THE EFFECT OF DIGITAL NOISE REDUCTION (DNR) IN HEARING AIDS ON AUDITORY LATE LATENCY RESPONSE (ALLR), SPEECH RECOGNITION ABILITY AND QUALITY

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CERTIFICATE

This is to certify that this dissertation entitled **The effect of Digital Noise Reduction (DNR) in hearing aids on Auditory Late latency response (ALLR), Speech Recognition Ability and Quality**is the bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student **(Registration No.10AUD027).**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 this dissertation entitled **The effect of Digital Noise Reduction (DNR) in hearing aids on Auditory Late latency response (ALLR), Speech Recognition Ability and Quality**has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation **The effect of Digital Noise Reduction (DNR) in hearing aids on Auditory Late latency response (ALLR), Speech Recognition Ability and Quality** is the result of my own study and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore **Registration No.:**10AUD027

May, 2012

Dedicated to my
Pappa, Amma, Sanju
& Chinnu

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CHAPTER 1

INTRODUCTION

Hearing loss and other perceptual problems related to aging cause communicative difficulties (Gelfand, Piper, & Silman 1986; Nabelek, 1988). Due to this communication difficulty, reduced psychosocial function has often been reported. In particular, there is decline in social interaction, intimate relations, self-concept, psychological status, and cognition (Weinstein & Ventry, 1982; Scherer & Frisina, 1998). Majority of persons with mild-to-moderate hearing loss indicate that their primary problem is difficulty hearing in noise (Kochkin, 2005). Listening in background noise presents a challenge that often leads to communication breakdowns. There are a few factors which contribute to the ability to hear a signal in the presence of noise including, reduced audibility, reduced frequency selectivity and reduced temporal resolution (Baer & Moore, 1993; Nejime & Moore, 1997). Also, it depends on the manner in which signals in noise are encoded throughout the peripheral and central auditory systems (Billings, Tremblay, Steckera, & Tolina, 2009).

As a consequence of reduced frequency selectivity, the auditory in people with cochlear hearing loss is broader (Pick, Evans, & Wilson, 1977; Glasberg & Moore, 1986; Tyler, 1986). This broadened auditory filter produce a more highly smoothed representation of the spectrum than normal auditory filters. Hence, the ability to determine the spectral shapes of speech sounds, and to separate components of speech from background noise is reduced (Baer & Moore, 1993; Nejime & Moore, 1997). Therefore, people with sensorineural hearing impairment perform more poorly than individuals with normal hearing when trying to understand speech in the presence of background sounds.

In addition, for the successful communication in difficult listening environments will dependent upon how the auditory system is able to extract signals of interest from other competing information. Thus cortical auditory evoked potential (CAEP) is another approach to study the encoding of signal in noise in the human central auditory system (CAS). It is a measure of CAS function that can provide valuable information about the way in which neurons encode signals in noise (Billings, Tremblay, Steckera, & Tolina, 2009).

There is dearth of literature on the cortical auditory evoked potentials associated with encoding signal in individuals with hearing loss. However, there are a few studies which have recorded the CAEPs in individuals with normal hearing. The results of such studies indicate that the latencies are more sensitive indicators of these masking effects than amplitudes (Whiting, Martin, & Stapells, 1988). Billings, Tremblay, Steckera, and Tolina (2009) investigated the effect of signal-to-noise ratio (SNR) on the latency and amplitude of evoked cortical potentials in 15 young adults with normal-hearing. The results revealed that SNR would be a key contributor to human CAEP characteristics, that is amplitude increased and latency decreased with increasing SNR.

Morphology of the P1-N1-P2 complex was driven primarily by SNR, highlighting the importance of noise when recording CAEPs. Since SNR is the one that determines the efficiency of DNR, CAEPs can also be used as a measure to evaluate this aspect.

Further, it is reported that the components of auditory evoked late latency response (ALLR) can be correlated with the behavioral measures of speech perception in quiet (Narne & Vanaja, 2008). Chandra and Barman (2009) investigated the relationship between the late latency response and the speech identification scores in noise at 0 dB SNR for different speech stimulus /da/, /ba/ and /ga/ in persons with auditory neuropathy. The results revealed that there was no correlation between the amplitude and latency of the potentials and the speech identification scores (SIS). Hence there are mixed results seen, regarding the correlation between the behavioural measure of speech perception and the ALLR.

The usual remedy for people with cochlear hearing loss is amplification through hearing aids. This hearing aid improves speech perception in quiet conditions mainly by increasing the audibility. However, in the presence of noise, a hearing aid amplifies the background noise as well the speech which causes annoyance due to the amplified background noise. This results in poor speech intelligibility, due to upward spread of masking at high listening levels, distortion caused by limited bandwidth of the hearing aid (Plomp, 1978). Therefore, there are a variety of hearing aids signal-processing techniques have been introduced to tackle this problem. The commercially available hearing aids have different algorithms to improve signal-to-noise ratio such as Digital Noise Reduction (DNR) and directional microphone. The goal of these algorithms is to improve speech intelligibility in noise or to provide comfort in noisy situations or both.

DNR in hearing aid has a general goal of providing less amplification over a specified frequency range, for noise than for speech. The DNR algorithm relies on the difference in physical characteristics of a signal to distinguish speech from noise (Ricketts, & Hornsby, 2005). There are studies that have investigated the efficacy of digital noise reduction on the perception of speech embedded in noise, using behavioral measures.

Alcantara, Moore, Kuhnel, and Launer (2003), have evaluated the effectiveness of a noise reduction system implemented in a commercial digital multi-channel compression hearing aid, in individuals with moderate sensori-neural hearing loss. The results reported ratings of sound quality; listening comfort and the SRT were very similar, with and without the noise reduction system. In contrast, Ricketts and Hornsby (2005) reported that their participants showed the strong preference for DNR processing and concluded that implementation of DNR processing improved sound quality but not the speech recognition in speech-in-noise condition. Also the study done by Mueller, Weber, and Hornsby (2006) report that DNR processing will increase ease of listening by reducing the annoyance in speech-in-noise situations. Thus, these researches have shown equivocal results on the sound quality of speech output by the implementation of DNR in hearing aids. But these results clearly state that the DNR signal processing will not have an effect on speech understanding in the presence of noise.

However, Bray and Nilsson (2001) reported that for noise was arriving from the front condition, the mean aided benefit was 2.6 dB SNR without DNR activated and 3.5 dB SNR with DNR activated. This led to the conclusion that, DNR algorithms in conjunction with directional microphone may be effective in improving speech perception in noise when the noise field is isotropic. So, the DNR alone will not improve the speech perception but it is useful in conjunction with directional microphone (Nordrum, Erler, Garstecki, & Dhar, 2006).

In summary, the above studies revealed that the DNR signal processing strategy will reduce the annoyance or aversion towards the hearing aid, caused by the background noise (Boymans & Dreschler, 2000) and few studies report there was improvement in the sound quality (Alcantara, Moore, Kuhnel, & Launer, 2003). Few researchers suggested that there was no effect of DNR processing on speech recognition threshold (Boymans & Dreschler, 2000; Alcantara, Moore, Kuhnel, & Launer, 2003).

Thus the current study will helps in understanding how the signal is encoded in presence of noise at the cortical level, in individuals with cochlear hearing loss under aided condition. Also how the signal in presence of noise is coded in presence of DNR signal processing.

1.1 Need for the study

There are abundant studies done in literature, which have evaluated the change in subjective measures like SRT, SIS and quality of speech output on DNR signal processing (Boymans & Dreschler, 2000; Alcantara, Moore, Kuhnel, & Launer, 2003). However, there is dearth of literature that reports on the effect of DNR in hearing aids on electrophysiological measures.

The reports on CAEPs related to encoding of signals in noise are limited. Only a few studies have data on recorded CAEP responses to signal-in-noise stimuli while varying SNR (Kaplan-Neeman, Kishon-Rabin, Henkin & Muchnik 2006; Whiting, Martin, & Stapells., 1998; Billings, Tremblay, Steckera, & Tolina, 2009; Chandra & Barman, 2009). These studies tested individuals with normal-hearing using speech-in-noise stimuli and found that the SNR is an important variable contributing to the latency and amplitude of the evoked response.

The studies reveal that the cortical potentials are sensitive to the relative intensity of the signal with respect to noise rather than the absolute level (Billings, Tremblay, Steckera, & Tolina, 2009).There are reports in the literature, which indicate that cortical responses may differ from expected when recorded via sensory devices (e.g., hearing aids) have provided the impetus for additional studies examining auditory evoked responses recorded with hearing aids. And also, when signal is presented with the noise and the recording CAEPs will help the understanding in cortical encoding of speech in the presence of noise.

However, there is a dearth of studies done in populations with perceptual difficulties in background noise such as those with hearing impairment or older adults. CAEPs may be a measure that is sensitive to signal-in-noise difficulties experienced by these groups. The findings of the study would improve one’s understanding on how the human auditory cortex encodes signal in noise, in individuals with hearing impairment. Thus the current study is taken up to explore whether the signal-to-noise ratio improved by the DNR is measurable at the level of cortex.

If there exists, any correlation between the SIS and components of LLR in individuals with cochlear hearing loss, with activated and deactivated DNR processing, it can be further applied to test difficult-to-test population.

1.2 Aim of the study

The preliminary aim of the study is to investigate the effect of digital noise reduction (DNR) on auditory late latency response (ALLR) and speech recognition scores (SRS) and quality of speech. The another aim of the study was to find the effect the white noise in individuals with normal hearing and individuals with hearing loss on components of ALLR (latencies of P1, N1 & P2 and amplitude of N1-P2 complex) and SRS.

