Bonferroni pair wise comparison was done for both the groups separately and shown in the Table 4.7.

Table 4.7*:* Pairwise comparison between any two conditions for amplitude of N1 for stimulus /ba/ within the SNHL and control group.

Group		**SNHL**		**CONTROL**	
Condition pair		**Std. Error**	**Significance. level**	**Std. Error**	**Significance. level**
Quiet	HPN	0.46	**0.004**	0.40	**0.005**
	SPN	0.64	**0.003**	0.42	**0.001**
HPN	SPN	0.48	0.381	0.29	0.575

From the above table 4.7 it can be seen that N1 amplitude obtained for quiet condition was significantly more than high pass and speech noise conditions, However, there was no significant difference between high pass and speech noise conditions in clinical group as well as for control group for stimulus /ba/.

To see the main effect of group in low pass noise condition of N1 amplitude obtained for /ba/ stimulus, Mann Whitney U test was administered as the amplitude values lay out of normal distribution. It was shown that there was no significant difference in N1 amplitude between the control and clinical group for the low pass noise condition ($Z = -1.141$, $P > .05$).

To see the significant difference in N1 amplitude between the conditions (quiet, high pass and speech noise) with the low pass noise within SNHL and control group. Wilcoxon signed rank test was done. The below table shows Z- values and significant level for the same.

From the above table, it can be seen that the N1 amplitude of quiet condition was significantly higher than the low pass noise condition and there was no significant difference between low pass noise condition and the highpass or speech noise conditions.

Table 4.8: *Z -value along with significance values for N1 amplitudes of low pass noise condition and the other conditions in SNHL and control group obtained for /ba/ stimulus:*

Groups	**SNHL**			**Control**		
Condition pair	**LPN-Quiet**	**LPN - HPN**	**SPN - LPN**	**LPN-Quiet**	**LPN - HPN**	**SPN - LPN**
/Z/- value	3.12	1.44	1.30	3.23	0.28	0.79
Asymp. Sig. (2-tailed)	**0.002**	0.147	0.191	**0.001**	0.776	0.427

To analyze the main effects for groups, main effect of conditions and interaction effect between group and conditions on N1 amplitude elicited for /da/ stimulus, Mixed ANOVA was used, as the amplitude values across conditions were normally distributed. The results showed no significant main effect of groups for /da/ stimulus, [$F (1,28) = 1.25$, $p > 0.05$]. There was a significant main effect of conditions [$F (3, 84) = 19.20$, $p< 0.05$]. However, there was no significant interaction seen between the groups and conditions, [$F (3, 84) =0.69$, $p> 0.05$]. As the condition has shown significant main effect, to see the pairwise comparison between conditions, Bonferroni Pairwise comparison was done. The below table represents pairwise comparison between any two conditions for N1 amplitude elicited by the stimulus /da/.

Table ***4.9***: *Pairwise comparison between any two conditions for N1 amplitude obtained for stimulus /da/.*

(Clinical) N1A	**(Control) N1A**	**Std. Error**	**Significance level**
Quiet	HPN	0.33	**0.013**
	LPN	0.39	**0.001**
	SPN	0.32	**0.000**
HPN	LPN	0.29	0.304
	SPN	0.25	**0.001**
LPN	SPIN	0.45	**0.007**

It can be seen from the table that the N1 amplitudes in quiet is significantly more compared to the noise conditions i.e. high pass, low pass and speech noise conditions. N1 amplitude obtained at high pass noise condition was also significantly different from speech noise condition. However, N1 amplitude at low pass noise and speech noise did not differ significantly.

As the conditions have shown significant main effects, Repeated Measures ANOVA was administered for N1 amplitude elicited by /da/ stimulus within group. The results showed that there was a significant main effect of conditions for SNHL group, [$F(3, 42) = 10.06$, $p<0.05$] and control group [$F(3,42)= 9.82$, $p< 0.05$]. To see between which two conditions there was a significant difference, Bonferroni pair wise comparison was done for both the groups separately and the Table 4.10 has the details of the same.

Table *4.10**: pairwise comparison between any two conditions for N1 amplitude obtained for stimulus /da/ within SNHL and control group***

Group		**SNHL**		**CONTROL**	
Condition pair	**(Control) N1L**	**Std. Error**	**Significance level**	**Std. Error**	**Significance level**
Quiet	HPN	0.55	0.653	0.37	**0.019**
	LPN	0.49	**0.008**	0.61	**0.050**
	SPN	0.44	**0.002**	0.47	**0.001**
HPN	LPN	0.34	0.068	0.46	1.000
	SPN	0.38	**0.041**	0.34	**0.035**
LPN	SPN	0.41	1.000	0.38	0.176

It can be seen from the table that in control group, the N1 amplitudes obtained in quiet is significantly more compared to any noise conditions. Also, there is significant increase in N1 amplitude of high pass noise condition compared to amplitudes in speech noise condition. There was no significant difference between the other noise conditions in control group. In SNHL group, N1 amplitude obtained in quiet was significantly more compared to low pass and speech noise conditions and also N1 amplitude obtained for the high pass noise condition was significantly more than the speech noise condition. There was no significant difference between other noise conditions in SNHL group.