1.3 Objectives of the Study

The present study is designed with the following objectives:

a) To explore the effect of DNR activation in hearing aid on the latencies of P1, N1, P2 and amplitude of N1/P2 of ALLR, in individuals with hearing loss.

b) To study the effect of DNR activation on Speech Recognition Scores (SRS) in individuals with hearing loss.

c) To examine the effect of DNR on perceptual quality of speech through the hearing aid in individuals with hearing loss.

d) To investigate the effect of 0 dB SNR on latencies of P1, N1, P2 and N1/P2 amplitude in individuals with normal hearing and in individuals with sensori-neural hearing loss.

e) To study the relationship between the amplitude of N1/P2 complex and SRS across quiet and in noise (0 dB SNR) condition, in individuals with normal hearing and in individuals with sensori-neural hearing loss.

f) Also, to assess the test-retest reliability of perceptual quality ratings obtained between two sessions across DNR activated and deactivated, in individuals with hearing loss.

CHAPTER 2

REVIEW OF LITERATURE

Individuals with sensorineural hearing loss often complain about difficulty understanding speech in background noise. This adverse effect of noise could be seen even after providing the appropriate amplification, as the SNR remains unchanged. The hearing aid often amplifies the background noise along with speech, thus causing annoyance and the rejection of hearing aids. Thus, traditional amplification would require a special circuitry to tackle this problem.

The literature review was done to inquire major physiological differences between the individual with normal hearing and hearing loss that caused the deterioration of speech understanding in the presence of noise, for people with hearing loss. And also how these physiological changes seen in individuals with cochlear hearing loss, are resolved by the current signal processing strategies in the hearing aid.

The literature review is discussed under the following subheadings:

2.1 Effect of noise on normal and pathological auditory systems

2.2 Deleterious effects of noise on speech recognition ability

    2.2.1 Effects of noise on speech recognition ability in individuals with normal hearing and those with hearing loss

    2.2.2 Effects of amplification on speech recognition in the presence of noise in individuals with hearing loss

2.3 Deleterious effects of noise on auditory late latency potentials

2.4 Effect of DNR circuitry on speech recognition scores and quality of speech in noise

2.5 Other methods and the combination of methods for alleviating the deleterious effect of noise

2.1 Effect of noise on normal and pathological auditory systems

A major consequence of sensorineural hearing loss (SNHL) is difficulty in communication especially in the presence of background noise and/or reverberation (Dubno, Dirks & Morgan, 1982). Background noise is any noise that interferes with one’s ability to hear, understand, and/or pay attention to the desired signal. It includes traffic noise, reverberation that causes sounds to echo when reflected off hard surfaces; voices such as children playing and laughing, several people talking at once, or even one person talking in a way that prevents or distracts the person from listening to a signal one want to hear. Background noise is one of the major problems for individuals with hearing impairment. And hence individuals with hearing impairment require a more favorable signal-to-noise ratio to achieve acceptable speech understanding in a given background noise.

The structural differences and the functional consequences of these structural differences between the normal auditory system and pathological auditory system have led to the difficult perception of speech in noise. The functioning of the normal cochlea appears to reflect the active mechanism that is dependent on the integrity of the outer hair cells (OHCs) within the cochlea (Rhode & Robles, 1974). The OHCs play an important role in sharp tuning on the BM and thus producing the high sensitivity of the BM to weak sounds. Active mechanism strongly influences responses on the BM at low and medium sound levels, but its contribution progressively reduces as the sound level increases. In a normal ear, the response of the BM is non-linear i.e., when the input magnitude is increased, the magnitude of the response does not grow directly in proportion to the magnitude of the input (Rhode, 1971; Rhode & Robles, 1974). This compressive input-output function of the basilar membrane plays a significant role in the ability of the auditory system to cope with the large dynamic range (Sellick, Patuzzi & Johnstone, 1982; Robles, Ruggero and Rich, 1986; Ruggero, 1992; Robles & Ruggero, 2001). Other BM non-linearities include two-tone suppression (Ruggero, Robles, & Rich, 1992), and generation of combination tones (Robles, Ruggero, & Rich, 1986. These non-linearities also appear to depend on the operation of the active mechanism.

Cochlear hearing loss often involves damage to the OHCs and inner hair cells (IHCs), the stereocilia may be distorted or destroyed, or entire hair cells may die. The OHCs are generally more vulnerable to damage than the IHCs (Borg, Canlon, & Engstrom, 1995). When OHCs are damaged, the active mechanism tends to be reduced in effectiveness or could be lost. In addition, reduction or loss of the compressive non-linearity in input-output function of the basilar membrane will be observed. As a result, the sensitivity to weak sounds is reduced, so sounds need to be more intense to produce a given magnitude of response on the BM. Along with this, the tuning curves on the BM become much more broadly tuned and all of the frequency selective non-linear effects weaken or disappear altogether. Also, the hearing thresholds may go up to 50-60 dB HL which reflects only OHC damage with intact inner hair cells (Kates, 1994).

Hence, audibility is one of the factors causing the difficulty in perception of speech under noise condition, in individuals with hearing loss. Audibility is crucial for speech intelligibility, if part of the speech spectrum is masked by background sound or is below the absolute threshold, then certain part of information is lost, and so also the intelligibility. When the noise and the speech are differently oriented, head shadow effect often increases the signal-to-noise ratio at one ear. Thus, loss of ability to hear high frequencies may extremely reduce the ability to take advantage of head shadow effects (Bronkhorst & Plomp, 1989). Also Lee and Humes (1993) demonstrated that the "distortion" may actually be a consequence of the loss of audibility in the high frequencies. In addition to inability to hear speech sounds, loss of audibility may also aggravate the problem by adding distortion to the signal.

The next factor causing difficulty perceiving speech in background noise is reduced frequency selectivity. Due to the loss of active mechanism, the tuning curves often become wider. It is well established broadened auditory filters likely contribute to greater upward spread of masking in impaired ears than in normal ears (Trees & Turner, 1986). And this upward spread of masking make the understanding more difficult for persons with hearing loss than normal hearing persons to perceive speech in background noise (Martin & Pickett, 1970). Thus, frequency resolution is poor in individuals with cochlear hearing loss. As a consequence of reduced frequency selectivity, the auditory filters in people with cochlear hearing loss are broader (Pick, Evans, & Wilson, 1977; Glasberg & Moore, 1986; Tyler, 1986). This broadened auditory filter produces a more smoothed representation of the spectrum than normal auditory filters. If spectral features are not sufficiently prominent, they may be smoothed to such an extent that they become imperceptible. Adding a background noise to speech fills in the valleys between the spectral peaks and thus reduces their prominence, there by exacerbating the problem of people with cochlear hearing loss (Moore, 1995). Hence, the ability to determine the spectral shapes of speech sounds, and to separate components of speech from background noise is reduced (Baer & Moore, 1993; Nejime & Moore, 1997).

The other potential problem of reduced frequency selectivity on speech perception in noise is connected with the temporal patterns at the outputs of individual auditory filters (Moore, 2003). The perceived frequency of a given formant and/or the fundamental frequency of voicing may be partly determined by the time pattern at the outputs of the auditory filters tuned close to the formant frequency (Rosen & Fourcin, 1986; Young & Sachs, 1979; Miller, Schilling, & Franck, &Young,1997).Background noise disturbs this time pattern, which may lead to reduced accuracy in determining these frequencies. This effect would be greater in people with reduced frequency selectivity, since broader filters generally pass more background noise. Therefore, the effects of masking are more pronounced in individuals with hearing impairment than in individuals with normal hearing. However, the size of this difference depends greatly on the spectral characteristics of the signal and the masker. The problem will particularly be large when the background is fluctuating, when the target speech and background are spatially separated, on extent of broadening of auditory filters and also on asymmetry of the auditory filters (Moore, 2003).

To summarize, the speech perception of individuals with hearing impairment is very often affected much more by noise than is the speech perception of individuals with normal hearing. This is largely because of the most important consequence of reduced frequency selectivity. The broadening and flattening of peaks as a consequence of broaden and asymmetric auditory filters (Pick, Evans, & Wilson, 1977; Glasberg & Moore, 1986; Tyler, 1986). The flat, less detailed spectra of people with reduced frequency selectivity are already much less discriminable from each other than is the case for individual with normal hearing. Peaks that are still evident typically have a much reduce peak to valley distance and these valleys are more likely to be filled by noise than would be the case for the auditory spectra of individual with normal hearing.

2.2 Deleterious effects of noise on speech recognition ability in individuals with cochlear hearing loss

There are several tests used to assess speech communication in noise such as SPIN (Kalikow, Stevens, & Elliot, 1977) and synthetic sentence identification (Speaks & Jerger, 1965). These tests have been designed to measure percent intelligibility at fixed speech and/or noise levels. These tests produce reliable estimate of performance. However, the most accepted measure is SNR-50. The SNR-50 is defined as the presentation levels necessary for the listener to recognize the speech materials correctly, a specified percent of the time which is usually 50%. The technique for measuring SNR-50 is derived from an adaptive measure where the presentation level of the noise is increased or decreased by a fixed amount, depending on the listener's ability to repeat the speech material correctly. Hence, a simple up-down adaptive procedure with fixed step size is used to measure the SNR-50. The difference in SNR-50 between people with normal hearing and hearing loss is called SNR-loss (Killion, 1997). However, Carhart and Tillman (1970) suggested that in addition to the measurement of pure-tone sensitivity and word recognition in quiet, communication handicap should be quantified in terms of word recognition in a background of competing speech.

The speech recognition in people with hearing loss can be considered in two ways.

2.2.1 Effects of noise on speech recognition ability in individuals with normal hearing and those with hearing loss

2.2.2 Effects of amplification on speech recognition in the presence of noise in individuals with hearing loss

2.2.1 Effects of noise on speech recognition ability in individuals with normal hearing and hearing loss

Several researchers have demonstrated that individuals with hearing impairment require a greater signal-to-noise ratio (SNR) than those with normal hearing to achieve the same performance in speech-in-noise tests (Plomp & Mimpen, 1979; Dirks, Morgan, & Dubno, 1982). The SNR of conversation in public places is typically around +5 dB to +10 dB (Plomp,& Mimpen, 1979). According to studies by Tillman, Carhart, and Olsen (1970) and Gengel (1971), SNRs of +10 dB to +15 dB are necessary for the hearing aid users. Every 4-5 dB improvement of the SNR may raise the speech intelligibility by about 50% (Plomp, 1978).

Keith and Talis (1972) studied the effect of white noise on words in 10 individuals with normal hearing, 10 individuals with high frequency hearing loss and 10 individuals with flat hearing loss. CID auditory test W-22 was presented in quiet and in the presence of white noise at 40 dB SL. Three signal-to-noise ratios were tested (+8, 0 and –8 SNR). The PB scores of listeners with flat hearing loss had a deterioration of approximately 67% from the quiet condition to the -8 dB SNR. These results suggested that background noise which is mildly disruptive for individuals with normal hearing can be highly disruptive to those with hearing impairment.

Also, the speech recognition in presence of noise depends on the temporal structures of the masking noise. Arlinger and Gustafsson (1991) reported that amplitude-modulated noise reduced masking compared to unmodulated noise in listeners with normal hearing, using low-redundancy sentences as speech material. For the people with hearing impairment, this release of masking was not seen, presumably because of the reduced temporal resolution commonly found in sensorineural hearing loss. These findings agree with results reported by Festen and Plomp (1990), using sinusoidal intensity-modulation of the masking noise, and by Dirks, Wilson, and Bower (1969), using pulsed or square wave amplitude-modulated noise.

On the other hand, Carhart, Tillman, and Greetis (1969), employing spondee thresholds, and Danhauer, Doyle, and Luks (1985), using nonsense-syllable and single-word tests, reported an increased masking effect for subjects with normal hearing, when the background masking noise was amplitude modulated with a signal which corresponded to the amplitude variations of speech. Thus, these studies report that, there is substantial amount of release from masking when the noise is amplitude-modulated to the signal, but not when the amplitude-modulated masker was approximating speech in individuals with normal hearing but individual with hearing loss often fail to obtain beneficial effect of release from masking. Thus individuals with hearing impairment and those with normal hearing differ substantially in how they are affected by background noise and background speech when trying to comprehend the foreground speech.

Similarly, Festen, and Plomp (1990) reported that the deficit in SRT was greater, typically 6–12 dB, when a fluctuating background noise or a single competing talker was used instead of a steady noise. People with normal hearing are able to take advantage of temporal and spectral 'dips' in the interfering sound to achieve a much lower SRT than when steady background noise is used. People with cochlear hearing loss seem less able than those with normal hearing to take advantage of the temporal and spectral dips (Duquesnoy, 1983; Festen & Plomp, 1990; Hygge, Ronnberg, Larsby,& Arlinger, 1992; Baer & Moore, 1993; Peters, Moore, & Baer, 1998).

People with normally hearing, rely on time and frequency gaps in noise to assist in the analysis of masked speech. Noise, being random, is not constant and so at certain times the intensity of noise over the various bands of speech information randomly reduces to a level where the speech acoustic cues become relatively more prominent and so more analyzable. Among the different masking noise, the noise which is more spectrally similar to the speech material will have the detrimental effect on speech understanding. For persons with normal hearing, forward and reversed background speech do not differ and are relatively easy to cope with as compared to broadband noise. Whereas for those with hearing impairment, broadband noise and forward or reversed speech are equivalent. The explanation for this is the inability of the individuals with hearing impairment to make an adequate temporal resolution of sounds **(**Hygge, Ronnberg, Larsby, & Arlinger, 1992).Poor temporal and frequency acuity may have the effect of spreading the more intense components of the noise over adjacent regions of temporarily lower noise intensity (forward masking and upward spread of masking). The person with hearing impairment is therefore less able to utilize these gaps in the segregation of speech from noise. And hence reduced temporal resolution has been cited as a limitation of persons with hearing loss.

Bronkhorst and Plomp (1992) reaffirmed the finding of Festen and Plomp (1990) that envelope modulations in a masker are an important cue for listeners with normal hearing that cannot be used to provide the same degree of benefit by those with hearing impairment. The authors also pointed out that since fluctuating interfering sounds are common during every day listening, the true handicap of individuals with hearing impairment may be underestimated when only steady-state maskers are used in speech recognition testing. Reduced frequency selectivity is thought to cause the inability of individual with hearing loss to take advantage of spectral dips (Moore, 1982).

From these studies, it appears that noise has a more devastating effect on individuals with sensorineural loss than on those with normal hearing, as sensorineural hearing loss will impair peripheral spectral- or temporal- resolution processes that may be critical to the understanding of speech (Fitzgibbons & Gordon-Salant, 1996).

Finally, people with cochlear hearing loss are less able than individuals with normal hearing to take advantage of spatial separation of the target speech and the interfering sound(s). When the background sound is a single talker spatially separated from the target speech, the deficit in SRT is 12 to 19 dB (Duquesnoy, 1983). Amongst individuals with hearing loss, noise appears to have a differential effect on speech recognition ability even among persons with similar hearing loss magnitudes, configurations, and etiologies. To explain, it is known that some individuals with sensorineural hearing loss evidence increased spread-of-masking effects (Leshowitz, 1977), and some evidence low loudness discomfort levels (LDLs)(Kamm, Dirks, & Mickey, 1978).

Thus, the speech recognition in background noise is severely deteriorated for persons with cochlear hearing loss. The utility of traditional amplification strategies on speech understanding in background noise is discussed below.

2.2.2 Effects of amplification on speech recognition in the presence of noise in individuals with hearing loss

A sensorineural hearing impairment is composed of two factors, one is the attenuation factor which reduces the overall level of both speech and noise and other is the distortion factor, where individuals with hearing impairment need a higher speech-to-noise ratio (SNR) to reach the same degree of speech recognition as individuals with normal hearing (Hagerman, 1984; Plomp, 1986). Amplification through hearing aid compensates for attenuation factor, but the distortion factor is difficult to deal with. A hearing aid improves speech perception in quiet conditions mainly due to increased audibility. However, in the presence of noise the hearing aid often shows limited benefit. This is due to the fact that the hearing aid amplifies both the wanted speech signal and the interfering sounds.

People with hearing impairment are satisfied with their aid when they are listening to one person in quiet, whereas group conversation and in adverse listening conditions, the hearing aid did not benefit them (Plomp, 1978). Therefore, individuals with hearing impairment despite understanding speech in quiet almost equivalent to individuals with normal hearing with amplification, have great difficulties when speech is presented in background noise (Plomp, 1994). This is true even though amplification is provided by means of a hearing aid wherein speech falls within the range of audibility (Kochkin, 2000). Furthermore, this difficulty becomes more pronounced as the degree of hearing loss increases (Killion, 1997). People with cochlear hearing loss frequently complain that their hearing aids are of limited benefit in such situations. Since in presence of noise, a hearing aid amplifies the background noise together with speech, thus the signal-to-noise ratio (SNR) is unchanged. Consequently, this results in poorer speech intelligibility, due to upward spread of masking at high listening levels, distortion caused by hearing aid and limited bandwidth of the hearing aid (Plomp, 1986). Furthermore, one of the common performance related complaints with hearing aids is annoyance from the amplified background noise (Kirkwood, 2005). Hence the main challenge for an audiologist, while fitting a hearing aid is to decrease the adverse effects of noise without affecting or minimally affecting the speech intelligibility, and also acceptance of hearing aid in the presence of noise.

van Tasell (1993) also reported that hearing aids cannot improve the ratio of audible speech information to audible noise because they cannot separate the two. For quiet environments, van Tasell (1993) stated that for those with mild-to-moderate losses the most important for effective amplification is the need to preserve and ensure the audibility of the spectro-temporal aspects of speech. Following several studies, Plomp (1978) concluded that no hearing aid could improve SNR to that of the individuals with normal hearing. Amplification typically produces only a small improvement in the SRT in fluctuating background sounds (Peters, Moore, & Baer, 1998; Moore, Hine, Jiang, Matsuda, Parsons, & King, 1999).

Consequently, speech recognition tasks in presence of noise is difficult for individual with hearing loss due the loss of audibility, other factors such as reduced frequency selectivity, loudness recruitment may also contribute to the excessive amount of masking in listener’s with hearing impairment. Even as the audibility deficit is resolved with the use of hearing aid amplification, the listener can expect reduced performance in adverse listening situations due to the excessive masking effects of noise (Tillman, Carhart, & Olsen, 1970). Therefore in the presence of noise, compensating the audibility factor alone does not bring back the understanding of speech comparable to individuals with normal hearing. Early studies comparing performance of listeners with normal hearing and hearing loss has indicated that, individuals with hearing loss require a higher signal-to-noise ratio (SNR) than those with normal hearing (Plomp, 1978). Hence there is a need for the distinct clinical circuits for the processing of speech in presence of noise which is capable of enhancing SNR to make the speech intelligible.

2.3 Deleterious effects of noise on auditory late latency potentials in individuals with normal hearing and hearing loss

Understanding speech in background noise is challenging for a listener, including those with normal peripheral hearing. This difficulty owes in part to the disruptive effects of noise on neural synchrony, resulting in degraded representation of speech at cortical level and is reflected by electrophysiological responses (Warrier, Johnson, Hayes, Nicol, & Kraus, 2004; Billings, Tremblay, Souza, & Binns, 2007). However, these problems are especially pronounced in clinical populations such as individuals with hearing loss. Speech consists of rapidly changing elements that require fine-grained neural representation of temporal information, especially in background noise. It is well established that neural synchrony is degraded in noise, leading to delayed and reduced auditory evoked responses from cortical structures (Warrier, Johnson, Hayes, Nicol, & Kraus, 2004; Billings, Tremblay, Souza, & Binns, 2007; Russo, Zecker, Trommer, Chen, & Kraus, 2009).