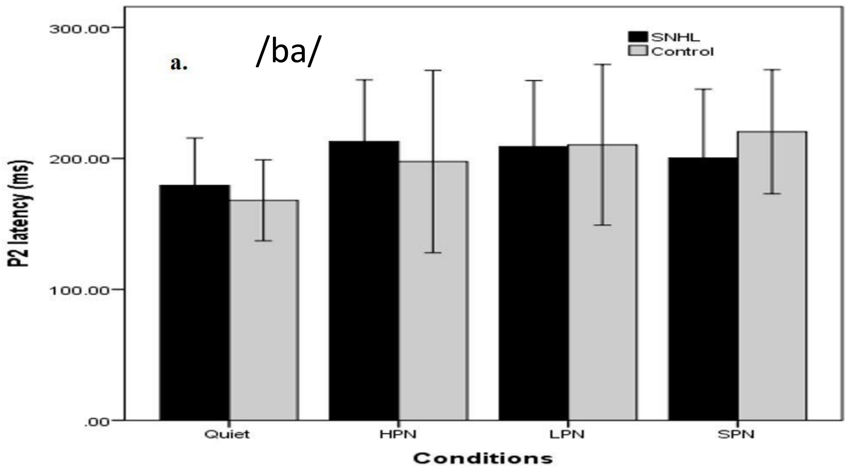
4.5 Latency of P2 between groups and across conditions:

The descriptive statistics was done for the latency of the peak P2 elicited by the syllables /ba/ and /da/ at 80 dB SPL. This was done across different conditions for the control and clinical group. The mean and standard deviation values for the same have been given in the Table 4.11.

Table 4.11: *Mean and standard deviation for latency of P2 elicited by /ba/ and /da/ stimulus across conditions in clinical and control group.*

		Control group		Clinical group	
Parameters	**Syllable**	**Mean (ms)**	**SD**	**Mean (ms)**	**SD**
P2 Quite	/ba/	168.00	15.45	179.47	18.02
	/da/	161.00	9.43	168.13	17.82
P2 HPN	/ba/	197.60	34.81	212.93	23.50
	/da/	186.53	22.88	200.07	20.40
P2 LPN	/ba/	210.33	30.66	211.07	25.19
	/da/	189.67	26.83	189.80	16.21
P2 SPN	/ba/	220.33	23.67	200.27	26.30
	/da/	196.73	40.264	207.67	25.44

For the pictorial representation, bar graph representing mean P2 latency along with standard error obtained for syllable /ba/ and /da/ in two groups is given in Figure 4.3.



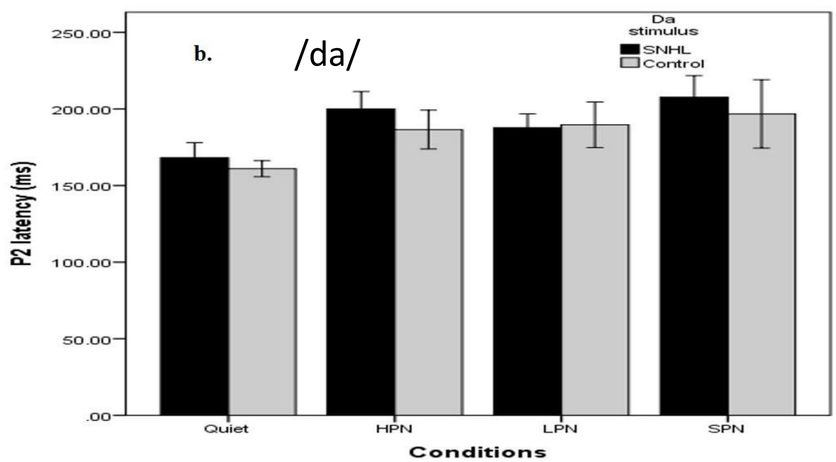


Fig 4.3: a and b shows the Mean and error bar of P2 latency obtained across conditions for stimuli /ba/ and /da/ in both the groups

From the above Table 4.11 and Fig 4.3, it can be noted that the P2 latencies obtained in quiet stimulus condition occurred earlier than the latencies elicited from high pass, low pass and speech noise conditions in both the groups, for stimulus /ba/ and /da/. It can also be seen that the P2 latencies of clinical group is slightly higher than the control group for quiet and high pass noise conditions for /ba/ and quiet, high pass and speech noise conditions for /da/.