Speech evoked P1-N1-P2 cortical auditory evoked potentials (CAEPs) are frequently used to study the neural representation of speech sounds in populations with impaired speech understanding. The underlying assumption is that speech perception is dependent on the neural detection of time-varying spectral and temporal cues contained in the speech signal. The P1-N1-P2 complex reflects the neural detection of time-varying acoustic cues such as speech. The P1-N1-P2 complex is recently being used to examine the neural representation of speech sounds in older adults with and without hearing loss, since older adults often have difficulty understanding speech (Tremblay, Piskosz, & Souza, 2002). Because speech is a complex signal, composed of multiple time-varying acoustic cues, numerous investigators have hypothesized that hearing loss and aging adversely affects the ability to process temporal cues.

Whiting, Martin, and Stapells (1998) investigated the effects of decreased audibility produced by broadband noise masking on the cortical event-related potentials (ERPs) such as N1, N2, and P3 to the speech sounds /ba/ and/da/. Ten individuals with normal hearing actively (button-press response) discriminated the speech sounds /ba/ and /da/ presented in quiet (no masking) and with broadband masking noise (BBN), using an ERP oddball paradigm These results indicate that decreased audibility as a result of masking affects the various ERP peaks in a differential manner, where N1 was more affected than other peaks and authors also reported that latencies are more sensitive indicators of these masking effects than are amplitudes.

Martin and Stapells (2005) investigated the effects of decreased audibility in low-frequency spectral regions, produced by low-pass noise masking, on cortical event-related potentials (ERPs) to the speech sounds /ba/ and /da/.The speech sounds were presented to individuals with normal hearing at 65 and 80 dB ppe SPL. The participants were engaged in an active condition (pressing a button to deviant sounds, to obtain MMM) and a passive condition (ignoring the stimuli and reading a book to obtain N1). Broadband masking noise was simultaneously presented at intensity sufficient to mask the response to the 65 dB speech sounds and subsequently low-pass filtered. The conditions were quiet (no masking), low-pass noise with cut-off frequencies of 250, 500, 1000, 2000, and 4000Hz, and broadband noise. The results revealed that as the cut-off frequency of the low-pass noise masker was raised, ERP latencies increased and amplitudes decreased. The study concluded that decreased audibility, resulting from the masking, increase the latencies of the ERP peaks.

However, the study done by Whiting, Martin, and Stapells (1998) and Martin and Stapells (2005) are not comparable as the method (active and passive condition) involved in eliciting the response of N1 was different, though these procedure must not be focused when looking at obligatory encoding of stimulus acoustics. Nevertheless, both the studies reveal N1 response elicited by speech sounds is reduced in amplitude and increased in latency as the masking noise is increased.

Billings, Tremblay, Steckera, and Tolina (2009) investigated the effect of signal level and signal-to-noise ratio (SNR) on the latency and amplitude of evoked cortical potentials. Cortical auditory evoked potentials (CAEPs) were recorded from 15 young individuals with normal hearing in response to a 1000 Hz tone presented at two tone levels in quiet and while continuous background noise levels were varied in five equivalent SNR steps. These 12 conditions were used to determine the effects of signal level and SNR level on CAEP components P1, N1, P2, and N2. Results revealed that SNR, would be a key contributor to human CAEP characteristics, that is amplitude increased and latency decreased with increasing SNR. Morphology of the P1-N1-P2 complex was driven primarily by SNR, highlighting the importance of noise when recording CAEPs.

These studies reveal that the cortical potentials are sensitive to the relative intensity of the signal with respect to noise rather than the absolute level. There exists differential effect of SNR on components of late latency potentials (Martin & Stapells, 2005).

It is interesting if there exists a correlation between the electrophysiological measures and behavioural measures. Narne and Vanaja (2008) investigated the relationship between speech identification scores in quiet and parameters of cortical potentials (latency of P1, N1, and P2; and amplitude of N1/P2) in individuals with auditory neuropathy. Ten individuals with auditory neuropathy (five males and five females) and ten individuals with normal hearing in the age range of 12 to 39 years participated in the study. Speech identification ability was assessed for bi-syllabic words and cortical potentials were recorded for click stimuli. The results revealed that the Speech identification scores showed a good correlation with the amplitude of cortical potentials (N1-P2 complex) but did not show a significant correlation with the latency of cortical potentials.

In contrary, Chandra and Barman (2009) also investigated the relationship between the late latency response and the speech identification scores in noise at 0 dB SNR for different speech stimulus /da/, /ba/ and /ga/ in persons with auditory neuropathy. The results revealed that there was no correlation between the amplitude and latency of the potentials and the SIS scores.

The discrepancy between the studies could be attributed to the type of stimuli used, as well as the conditions. Narne and Vanaja, (2008) used click stimuli to record ALLR, SIS and ALLR were recorded in noise condition. Whereas Chandra and Barman (2009), used /da/, /ba/ and /ga/ stimuli and they were recorded under noise condition (0 dB SNR).

2.4 Effect of DNR circuitry in the hearing aid on speech recognition scores and quality of speech in noise

Digital noise reduction is one of the techniques used to improve the speech understanding in noisy environments. The term ‘Digital Noise Reduction’ (DNR) in hearing aid is used to describe the processing of a signal, with a general goal of providing less amplification over a specified frequency range, for noise than for speech. Noise reduction algorithms are designed to take advantage of the temporal separation and spectral differences between speech and noise. Noise reduction algorithms are different from the speech enhancement algorithms in that the noise reduction algorithms aim to reduce noise interference whereas speech enhancement algorithms are designed to enhance the contrast between vowel and consonants (Bunnel, 1990; Cheng & O’Shaughnessy, 1991). The DNR algorithm relies on difference in physical characteristics of a signal to distinguish speech from noise (Ricketts & Hornsby, 2005). The primary goal in the design of DNR algorithm is to improve speech intelligibility in background noise. If the characteristics of speech and noise are known, DNR algorithm will certainly have the potential to improve speech understanding. A secondary goal of DNR is to provide relaxed listening or to improve ease of listening. That is, the reduction of background noise, even when speech is not present, may reduce listening fatigue and increase listening awareness. In addition, in difficult listening situations, an improvement in central auditory space allocation could result, which could assist in cognitive processing. A potential benefit of DNR therefore, would be a more alert and focused listener.

The earliest attempts relied on the assumption that unwanted noise typically existed at the lower frequencies, and attenuated and/or compressed the output of the hearing aid at these frequencies to achieve an SNR advantage. However, such pure frequency-based algorithms are not effective under a majority of circumstances (Boymans & Dreschler, 2000; Kuk, Ludvigsen, & Paludan-Muller, 2002).

Second generation DNR algorithm is based on detection of speech in the incoming signal using rapid analysis of multiple components of incoming signal. One technology currently available monitor's higher frequency channel for the synchronous energy, such energy is suggestive of formants. Hence, better synchrony indicates the presence of speech in the signal (Chung, 2004).

Another type of DNR is referred to as 'adaptive Weiner filtering'. Weiner filter was first described by Nobert Weiner in 1940s. It is a theoretically derived filter that has the goal of estimating the original signal from a degraded version of the signal. In hearing aid applications, this translates into a goal of providing the greatest attenuation for frequencies not containing speech. The goal of modulation based DNR (MDNR) and adaptive Weiner filtering are similar as both intend to provide more gain for frequency range containing speech information than those containing noise. The Wiener filter is optimally derived when the speech and noise spectra are known; the success of adaptive Wiener filters in hearing aid applications, however, is highly dependent on accurate estimation of the speech and noise power in degraded samples with no prior knowledge. Consequently, it is not surprising that multiple iterations of the adaptive Wiener filter have been developed with varying degrees of success.

Next generation of DNR rely on the common feature of detecting the modulation in the incoming signal to infer the presence or absence of the speech signal and to estimate the SNR in the microphone output. Speech has a modulation rate centered at 4 to 6 Hz. Noise in most listening environments has either a constant temporal characteristic or a modulation rate outside the range of speech. Further, speech exhibits co-modulation, another type of modulation that is generated by the opening and closing of the vocal folds during the voicing of vowels and voiced constants (Rosen, 1992). The rate of co-modulation is the fundamental frequency of the person's voice. Depending on the type of modulation detection used, noise reduction algorithms are divided into two categories: multichannel adaptive noise reduction algorithms that detect the slow modulation in speech, and synchrony-detection noise reduction algorithms that detect the co-modulation in speech.

Most of the noise reduction algorithms in commercial hearing aids use the multichannel adaptive noise reduction strategy. These algorithms are intended to reduce noise interference at frequency channels with noise dominance. In theory, multichannel adaptive noise reduction algorithms are the most effective in their noise reduction effort when there is a spectral difference between speech and noise. The major limitation of these noise reduction algorithms is that they cannot differentiate between the desired signal and the unwanted noise if speech is the competing noise. Other similar methods attempt to identify noise by analyzing modulation depth or frequency. Some noise reduction algorithms may also detect other dimensions of the incoming signal, such as the intensity-modulation-temporal changes within each frequency channel (Tellier, Arndt, & Luo, 2003) or the spectral-intensity-temporal patterns of the incoming signal across frequency channels (Kuk, Ludvigsen, & Paludan-Muller, 2002). The intensity distribution of the signal is monitored over 10-

to 15- second periods in each frequency channel. The assumptions are that the level of noise is relatively stable within and across frequency channels, whereas the level of speech varies rapidly within and across frequency channels.