Inferential statistics was done to see significant main effects of different stimulus conditions i.e. (in the presence of quiet, high pass, low pass and speech noise) and groups on P2 latency using Mixed ANOVA. The mixed ANOVA revealed no significant main effect of groups for /ba/ stimulus, [$F (1,28) = 0.05$, $P>0.05$], and for /da/ stimulus [$F (1,28) = 1.45$, $P>0.05$]. There was a significant main effect of conditions [$F (3, 42) = 8.42$, $p< 0.05$], [$F (3, 84) = 20.38$, $p< 0.05$] for /ba/ and /da/ stimulus respectively. There was significant interaction effect seen between the groups and conditions, [$(3, 84) =3.4$, $p< 0.05$] for /ba/ whereas no significant interaction effect [$F (3, 84) =0.892$, $p> 0.05$] /da/ stimulus. To see the pairwise comparison between conditions, Bonferroni Pairwise comparison was done as the condition shows significant main effect. The below Table 4.12 represents pairwise comparison between different conditions for the stimulus /ba/ and /da/.

Table 4.12: *Pairwise comparison for between conditions for P2 latency obtained for stimulus/ba/ and /da/.*

Stimulus		**/ba/**		**/da/**	
Combination pair		**Std. Error**	**Significance. level**	**Std. Error**	**Significance. level**
Quiet	HPN	6.50	**0.000**	3.44	**0.000**
	LPN	5.13	**0.000**	4.49	**0.000**
	SPN	4.34	**0.000**	5.25	**0.000**
HPN	LPN	6.14	1.000	5.16	1.000
	SPN	6.21	1.000	4.37	0.308
LPN	SPN	5.53	1.000	6.85	0.356

It can be seen from the Table 4.12 that the P2 latencies obtained in quiet condition is significantly less compared to any other noise conditions i.e. in the presence of high pass, low pass and speech noise. There is no significant difference between P2 latency obtained in any two noise conditions for both /ba/ and /da/ stimulus.

4.5 *Within group across condition comparison:*

As the conditions have shown significant main effects, Repeated Measures ANOVA was administered for each group for stimulus /ba/ to see which group has significant main effect of conditions. The results showed that there was significant main effect of conditions for SNHL [$F(3, 42) = 8.42$, $p < 0.05$] and for control group [$F(3, 42) = 13.41$, $p < 0.05$]. To see between which two conditions there was a significant difference, Bonferroni pair wise comparison was done and the Table 4.13 shows the details.

Table ***4.13:*** *Pairwise comparison between any two conditions for P2 latency for stimulus /ba/ in SNHL group and control group.*

Stimulus					
		SNHL		**CONTROL**	
(C**linical) N1L**	**(control) N1L**	**Std. Error**	**Significance level**	**Std. Error**	**Significance level.**
Quiet	HPN	7.98	**0.005**	10.26	**0.072**
	LPN	6.90	**0.005**	7.60	**0.000**
	SPN	5.35	**0.010**	6.83	**0.000**
HPN	LPN	6.87	1.000	10.19	1.000
	SPN	9.05	1.000	8.52	0.111
LPN	SPN	6.92	1.000	8.64	1.000

From the above table it can be seen that P2 latencies obtained in quiet condition is significantly less compared to the noise conditions i.e. high pass, low pass and speech noise. There is no significant difference between any two noise conditions in SNHL and control group for /ba/ stimulus.

For stimulus /da/, the results showed that there was significant main effect of conditions for SNHL group [$F (3, 42) = 24.4, p<0.05$] and for control group [$F (3, 42) = 6.28, p<0.05$]. To see between which two conditions there was a significant difference, Bonferroni pair wise comparison was done for each group separately and the Table 4.14 shows the details.

Table *4.14**:** Pairwise comparison between any two conditions of P2 latency obtained for stimulus /da/ within the SNHL and control group***.***

Group		SNHL		CONTROL	
Condition pair		**Std. Error**	**Significance level**	**Std. Error**	**Significance level**
Quiet	HPN	4.59	**0.000**	5.13	**0.001**
	LPN	4.89	**0.008**	7.54	**0.012**
	SPN	4.44	**0.000**	9.52	**0.013**
HPN	LPN	4.95	0.160	9.07	1.000
	SPN	4.11	0.516	7.71	1.000
LPN	SPN	6.33	0.044	12.15	1.000

From the above table it can be seen that P2 latencies obtained in quiet condition is significantly less compared to the noise conditions i.e. high pass, low pass and speech noise. There is no significant difference between any two noise conditions in SNHL and control group for N1 latency elicited by /da/ stimulus.

4.6 P2 Amplitude across conditions and groups:

The descriptive statistics was done for the P2 amplitude elicited by syllables /ba/ and /da/ at 80 dB SPL. This was done across different conditions for the control and clinical group. The mean and standard deviation values for the same have been given in the Table 4.15

Table 4.15: *Mean and standard deviation for P2 amplitude elicited by /ba/ and /da/ stimulus across conditions in clinical and control group.*

		Control group		**Clinical group**	
Parameters	**Syllable**	**Mean (μV)**	**SD**	**Mean (μV)**	**SD**
P2 Quite	/ba/	2.39	1.52	2.83	2.07
	/da/	2.62	1.26	2.79	2.83
P2 HPN	/ba/	3.77	1.50	2.83	2.31
	/da/	4.13	1.59	4.25	1.28
P2 LPN	/ba/	3.63	1.38	3.86	1.42
	/da/	3.43	1.60	4.46	1.80
P2 SPN	/ba/	2.93	1.24	2.73	2.22
	/da/	3.30	1.38	3.67	1.77

For the pictorial representation, bar graph representing mean P1 amplitude along with standard error obtained for syllable /ba/ and /da/ in two groups is given in Figure 4.4.

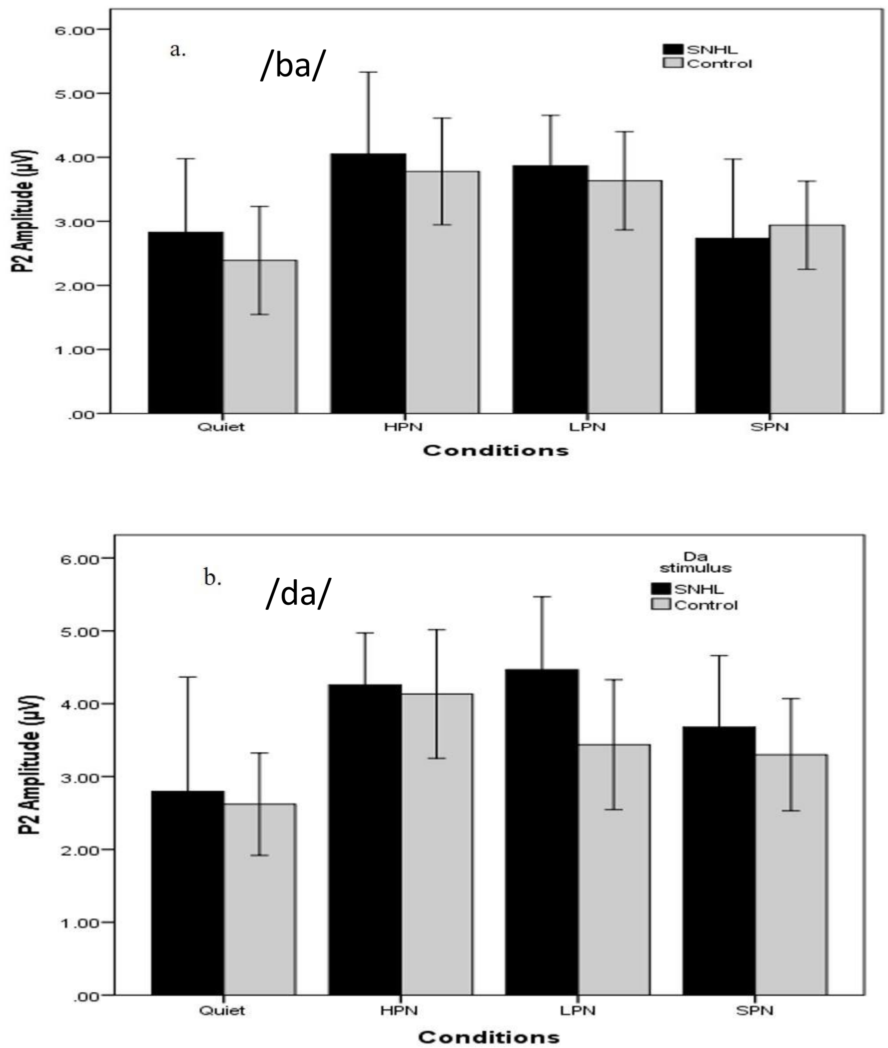


***Fig 4.4**:* a and b shows the Mean and error bar of P2 amplitude obtained across conditions for stimuli /ba/ and /da/ in both the groups

From the above Table 4.15 and Fig 4.4, it can be noted that the P2 amplitudes obtained in quiet stimulus condition had lesser amplitude than the amplitudes elicited from high pass, low pass and speech noise conditions in both the groups, for stimulus /ba/ and /da/. It can also be seen that the amplitudes of clinical group are higher than the control group, except for that was obtained in the low pass noise condition for /da/ stimulus.