In theory, multichannel adaptive noise reduction algorithms work the best when there is a spectral difference between speech and noise. If noise only exists in a very narrow frequency region, the multichannel adaptive noise reduction algorithm can reduce the gain of the hearing aid at that particular region without affecting the speech components in other frequency regions.

The most commonly used noise reduction system in the current commercial multi-channel digital hearing aids is based on identification of modulation in multiple channels allowing for an estimation of modulation-to-steady-state ratio (MSSR), which is the variation of multichannel adaptive noise reduction algorithms. The system assumes that signals those are primarily steady-state are ‘noise’, while signals with greater modulation are more ‘speech like’. Gain is then reduced in the channel in which the MSSR indicates that the incoming signal is steady state (van Dijkhuizen, Festen, & Plomp, 1991). While the modulation based DNR is implemented by several manufacturers, specific characteristics including time constant/analysis time, magnitude of gain reduction, and rules for estimating MSSR and implementing gain reduction vary significantly.

The second category of noise reduction algorithms detects the fast modulation of speech across frequency channels and takes advantage of the temporal separation between speech and noise. The rationale is that the energy of speech sounds is co-modulated by the opening and closing of the vocal folds during the voicing of vowels and voiced consonants. Noise, on the other hand, is rarely co-modulated. In other words, the speech components across the speech frequency spectrum are modulated by the opening and closing of the vocal folds at the same rate and at the same instance. The rate of co-modulation is the fundamental frequency of the human voice, which ranges from 100 to 250 Hz for adults and up to 500 Hz for children.

Thus, there are different noise reduction algorithms, each of which identifies the speech with their own premise. So these algorithms are beneficial in identifying the speech and reducing the amount of noise allowed through the hearing aid. However, greater the differences in acoustic characteristics between speech and noise, more is the effectiveness of noise reduction algorithm (Levitt, 2001).There have been several studies in literature, to find the effectiveness of the DNR system in the hearing aid, for the people with hearing loss.

Alcantara, Moore, Kuhel, and Launer (2003) evaluated the effectiveness of a noise reduction system implemented in a commercial digital multi-channel compression hearing aid. Eight experienced hearing aid users with moderate sensorineural hearing loss were fitted bilaterally according to the manufacturer’s fitting guidelines. After a 3-month period of regular use of two programs, one with and without the noise reduction system, speech recognition threshold (SRTs) was measured in four types of background noise, including steady-state noise. The SRTs were markedly lower than unaided listening conditions. While the SRT and ratings of sound quality, listening comfort were very similar with and without the noise reduction system in the hearing aid. Hence, the results of this study reveal that the hearing aid, with and without DNR signal processing, yielded the same speech recognition and sound quality rating.

In contrast, Ricketts and Hornsby (2005) studied the effect DNR processing on aided speech recognition and sound quality measures in 14 adults fitted with commercial hearing aid. Speech recognition and sound quality measures were obtained in two different speech-in-noise conditions (71 dB A speech, +6 dB SNR and 75 dB A speech, +1 dB SNR). The results revealed that the presence or absence of DNR processing did not impact speech recognition in noise (either positively or negatively). Paired comparisons of sound quality for the same speech in noise signals, however, revealed a strong preference for DNR processing. Similarly, Boymans, Dreschler, Schoneveld, and Verschuure (1999) concluded that implementation of MDNR (modulation based digital noise reduction algorithm) processing may lead to improvement in sound quality in the absence of significant improved speech recognition. However, these data suggest that the implementation of DNR processing will provide improved sound quality for speech in the presence of noise.

On the basis of these studies, it appears that the effectiveness of DNR in minimizing the deleterious effects of background noise on recognition performance remains equivocal. A few studies report that there is significant improvement in sound quality on DNR processing for speech-in-noise condition (Boymans, Dreschler, Schoneveld, & Verschuure, 1999; Boymans & Dreschler, 2000; Ricketts & Hornsby, 2005) and others report that the listening comfort and sound quality rating were very similar with and without noise reduction system (Alcantara, Moore, Kuhel, & Launer, 2003). Although the actual reasons for the discrepant finding across studies are unclear, it is assumed that differences in the speed and magnitude of gain reduction for steady-state signal as well as differences in experimental method (eg. type of competing signal) play a role. Overall, these studies report that there is no degradation in speech recognition or sound quality have been reported for MDNR processing implemented in commercial hearing aids (Ricketts & Dahr, 1999; Boymans & Dreschler, 2000; Walden, Surr, Cord, Edwards & Olsen, 2000; Alcantara, Moore, Kuhel, & Launer 2003).

2.5 Other methods and combination of clinical strategies on hearing aids, to improve speech recognition in noise

There are many more strategies to improve speech perception in noise. Currently, hearing aids are implementing various clinical strategies and circuitry schemes imposed in an attempt to improve speech understanding in both quiet and noisy environments. The most effective way to improve speech recognition in noise is to improve the signal to noise ratio (SNR). This can be achieved by technologies such as Frequency Modulation (FM) systems and directional microphone.

FM systems are proven to improve speech understanding in noise. The SNR improvement given by the FM hearing aid would be 6-10 dB. Directional microphones are designed to take advantage of the spatial differences between speech and noise to improve the SNR for hearing aid users. Directional microphones are more sensitive to sounds coming from the front than sounds coming from the back and the sides. Directional microphone alone has proved to be effective in speech understanding in noisy condition (Leeuw& Dreschler, 1991;Ricketts & Hornsby, 2003). In addition, greater improvements are generally observed in less reverberant environments than in more reverberant environments (Hawkins & Yacullo, 1984; Ricketts & Dhar, 1999; Ricketts & Henry, 2002).

There are many researches done to find the combined effectiveness of directional microphone and the digital noise reductions systems. Boymans and Dreschler (2000) evaluated the efficacy of a digital hearing aid implementing dual microphone and active noise reduction in isolation and in combination. This was conducted in well-controlled clinical field trial in 16 hearing aid users, using single blind crossover design. Performance measurements (speech recognition tests in background noise), paired comparisons, and self-report measurements (questionnaires) were assessed. The speech recognition or reception tests were performed before and after each field trial, the paired comparisons were performed in weeks 4 and 12, and the questionnaires were administered after each field trial. In the last week, for all subjects, results were obtained for different settings which include without noise reduction, with noise reduction alone, dual microphone alone and both noise reduction and dual microphone combined. For the speech reception threshold tests and for the paired comparisons, the effect of directional microphone was clearly positive. Although the effects of noise reduction were not significant for any of the four APHAB sub-scales, several questions within the sub-scale showed significance in favor of the noise reduction for the loud and or aversive situations. These results suggest that the aversive reaction of background noise caused by the amplification is reduced by DNR implementation in the hearing aids. However, the addition of DNR circuit to the directional microphone did not further increase the performance.

Conversely, Bray, and Nilsson (2001) concluded that DNR algorithms may be effective in improving speech perception in noise when the noise field is isotropic. Twenty adults with age range from 34 to 84 years having bilateral, sensorineural mild-severe hearing loss participated in the study. Speech intelligibility in noise measures were obtained in the quasi-free field with modified hearing in noise test (HINT). The testing was in the sequence, under unaided, Omni directional mode, omnidirectional mode with DNR, directional mode, and directional mode with DNR along with different listening environment (noise-front and noise-diffuse) were counter balanced across subjects. For noise-front environment, there was a mean aided benefit of 2.6 dB SNR without DNR activated and 3.5 dB SNR with DNR activated. The significant effect of the DNR condition is due to the algorithm exploiting the temporal modulation differences between the fluctuating speech and the steady noise. In noise diffuse condition; there was benefit of 3.5 dB in the omni-directional and DNR condition which was greater than the omni-directional alone (2.5 dB SNR). There was a 4.8 dB SNR in the directional microphone condition which was greater than the omni-directional plus DNR condition, and benefit in the directional and DNR condition was 6.5 dB SNR, which was greater than the directional alone condition.

Limited data suggest that specific implementation of MDNR (modulation based digital noise reduction algorithm) may slightly improve speech recognition performance in the presence of steady-state noise. Isolated findings suggest that DNR algorithm, along with directional microphone may be effective in improving speech perception in noise when the noise and speech sources are not spatially separated (Bray, Sandridge, Newman, & Karnhass, 2002) or when noise is isotropic (Bray & Nilsson, 2001).

Nordrum, Erler, Garstecki, and Dhar (2006) evaluated the performance of 16 experienced adult hearing aid users on the Hearing in Noise Test (HINT) when directional microphone and DNR were activated independently and simultaneously, in four commercially available hearing aids. The HINT sentences were presented from a speaker at 0^0 azimuth, 1 meter from the listener at a height of 36 inches. The three channels of uncorrelated noise were presented from 7 speakers at 90^0, 180^0, and 270^0 azimuth, and also 1 meter from the listener. Across hearing aids, performance for directional microphone, directional microphone + DNR conditions were better than in the omnidirectional and DNR conditions. This result suggests DNR in conjunction with directional microphone resulted in better performance.

Yuen and Lau (2006) studied the ability of hearing aid circuitry to reduce the effects of noise in a sentence-in-noise test under three conditions: (i) adaptive directional microphone; (ii) multi-channel noise reduction system and (iii) a combination of the two. In the signal-front/noise side condition, adaptive directional microphone alone and combined adaptive directional microphone and DNR gave better performance than DNR alone in nearly all participants, whereas when the noise and signal are presented together, both the signal processing strategies (directional microphone and noise reduction system) and the combination of the two were ineffective in improving speech recognition in presence of noise.

These studies reveal that a combination of the signal processing strategies such as directional microphone and noise reduction system will be effective in improving speech perception in noise by increasing signal-to-noise ratio, especially when the signal and noise are coming from the same direction or when noise is diffuse (Bray & Nilsson, 2001).