The amplitudes of the P2 was different at different conditions (quiet, high pass noise and low pass noise) and were normally distributed; Mixed ANOVA was carried out to see the main effects of groups, conditions and interaction effect between groups and conditions for P2 amplitude elicited by stimulus /ba/. P2 amplitude obtained for speech noise condition was not normally distributed and hence was not considered for Mixed ANOVA. The mixed ANOVA showed significant main effect of groups [$F(1, 28) = 0.39$, $P>0.05$]. There was a significant main effect of conditions [$F(2, 56) = 9.20$, $p< 0.05$]. There was no significant interaction effect seen between the groups and conditions, [$F(2, 56) =0.05$, $p> 0.05$]. To see the pairwise comparison between conditions, Bonferroni Pairwise comparison was done. The below Table 4.16 represents pairwise comparison between different conditions for P2 amplitude obtained in quiet, high pass and low pass noises obtained for the stimulus /ba/.

Table ***4.16****: Pairwise comparison for different conditions of quiet, highpass noise and low pass noise, for amplitude of P2 obtained for stimulus /ba/*

Condition pair		Std. Error	Significance level
Quiet	HPN	0.29	**0.000**
	LPN	0.33	**0.006**
HPN	LPN	0.36	1.000

From the Table 4.16 it can be seen that P2 amplitude obtained in quiet condition is significantly less in amplitude than highpass and low pass noise conditions, but there is no significant difference between highpass and low pass noise conditions.

4.6 Within group across condition comparison of P2 amplitude

As the conditions (quiet, high pass and low pass noise) have shown significant main effects, Repeated Measures ANOVA was administered for each group to see which group has significant main effect of conditions. The results showed that there was a significant main effect of conditions (quiet, high pass and low pass noise) for SNHL group, [$F (2, 28) = 3.85$, $p<0.05$] .To see between which two conditions there was a significant difference, Bonferroni pair wise comparison was done for SNHL group is shown in the table 4.17.

Table *4.17*: *pairwise comparison between any two conditions for amplitude of P2 for stimulus /ba/ within the SNHL*

Condition pair		Std. Error	Significance level
Quiet	HPN	0.425	**0.037**
	LPN	0.465	0.128
HPN	LPN	0.526	1.000

From the above table it can be seen that P2 amplitude obtained for quiet condition is significantly less than high pass noise condition. However there is no significant difference between highpass and low pass noise conditions and quiet and low pass noise condition in clinical group as well as for control group for stimulus /ba/.

To see the main effect of group in speech noise condition of P2 amplitude obtained for /ba/ stimulus, Mann Whitney U test was administered as the amplitude values lay out of normal distribution. It was shown that there was no significant difference in P2 amplitude between the control and clinical group for the speech noise condition (Z= -0.35, p>.05).

To compare main effect of the conditions (quiet, highpass and low pass noise) within SNHL with the speech noise, Wilcoxon signed rank test was done. The below table shows Z- values and significant level for the same.

Table 4.18: *Z -value along with significance values for P2 amplitudes of low pass noise condition and the other conditions in SNHL group obtained for stimulus /ba/.*

Group	**SNHL**		
Condition pair	**SPN - Quiet**	**SPN - HPN**	**SPN - LPN**
/Z/- value	-0.17	-1.16	-1.87
Asymp. Sig. (2-tailed)	0.86	0.24	0.46

From the above table, it can be seen that the there was no significant difference between speech noise condition and any of the conditions for P2 amplitude obtained for /ba/ stimulus.

Repeated Measures ANOVA was done to the P2 amplitude obtained for /ba/ stimulus within control group as the values fell within normal distribution. Repeated Measures ANOVA for control group showed that there was a significant main effect of conditions (quiet, high pass and low pass noise,speech noise) [$F (2, 28) = 4.37$, $p<0.05$] .To see between which two conditions there was a significant difference, Bonferroni pair wise comparison was done for control group and the significance values are shown in the table 4.19.

Table 4.19: *pairwise comparison between any two conditions for amplitude of P2 for stimulus /ba/ within control group.*

Comparison pairs		**Std. Error**	**Significance level**
Quiet	HPN	0.40	**0.013**
	LPN	0.48	0.065
	SPN	0.32	0.073
HPN	LPN	0.29	0.304
	SPN	0.34	0.062
LPN	SPN	0.39	0.073

From the above table it can be seen that P2 amplitude obtained for quiet condition is significantly less than high pass and low pass noise condition. However there is no significant difference between quiet and speech noise condition and any other noise conditions for control group for stimulus /ba/.

To analyze the main effects for groups, main effect of conditions and interaction effect between group and conditions on P2 amplitude elicited for /da/ stimulus, Mixed ANOVA was used, as the amplitude values across conditions were normally distributed. The results showed no significant main effect of groups for /da/ stimulus, [$F(1, 28) = 1.29$, $p>0.05$]. There was no significant main effect of conditions [$F(2, 56) = 2.56$, $p>0.05$], there was no interaction seen between the groups and conditions, [$F(2, 56) = 1.08$, $p>0.05$].

4.7 Correlation of behavioral Speech in Noise and Cortical potentials:

To see the correlation of amplitude and latency measures for /ba/ stimulus of SNHL group across conditions with the behavioral Speech in Noise (SPIN), Pearson's correlation was done. It was seen that there was a moderate negative correlation with P2 latency in low pass noise condition, ($r = -0.53$, $p= .042$), moderate negative correlation with P2 latency in speech noise condition($r = -0.62$, $p=.012$). There was no significant correlation found with the amplitude parameters for /ba/ stimulus and SPIN scores.

For the /da/ stimulus, there was a moderate negative correlation with the P2 latency in quiet condition, ($r = -0.63$, $p=.011$). No other ALLR parameters showed any significant correlation with SPIN scores.

The Pearson's correlation was done also in the control group to see the correlation between the SPIN and LLR parameters. For the stimulus /da/ in control group, there was a moderate negative correlation for the N1 latency in quiet condition ($r= -0.59$, $p=.018$), a moderate negative correlation with N1 latency in speech noise condition, ($r= -0.61$, $p=.013$) .None of the other ALLR parameters showed any significant correlation with SPIN scores.

Chapter 5

Discussion

5.1 Effect of groups on ALLR amplitude

The groups consisted of Sensorineural hearing loss and normal hearing individuals and Late Latency Response (LLR) was elicited in both the groups in four different conditions for stimulus /ba/ and /da/ each.

The results showed there was a significant difference between the groups across all the conditions for N1 amplitude obtained for /ba/ stimulus. There was a significant increase of N1 amplitude in the clinical group compared to the control group. Though there was a trend for increase in amplitude in clinical group than control group, for the peak P2 obtained for both /ba/ and /da/ stimulus, it failed to reach statistical significance.

These results are in line with Oates, Kurtzberg, and Stapells, (2002) study, where they showed a significant increase in amplitude for the peaks N1 and P3 for individuals with moderate hearing loss at a presentation level of 80 dB SPL. They reasoned that as the stimulus was at suprathreshold, the recruitment phenomena in SNHL individuals might have caused an increase in amplitude of N1, as N1 is an indicator of the level of audibility and sensitive to level changes.

A study by Gonzalez (2015) also showed an increase in N1 and P2 amplitudes for individuals with hearing loss when stimulus was presented along with 50 dB of noise. She reasoned that this may be due to increase in excitation. Similar results were shown by Sumitha (2008) when LLR was elicited at 70 dB nHL and 40 dB SL in SNHL group and in individuals with normal hearing. There was an increase in amplitude of the peak N1-P2 in SNHL group. This was explained by the phenomena of excitation of more number of neurons in SNHL population due to recruitment, that is absent in individuals with normal hearing.

In the present study, there is a significant increase in amplitude in N1 amplitude in SNHL group, also which can be explained because of the phenomena of recruitment in the population at suprathreshold levels.

5.2 Effect of groups on ALLR latency

The results showed that there was a trend towards increase in latency of N1 and P2 in the SNHL group compared to the control group, but failed to reach statistical significance. This is in line with the study by Polen (1984), where there was a significant increase in N1, P2 and N2 latencies in SNHL group compared to the control group. It was reasoned that the increase in latency was due to deficit in the auditory cortical structures that led to increased neuronal time of processing. Oates, Kurtzberg, and Stapells, (2002) also showed an increase of latency in later peaks P2, N2 and P3 in individuals with SNHL. In a study by Harkrider, Plyler and Hedrick (2006) the latency measure failed to reach statistical significance between older normal and older SNHL groups, whereas there was a significant increase in N1 amplitude. They say that the larger variability in the latency measures led to lack of significant difference between the groups.

In the present study, the trend towards increase in latencies for SNHL group might be because of the delay in neural processing due to the presence of the disorder (Oates, Kurtzberg, and Stapells, 2002). However, the latency values failed to reach statistical significance due to the presence of variability of latency measure in cortical studies which can be overcome by having a larger sample in the groups (Harkrider, Plyler and Hedrick , 2006).