CHAPTER 3

METHOD

The primary purpose of the study was to compare the aided performance of the participants with and without the digital noise reduction (DNR) is being activated; on speech recognition scores (SRS), auditory late latency response (ALLR) and the quality of speech. Another purpose of the study was to compare the effect of masking noise in individuals with normal hearing and hearing loss on SRS and ALLR. And also, test re-test reliability of the perceptual quality rating between the two sessions in individual with hearing loss across DNR activated and deactivated condition. In addition, the relation of N1-P2 amplitude complex to SRS was investigated. Repeated measures research design was used.

3.1 Participants

The data were collected from a total of 24 participants. All the participants were native speakers of Kannada language (Dravidian language spoken in southern part of India). The participants did not have any psychological and neurological problems. They did not have of middle ear pathology as confirmed by immittance evaluation. The participants were divided into two groups; Group A and Group B.

Group A: A total of 10 participants (N=10) were included in the group. The age of the participants ranged from 19 to 40 years (mean age of 27.90 years). The participants in this group had pure tone thresholds within 15 dB HL at octave frequencies between 250 Hz and 8 k Hz. They had ≥ 80% speech recognition scores (SRS) in quiet and > 60% speech recognition scores at 0 dB SNR on phonemically balanced bi-syllabic word list in Kannada (Yathiraj & Vijayalaksmi, 2005).

Group B: The participants in Group B had acquired hearing loss with adequate speech and language. The participants had flat sensorineural hearing loss (SNHL), with air-bone gap not greater than 10 dB and the difference between the highest and the lowest air-conduction threshold across frequency from 250 Hz to 8000 Hz did not vary more than 20 dB from each other (Pittman & Stelmachowicz, 2003). Their SRS was proportionate to the hearing loss (Vanaja & Jayaram, 2005). The Group B participants were further distributed into two Group B1 and Group B2, based on degree of hearing loss. Group B1 included 7 participants with mild flat sensorineural hearing loss in the age range of 35 to 55 years (mean age of 44.86 years), and Group B2 also comprised of 7 participants with moderate flat sensorineural hearing loss. Their age ranged from 30 to 55 years (mean age of 42.43 years).

3.2 Equipment and test material

The following instruments and material were used for data collection.

3.2.1 Instrumentation

(i) A calibrated two-channel diagnostic audiometer Madsen OB922 (version 2) with TDH-39 headphones housed in MX-41/AR ear cushions, was used for obtaining behavioural air-conduction thresholds, speech audiometry and also for delivering test stimulus during the unaided and aided testing. Radio ear B-71 bone vibrator of the audiometer was used for obtaining the bone-conduction thresholds. A loudspeaker (Martin Audio, C115) placed at 45 degree azimuth and at one meter distance from the participant’s aided ear was used for presenting the test stimuli.

(ii) A calibrated GSI-Tympstar (version 2) immittance meter was used to rule out middle ear pathology.

(iii) Unaided ALLR were recorded for participants in Group A whereas ALLRs were recorded in aided condition for participants in Group B, using Bio-logic Navigator Pro EP system with dB electronics loudspeaker.

(iv) The hearing aid chosen for the purpose of the study was a 4 channel digital behind-the-ear hearing aid. This hearing aid had two programs one for calm situations and the other for speech in noise situations. This hearing aid incorporated digital noise reduction and had a fitting range from mild to moderate degree of hearing loss. According to the manufacturer's published specifications, the frequency range of this hearing aid was from 100 Hz to 6800 Hz. The hearing aid was fitted to the ear of the participant using an appropriate sized ear tip.

(v) A personal computer with NOAH-3 and hearing aid specific software with Hearing instrument Programmer (Hi-Pro) interface were used to program the hearing aids and to activate/deactivate the DNR.

3.2.2 Test material

Phonemically balanced (PB) bi-syllabic word lists in Kannada (Yathiraj and Vijayalaksmi, 2005) were used to find out the speech recognition scores. It consisted of eight lists with 25 bi-syllabic words in each. An adult female, who was a native speaker of Kannada, recorded the word lists on a CD with normal vocal effort.

The Judgement of sound quality rating scale was developed by Gabrielsson, Schenkman, and Hagerman (1988), originally had eight dimensions related to sound quality, was modified and used in the study.

(i) Stimulus Recording and Preparation of /da/ Stimulus and Kannada Passage

The Consonant-Vowel (CV) token /da/ was spoken by a female adult speaker, whose mother tongue was Kannada with normal vocal effort. The /da/ stimulus were recorded in a sound-treated room using the Adobe Audition (Version 1.5) software, installed in personal computer, via a hand held unidirectional microphone (AHUJA, AUD-101XLR) placed at 10 cm away from the lips of the speaker. The recorded stimulus was digitized using 32-bit processor at 44,100 Hz sampling frequency. The /da/ stimulus was uttered thrice with the approximate duration of stimulus was 250 ms. Goodness test of /da/ stimulus was carried to see which of the /da/ stimulus was natural, by presenting the stimuli to five individual with normal hearing. The stimulus with highest rating of goodness was selected.

Likewise, the Kannada passage, picked up by a story was recorded in Abode Audition spoken by an adult female whose mother tongue was Kannada in clear conversational speech style. The passage was given to five individual with normal hearing for the Goodness test and they was rated the passage to be highly intelligible.

3.3 Test environment:

All tests were administered in an air-conditioned acoustically treated double/single room set-up.

3.4 Procedure:

The routine audiological evaluations which are described below were carried out in order to select the participants for the study.

3.4.1 Audiological evaluation for selection of participants

a) A brief case history was taken to confirm the participant inclusion criteria.

b) *Pure tone audiometry:* The air-conduction thresholds between 250 Hz and 8 kHz and the bone-conduction thresholds between 250 Hz and 4 kHz were obtained using a calibrated dual channel audiometer to estimate the degree and type of hearing loss.

c) *Speech audiometry:* Speech Reception Thresholds (SRT) was obtained by presenting paired words and Speech Recognition Score (SRS) was established by presenting the PB word list (Yathiraj & Vijayalaksmi, 2005) at a level of 40 dB SL (re: SRT). The participants were instructed to repeat the words heard. Uncomfortable Loudness Level (UCL) for speech for each participant was found out by gradually increasing the intensity of speech. The lowest level at which the participant reported the speech to be uncomfortably loud was taken as UCL for that participant.

d) *Immittance evaluation:* Tympanometry and reflexometry were done with a probe tone of 226 Hz at 85 dB SPL. This was done to rule out middle ear pathology.

After the audiological evaluation, the participants satisfying the selection criteria were considered for further evaluations conducted in Phases I, II, and III.

3.4.2 Phase I: Hearing aid fitting and optimizing hearing aid gain

3.4.3 Phase II: Behavioural testing

3.4.4 Phase III: Electrophysiological testing

3.4.2 Phase I - Fitting and optimizing hearing aid

In this phase, digital behind the ear hearing aid was programmed for each participant in the Group B1 and Group B2 and also the gain was adjusted according to each participant.

Programming hearing aid

The hearing aid was programmed using NOAH and hearing aid specific software on a personal computer. The hearing aid worn by the participant was connected to Hi-Pro through a connecting cable and the hearing aid was detected by the programming software. The hearing thresholds of each participant were fed into the programming software and target gain curves were obtained using the proprietary prescription formula of the hearing aid. The hearing aid gain was first-fit to match the target gain and fine-tuned based on the audibility of Ling's six sounds.

After the initial first-fit, the participants were asked to repeat the Ling's six sounds presented randomly (/a/, /i/, /u/, /s/, /sh/ and /m/). The gain was optimized for audibility of the Ling's six sounds by adjusting the gain of the hearing aid until the participants were able to identify all six Ling's sounds. The aided audiogram was also done to ensure adequate audibility.

The hearing aid was set to amplify omni-directionally with the volume control deactivated. The hearing aid chosen has two programs. Program 1 of the hearing instrument had speech in quiet program where in digital noise reduction was turned 'off'. Program 2 was similar to Program 1 except for the noise reduction algorithm turned 'on'. The settings were saved in the hearing aid for each participant. Finally, the fitting status was saved into the hearing aid. The programming cable was disconnected and the hearing aid was switched ‘on’. This was repeated for each test ear and for each participant.

3.4.3 Phase II: Behavioural Testing

The following data were collected from each test ear of each participant:

a) Speech Recognition Scores (SRS)

b) Perceptual quality rating

a) Speech Recognition Scores (SRS)

The Speech Recognition Scores (SRS) were obtained using recorded phonemically balanced (PB) word-list in Kannada (Yathiraj & Vijayalakshmi, 2005). The participants were made to sit comfortably on a chair in the test room at a distance of 1 meter and 45^0 azimuth from the loudspeaker of the audiometer. The recorded word list was routed to the loud speaker through the auxiliary input of the audiometer, at 45 dB HL. Before the presentation of the stimuli, the level of the presentation was set to 45 dB HL and level adjustments was done for the calibration tone such that the VU-meter deflections averaged at 0. The presentation level of the stimuli was monitored with VU meter. The non-test ear was given speech noise of 65 dB HL from the audiometer in order to avoid its participation.

i. SRS in quiet:

The recorded Speech material (PB word list) was presented at 45 dB HL to obtain SRS in quiet, through sound field. The SRS in quiet was obtained for all the participants. For participants in Group A, it was measured in unaided condition whereas for participants in Group B, the SRS was measured in aided condition. This was measured by presenting one complete PB word-list of 25 words for each condition. The participants were instructed to repeat the words being presented. The responses were scored as the number of words correctly identified. Each correct response was given a score of ‘1’ and each incorrect response was given score of ‘0’. The maximum score was 25 as each list consisted of 25 words. The total number of correctly repeated words in the list was noted. This was considered as the SRS of the participant for a particular test condition.

ii. SRS in noise:

The white noise was calibrated to give same output as speech stimuli, such that routing both speech and noise through the loud speaker would give 0 dB SNR. For obtaining SRS under noise condition, the recorded PB word-list was presented at 45 dB HL and the white noise was also routed through the same loudspeaker. The number of words correctly repeated was noted and this gave the SRS under noise condition. SRS in noise was obtained in unaided condition for participants in Group A. For participants in Group B, the SRS were obtained, under two aided test conditions, i.e., by activating and deactivating the digital noise reduction system in the hearing aid.

b) Perceptual Quality Ratings

Quality ratings for the speech output through the hearing aid was done only for the participants in Group B1 and Group B2. Quality ratings were obtained in aided conditions with DNR activated and deactivated in order to answer the research question of whether there is any sound quality difference seen between the activated and deactivated DNR signal processing.