5.3 Effect of conditions on ALLR latency:

The results showed significant early latency for quiet condition compared to the other 3 noise conditions for N1 and P2 and latency obtained for both /ba and /da/ stimuli in both normal and clinical group. There was no difference in latency between noise conditions. Thus there was a prolongation of latencies in the presence all conditions of noise, which is in line with the studies by Billings, Tremblay, Stecker and Tolin (2009) where they reported an increase in latency in the presence of noise when compared to the stimulus in quiet. Similarly the studies by Billings, Molis and Leek (2011) ; Kaplan and Neeman (2006); Martin and Stapells (1997, 1999, 2005) showed an increase in latency in the presence of noise. They reasoned that the loss of audibility caused by masking effect of the noise on specific spectral peaks leads to prolongation of latencies in the presence of noise. In the present study too, the prolongation of N1 and P2 latencies in noise in clinical and control group might be due to the loss of information and audibility of the speech signals due to masking in the presence of noise.

5.4 Effect of conditions on ALLR amplitude:

The results showed that there was a significant effect of conditions for N1 amplitude where there was improvement in amplitude for quiet condition compared to the conditions *in noise in clinical and control groups. There was no difference between the amplitudes obtained in different noise conditions.* This decrement of amplitudes in the presence of noise is in line with the studies by Billings, Molis and Leek (2011) ; Kaplan and Neeman (2006); Martin and Stapells (1997, 1999, 2005) . This decrease in amplitude in the presence of noise was statistically significant only for the N1 peak of the ALLR which is in line with the studies by Martin and Stapells (1997, 1999, 2005). They showed that the N1 parameter was the first to get masked while using different cut off noise. They concluded that the N1 amplitude is sensitive to the level of the signal determines the audibility of the stimulus reaching the cortex. Thus the reduced amplitude of N1 in the present study could be due to the loss of audibility due to masking by noise in noise conditions. Also it can be inferred from the present study that the N1 parameter codes for the audibility of the stimulus.

For P2 amplitude, the results showed that there was a significant difference of amplitude in quiet condition compared to low pass and high pass noise condition for /ba/ stimulus. There was a significant increase of amplitude for the condition in high pass noise in both clinical and control group for /ba/ stimulus.

Contrasting to the results of studies by Billings, Molis and Leek (2011) ; Kaplan and Neeman (2006), where there was a reduction in amplitude of the peaks N1, P2 and N2, the amplitude of P2 was significantly more in the presence of highpass noise compared to the quiet condition for /ba/ stimulus. The trend showed that the P2 amplitude increased in the presence of noise. In a study by Anderson, Chandrasekaran, Han- Yi and Kraus (2010), it was seen that there was an increase in N2 amplitude in the presence of noise in the individuals who had poor behavioral speech in noise scores. It was reasoned that the higher order processing is affected in the presence of noise and there is an increase in number of neurons firing in the presence of noise for higher order processing of the speech signal. As N2 represents higher order processing, the N2 amplitude was increased due to increase in firing of neurons. Similarly, the increase in P2 amplitude in the presence of noise can be explained as P2 also represents the higher order processing (Naatanen and Picton, 1987).

An overview of the results shows that there is an increase in latency and decrease in amplitude of the peaks in the presence of noise. Though not significant, the effect of different noise is different for different peaks and the effect of different noise differ with respect to the clinical and control groups. This could be more evident in studies with larger sample sizes. It was seen that the amplitude and latency of the peak N1 obtained for /ba/ and /da/ stimuli in both clinical as well as control groups was affected in a similar manner in which behavioral speech is affected by the noise. Miller (1947) showed that speech noise was the effective masker followed by the low frequencies and then the high frequency. The amplitude and latency of N1in the current study showed a similar trend where the speech noise condition had the least amplitude and highest latency, followed by low pass noise and then high pass noise condition. It can be inferred that the masking that is represented through the N1 amplitude and latency is similar to the masking that takes place during behavioral speech perception in both the groups (Miller 1947).

5.5 Correlation of behavioral Speech in Noise and Cortical potentials:

In the present study, behavioral speech in noise scores of SNHL group correlated with a negative correlation for P2 latency of LLR in low pass for /ba/ stimulus and P2 latency speech noise condition for /da/ stimulus. The behavioral speech in noise scores of control group correlated with the N1 latencies obtained in quiet condition and low pass noise condition.

In the study by Anderson, Chandrasekaran, Han- Yi and Kraus (2010), they found a correlation of behavioral speech in noise (SPIN) scores with the N2 amplitude of ALLR, where the N2 amplitude increased with the decrease in the speech in noise scores in children. They reasoned that N2 is an indicator of higher order processing and the lack of higher order processing in poor performers in SPIN task requires more nerve fibers to fire for the processing to happen than the good performers. Thus results in increased amplitude of later peaks of ALLR.In a study by Billings, Millan , Penman and Gille (20013), N1 amplitude and latency was shown to be correlating the best with speech perception in noise with the LLRs obtained in the presence of noise.

Thus it can be inferred that N1 latency correlates with behavioral responses in the control group, whereas P2 correlate with the behavioral speech in SNHL group and latencies are the sensitive measures for behavioral speech correlation than the amplitudes in both SNHL and control groups, where latencies decreased with improvement in the SPIN scores.