The participants in Group B were asked to rate the hearing aid in terms of quality of speech output, at 0 dB SNR when the DNR was activated and deactivated. For this, a recorded Kannada passage on the CD was routed to the loudspeaker through auxiliary input of the audiometer. The presentation level was at 45 dB HL, and white noise was also routed through the same loudspeaker with the SNR of 0 dB.

The participants were instructed to listen carefully to the recorded paragraph which was presented and to rate on four parameters of quality. The instructions were made simple and given in Kannada language. The instructions given to the participants were “You will now hear a passage, listen to it carefully. At the end of the passage, you will have to rate the quality of speech on four different parameters, on a Ten-point rating scale.

Following were the four perceptual parameters given to each participant

- Loudness: A rating of 10 was given when speech output through the hearing aid is sufficiently loud. In contrast, 0 was given if the speech was very loud /faint.

- Clearness: A rating scale of 10 was given when the speech was clear and distinct. Whereas for blurred and distorted speech, the rating was 0.

- Naturalness: A higher rating was given when the speech sounded as if there was no hearing aid, i.e., natural.

- Overall impression: the output of speech with little distortion, giving rise to speech that was very similar that in quiet condition.

The participants were asked to rate the above perceptual parameter on a 10-point rating scale, from 0 to 10, where 0 is very poor and 10 is excellent. The rating of speech was done while listening through the hearing aid with DNR being activated and deactivated, for participants in Group B1 and Group B2.

To assess the test re-test reliability of perceptual quality rating, the Group B participants were called to attend another session. Only five participants out of seven, in each Group of B attended the second session. The same instructions were given in the second session also. The gap between the two sessions was not less than 6 hours and more than one day.

3.4.4 Phase III: Electrophysiological Testing to record the auditory evoked late latency responses (ALLR)

For each participant, a new recording session was created by entering and saving the details of patient's demographic data in the Bio-Logic Navigator Pro AEP system. The AEP system was calibrated to give a 65 dB SPL output of /da/ stimulus from a distance of 1 meter at 45^0 azimuth. The white noise was also calibrated to give same output, such that 0 dB SNR was achieved.

The skin surface at two mastoids (M1, M2) and vertex (Cz) were cleaned with a skin preparation gel with a mild abrasive to obtain required impedance. It was ensured that the impedance at each electrode site was less than 5 kΩ and the inter-electrode difference in impedance was less than 2 kΩ. Silver chloride cup electrodes were used to record the responses and were placed in vertical montage. While recording ALLR, the non-inverting electrode (+) was placed on the vertex (Cz), the ground electrode was on mastoid of the non-test ear and the inverting electrode (-) on the mastoid of the test ear (M1 or M2). The participants were instructed to sit comfortably on a reclining chair and relax during the testing and they were asked to watch a muted movie played from a battery operated laptop. They were also instructed to ignore the stimulus and restrict the movement of head, neck and eye during testing.

The recorded natural /da/ stimulus was given through the loudspeaker, connected to Biologic Navigator Pro EP system, which was located at 45^0 azimuth and a distance of 1 meter from test ear. The non-test ear was given a 55 dB HL noise from the portable audiometer, in order to avoid its participation. To record ALLR in noise condition, white noise was routed to the same loud speaker at 0 dB SNR. The ALLR recording was initiated once a stable EEG was obtained. The stimulus and the recording parameters of speech evoked ALLR are given in the Table 3.1. The recording was done twice at each test condition to check for the replicability of ALLR and weighted average of two recordings was taken.

Table 3.1: *Stimulus and acquisition parameters for recording of ALLR*

Stimulus parameters	
Stimulus	Natural /da/
Intensity of stimulus	65 dB SPL
Transducer	Loud speaker at 45^0 azimuth, 1m
Mode of presentation	Monoaural
Number of samples	300
Stimulus polarity	Alternating
Repetition rate	1.1/sec
Ipsilateral masking	White noise (0 dB SNR)

Acquisition Parameters	
Filter setting	1-30 Hz
Notch filter	Off
Analysis window	-100 to +446 ms
No. of channel	Single channel
Amplification	50,000
Artifact rejection	75µV
Electrode Montage	
Non-inverting	Vertex (Cz)
Inverting	Test ear mastoid (A1/A2)
Ground	Non-test ear mastoid (A1/A2)

The same procedure was followed for participants in Group B1 and Group B2 under two aided conditions. In the first aided condition, the ALLRs were recorded in the presence of noise at 0 dB SNR, by deactivating the digital noise reduction. In second condition, ALLRs were recorded again in noise condition by activating the DNR in the hearing aid. Thus, the effect of DNR signal processing on the ALLR peaks was studied by comparing the two aided conditions.

3.4.5 Analysis of ALLR

The latency of the wave P1, N1 and P2 and amplitude of N1-P2 complex, in the two recording were identified and marked visually by two experienced audiologists. The latencies of the peaks were tabulated for P1, N1 and P2. The peak-to-peak amplitude of N1-P2 was measured and tabulated. The latencies of components of ALLR (P1, N1 and P2) were marked at the center of the peak, if the peak was broader and if the peak was broader with unequal amplitude then the one with greater amplitude was marked.

In addition, the audiologists were also asked to rate the morphology of the peaks under DNR activated and deactivated condition on five-point rating scale. Where 0 indicates no response, 1 for poor morphology, 2 for moderate morphology, 3 indicated good morphology whereas 4 for excellent morphology. The average of the ratings given by the two audiologists were calculated and tabulated.

In summary, the following data were collected,

a) For each participant in Group A, the SRS and ALLRs were obtained in quiet condition and with noise at 0 dB SNR

b) For each participant in Group B, the SRS and ALLRs were obtained under three aided conditions i.e., in quiet and with noise at 0 dB SNR, with DNR being activated and deactivated.

c) For each participant in Group B, perceptual quality rating of speech output were obtained for four parameters when listening to speech through hearing aid under two conditions, when DNR was activated and in deactivated condition.

Appropriate statistical analysis was carried out on the data to verify the objectives of the study.

CHAPTER 4

RESULTS AND DISCUSSION

The current study investigated the effectiveness of digital noise reduction (DNR) through behavioural and electrophysiological measures in two groups of participants with hearing loss. In addition, the study examined the effect of noise on behavioural and electrophysiological measures in individuals with normal hearing and hearing loss. Group A consisted of ten individuals with normal hearing and Group B consisted of 14 individuals with hearing loss. Group B was further divided into Group B1 and Group B2. Group B1 included of seven individuals with mild flat sensorineural hearing loss whereas Group B2 comprised of seven individuals with moderate flat sensorineural hearing loss.

Data on two behavioural measures, speech recognition scores (SRS) and perceptual rating of quality, were tabulated for statistical analysis. The SRS were obtained in quiet condition and in noise at 0 dB SNR, for Group A. Whereas for Group B1 and Group B2, the SRS was obtained in quiet condition, and in noise (0 dB SNR) with and without DNR activated in the hearing aid. Further, perceptual ratings for four parameters of quality were obtained for Group B1 and Group B2 across two aided conditions, i.e., under noise at 0 dB SNR with DNR activated and deactivated conditions.

The electrophysiological measures included auditory late latency responses (ALLR). The ALLRs were obtained in quiet and in noise at 0 dB SNR for participants in Group A. For Group B1 and Group B2 participants, ALLR were recorded in quiet, under noise (0 dB SNR) with DNR activated and deactivated conditions.

The data from a total of 24 participants were tabulated for statistical analysis using SPSS software (version 18). There were three independent variables i.e., three groups of participants (Group A, Group B1 & Group B2), two conditions (in quiet & in noise at 0 dB SNR) for Group A participants; and three test conditions (in quiet, & in noise at 0 dB SNR with DNR activated and deactivated condition) for Groups B1 and B2. The dependent variables included SRS and components of ALLR (latencies of P1, N1 & P2 and amplitude of N1-P2) for Group A.

In addition to the above data, the perceptual measure of quality rating (Loudness, Clarity, Naturalness & Overall impression) for Group B1 and Group B2 were obtained. This was done to see if the noise reduction strategy used in the study had any effect on the quality of speech.

The Shapiro-Wilk's test of normality was used to assess whether the scores in each group are normally distributed around the sampling mean, or to see if the the sampling distribution between means was normal (Howell, 2008). The results of the this test claimed to be accurate for sample size from 3 to 5000. The sample size less than three will not produce a Shapiro-Wilk statistic (Royston, 1995). Normality thus needs to be checked for each of the independent variables for each of the sample groups. A sample with a p-value equal to or greater than 0.05 was considered to be a normally distributed sample. Table 4.1 shows the p values for each dependent variables under each test conditions. The p values are greater than 0.05 for all the dependent variables for all conditions except the SRS for Group A under two conditions. Therefore, it can be assumed that the data represent the sample from normal distribution. However, the SRS data for Group A do not follow the normal distribution. Since the results of other parameters showed that the groups were normally distributed, parametric tests were administered.