Chapter 6

Summary and Conclusion

Neural encoding of speech can be studied through auditory late latency responses (Sharma &Dorman, 1999). Studying neural coding of speech in various population gives insight about the speech processing that happens in those populations. It is known that the speech perception is poor in individuals with sensorineural hearing loss in quiet and in presence of noise compared to that of normal hearing individuals. This study was carried out to see whether these behavioral difficulties of individuals with SNHL could be reflected in the cortical evoked potentials.

Thus the present study aimed at the following aspects:

1. To evaluate the differences in ALLR responses in quiet and different spectrum of noise between the two groups.
2. To study the differential effects of different spectrum of noise on the ALLR responses in normal hearing individuals and individuals with SNHL.
3. To study the correlation between behavioral speech in noise scores with the cortical responses elicited in quiet and noise conditions.

The participants in the study included control group having normal hearing individuals and clinical group having individuals with SNHL in the age range of 18-50 years. ALLRs were evoked from all the participants to /ba/ and /da/ stimuli in quiet, high pass noise, low pass noise and speech noise conditions at 80 dB SPL. The speech in noise stimulus had an SNR value of 0 dB. ALLRs elicited in control and clinical groups were marked with N1 and P2 peaks by experienced audiologists. The absolute amplitudes and latency values were noted for further analysis. The following analysis were done using SPSS software version 15.

- Descriptive statistics to note down the mean and standard deviation of latency and amplitudes in both the groups.
- Comparison of main effect of groups on amplitudes and latencies.
- Comparison of main effect of conditions on amplitudes and latencies within group.
- Correlation of behavioral speech in noise scores with the latency and amplitudes of cortical potentials.

6.1 Effect of groups on amplitudes and latencies:

The responses elicited by the speech stimuli differed between the control and clinical groups. There was a trend towards increased latency of peaks N1 and P2 in SNHL group in all the conditions compared to the normal counterparts. It was concluded that the increase in latency in the clinical group might be because of the reduced neural processing indicating the affected speech perception in individuals with SNHL.

There was a significant increase in N1 amplitudes in SNHL individuals compared to the normal hearing individuals. One of the possible reasons may be due to the phenomena of recruitment in individuals with SNHL and the other possible reason being affected efferent pathway which causes reduced inhibition causing increased amplitudes.

6.2 Effect of conditions on amplitudes and latencies:

There was a significant difference in amplitude and latency between LLRs obtained in quiet conditions and those obtained in noise conditions. There was a significant increase in latency of the peaks N1 and P2 and decrease in amplitude of the peak N1 in the presence of noise. This could be due to the effect of masking which reduces the audibility of speech sounds causing the increase of latency and decrease of amplitude. It was also seen that there was an increase in P2 amplitude in the presence of noise compared to the amplitudes elicited in quiet condition. This could be due to the increase in neuronal firing due to the ambiguity in higher order processing of speech sound due to the presence of noise. As the P2 represents the higher order processing of speech, the increase in neural firing might have caused increased P2. Though there was a differential effect of different noises on the peaks of ALLR, it could not reach statistical significance.

6.3 Correlation between speech in noise scores and ALLR parameters

It was also seen that there was a significant correlation of N1 latency in normal hearing individuals and P2 latency in SNHL individuals with behavioral speech in noise scores. This may be due to the affected audibility that affects speech perception in noise in normal individuals that is correlated through N1 latency and the affected higher order processing that affects speech perception in noise in SNHL individuals that is correlated by P2 latencies.

Conclusion:

It can be concluded that ALLR responses are different in both normal hearing and SNHL individuals indicating difference in neurophysiological processing for speech perception in both the populations and account for the affected speech perception in the SNHL population. The N1 amplitudes are the better indicators of the differential processing present in the two groups as they showed a significant difference between the groups.

Also, it can be concluded that the processing of speech is affected in the presence noise in both the groups. Though no significant differences between the different spectrums of noise could be seen, there was a trend towards differential effect of noises on ALLR responses. There can be a possible significant difference by taking larger samples for the study. Also, the study could be carried out at different SNRs to arrive to the significant effects of different spectrum of noise.

Implications of the study:

- ALLR elicited to speech stimuli can be used as a tool to study speech perception in normal and clinical population.
- ALLRs can also be used as a tool to study speech perception in noise and quantify the effect of noise on speech perception in clinical and normal hearing population.
- To study the benefit of noise reduction algorithms in hearing aids in hearing impaired population.
- To study the perception of speech in noise in cochlear implant users.

- Outcome of the study also gave an idea that earlier peaks are more affected by low pass noise and later peaks by high pass noise, thus suggesting utilizing of appropriate masker to study audibility and discrimination ability.

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