Table 4.1: *Results of Shapiro-Wilk's test of normality-test statistic (W) and p-values for each independent variables.*

Groups	***Conditions***	***SRS***		***P1***		***N1***		***P2***		***N1P2***	
		W	*p*	*W*	*p*	*W*	*P*	*W*	*P*	*W*	*P*
Group A (N=10)	Quiet	**0.67**	**0.00**	0.90	0.22	0.90	0.22	0.90	0.23	0.96	0.79
	Noise	**0.75**	**0.00**	0.94	0.62	0.96	0.88	0.89	0.18	0.79	0.14
Group B1 (N=7)	Quiet	0.81	0.06	0.94	0.67	0.94	0.71	0.95	0.81	0.93	0.55
	Noise	0.85	0.13	0.92	0.47	0.80	0.05	0.94	0.67	0.96	0.83
	DNR activated	0.81	0.06	0.85	0.13	0.83	0.08	0.91	0.41	0.89	0.31
Group B2 (N=7)	Quiet	0.84	0.09	0.85	0.14	0.96	0.86	0.83	0.09	0.98	0.96
	Noise	0.89	0.29	0.90	0.34	0.90	0.37	0.94	0.69	0.95	0.75
	DNR activated	0.84	0.09	0.93	0.58	0.95	0.73	0.88	0.26	0.95	0.75

The results of the study are discussed under the following headings:

4.1 Effect of Noise on Speech Recognition Scores (SRS) and Auditory Late Latency Responses (ALLR) in participants with normal hearing and hearing loss.

4.2 Effect of DNR on Speech Recognition Scores (SRS), Auditory Late Latency Responses (ALLR) and Perceptual quality rating in participants hearing loss.

4.3 Test Re-Test Reliability on Perceptual quality rating across two conditions and two Groups (B1 & B2) of participants with hearing loss.

4.4 Correlation between the SRS and N1-P2 amplitude in Group A and Group B.

4.1 Effect of Noise (0 dB SNR) on Speech Recognition Scores (SRS) and Auditory Late Latency Responses (ALLR) in participants with normal hearing and hearing loss

To find out the effect of 0 dB SNR in individual with normal hearing and hearing loss, different measures such as SRS and ALLR were obtained under quiet condition and in noise, at 0 dB SNR condition. For individuals with normal hearing (Group A), SRS and ALLRs were obtained in the unaided condition; whereas for individuals with hearing loss (Group B1 & Group B2) these were obtained in the aided condition.

4.1.1 Effect of 0 dB SNR on SRS in Group A, Group B1 and Group B2

Descriptive statistics was done on the speech recognition scores (SRS) obtained in quiet condition and in noise at 0 dB SNR for Group A (N=10), Group B1 (N=7) and Group B2 (N=7) to get the mean and standard deviation. The mean and standard deviation of speech recognition scores obtained in both the conditions (with and without noise) in all three groups of participants were computed. The results are outlined in Table 4.2.

Table 4.2: *Mean and standard deviation (in brackets) values of SRS obtained in quiet condition and in noise at 0 dB SNR, in the three groups.*

	Conditions	***Group A***	***Group B1***	***Group B2***
SRS	*In quiet*	24.40 (0.96)	20.86 (0.90)	19.86 (0.69)
	In noise	20.10 (0.56)	17.00 (1.15)	16.14 (1.06)

From the Table 4.2, it can be inferred that as expected, the mean SRS in quiet is greater than the scores obtained in noise condition for all the three groups. Further, in quiet and noise conditions, the mean speech recognition scores were greater for Group A than that for Group B1 and Group B2. The participants in Group B1 performed better than those in Group B2.

Two way repeated measures ANOVA (3 groups x 2 condition) was done for SRS to see the main effect of the condition, group as well as the interaction between the group and condition. The results indicated that there was no significant interaction between conditions and the groups [F (2, 21) =1.034, p>0.05]. However, there was a significant effect main of condition [F (1, 21) = 468.26, p<0.05] and the group [F (2, 21) = 70.837, p<0.05].

Hence, the data were subjected to Bonferroni's multiple comparison to find out the pair of groups that was significantly different. The results revealed that, Group A was significantly different from Group B1 and Group B2 (p<0.05). However, there was no significant difference between Group B1 and Group B2 (p>0.05), across the two conditions. In other words, the speech recognition scores obtained in quiet and noise conditions are similar for the Group B1 and Group B2, whereas SRS obtained across two conditions were significantly higher for Group A compared to Group B1 and B2.

The speech recognition scores of words are decreased by the addition of white noise, in all the three groups. Further, to investigate the degree to which these three groups are being affected by the white noise, the difference between the speech recognition scores in quiet and noise were calculated. The mean and standard deviation of the difference in speech recognition score are displayed in Table. 4.3.

Table 4.3: *Mean and standard deviation (in brackets) of the difference values of SRS, across three groups*

	Group A	***Group B1***	***Group B2***
SRS	4.30 (0.94)	3.86 (0.69)	3.72 (0.95)
Reduction in mean SRS (in percent)	17.62	18.50	18.73

Since the SRS obtained in quiet were not were not comparable across the groups. The mean of the difference in SRS (in %) were used to find out the impact of noise, across the three groups. These reductions in mean SRS obtained in percentage were greater for Group B2, while it is least for Group A.

The present results suggested, the speech recognition scores of words are significantly reduced in the presence of white noise. The above results are in accordance with the finding of studies in literature, which report that the speech recognition scores in the presence of noise are reduced when compared to that obtained under quiet condition (Keith & Talis, 1972; Carhart, Tillman, & Greetis, 1969; Danhauer, Doyle, & Lucks, 1985). These studies also report that the individuals with hearing loss are more susceptible to background noise than individuals with normal hearing.

The result of the present study is in consonance with the findings reported in literature, which revealed that both participants with hearing loss (Group B1 & B2) are affected by noise to a greater degree than compared to individuals with normal hearing. This could be attributed to the reduced frequency selectivity and excessive upward spread of masking in individuals with hearing loss (Martin & Pickett, 1970; Trees & Turner, 1986).

4.1.2 Effect of 0 dB SNR on P1, N1, and P2 latencies and amplitude of N1-P2 complex in Group A, Group B1 and Group B2

The latencies of P1, N1, and P2 and the amplitude of N1-P2 complex of the ALLR were computed in quiet and noise conditions for individuals with hearing loss (Group B1 & Group B2) and normal hearing (Group A), to find out the effect of white noise.

i) Effect of 0 dB SNR on P1 latency

The mean and standard deviation were obtained for P1 latency, using descriptive statistics. As it is evident from Table 4.4, the mean value of P1 latency under noise condition is longer when compared to P1 obtained in quiet condition, across all the three groups.

Table 4.4: *Mean and standard deviation (in brackets) and p values of P1 latency across three groups, under quiet and noise conditions.*

Parameter	***Condition***	***Group A***	***Group B1***	***Group B2***
P1 latency (ms)	*In quiet*	68.34 (5.31)	75.06 (6.69)	71.94 (5.88)
	In noise	81.19 (5.16)	89.60 (8.83)	85.62 (6.67)
	p	0.00*	0.00*	0.02*

Note: * indicates significant difference at 0.05 level of significance

The influences of white noise on P1 latency across the three Groups were found out using two way repeated measures ANOVA. This was done to find out the main effect of condition (P1 in quiet, P2 in noise) and groups (Group A, Group B1 & Group B2) and also their interaction. The results revealed that there is no significant interaction between the groups and conditions [F (2, 21) =0.270, p>0.05)]. In addition, there was no significant main effect of group [F (2, 21) =3.406, p<0.05)]; whereas there was significant main effect of the condition on P1 latency across all the three groups [F (1, 21) =200.202, p<0.05)].

Thus, the results showed that P1 latency is significantly prolonged under noise condition, in all the three groups. Nonetheless, the effect the noise on P1 latency is similar across all the three groups.

ii) Effect of 0 dB SNR white noise on N1 Latencies

The mean and standard deviation were obtained for N1 latency across all the three groups under quiet and noise conditions, using descriptive statistics. As it is shown in Table 4.5, the N1 latency is greater in noise condition, when compared to N1 obtained in quiet condition in the three groups of participants. Also, under quiet condition, the N1 latencies are comparatively prolonged for Group B when compared to the latencies of N1 for Group A.

Table 4.5: *Mean standard deviation (in brackets) and p value of N1 latency across three groups, in quiet and noise conditions.*

Parameter	***Condition***	***Group A***	***Group B1***	***Group B2***
N1 latency (ms)	*In quiet*	109.08 (5.54)	127.05 (9.32)	120.18 (8.25)
	In noise	125.47 (5.61)	140.98 (14.03)	135.51 (8.05)
	p	0.00*	0.03*	0.008

Note: * indicates significant difference at 0.05 level of significance

Two way repeated measures ANOVA revealed that there was no interaction between the groups and the conditions [F (2, 21) =0.237, p>0.05)]. But, there was a significant main effect of group [F (2, 21) = 103.15, $p<0.05$)] and also conditions [F (1, 21) =10.20, $p<0.05$)].

The data were subjected to Bonferroni's pair-wise analysis across three groups and in two conditions. The test results revealed that in quiet condition, there was a significant difference between Group A and Group B1 ($p<0.05$), Group A and Group B2 ($p<0.05$). But the difference between Group B1 and Group B2 was not statistically significant ($p>0.05$). In noise condition, there is a significant difference between the Group A and Group B1 ($p<0.05$). There was no significant difference between the Group A and Group B2 ($p>0.05$), Group B1 and Group B2 ($p>0.05$).

Therefore from the results it can be inferred that, by the addition of white noise, there is a significant prolongation of N1 in all the three groups. However, the latency of N1 obtained in quiet condition for individuals with hearing loss (Group B1 & Group B2) was significantly prolonged than participants with normal hearing (Group A).

iii) Effect of 0 dB SNR white noise on P2 Latencies

As shown in Table 4.6, the mean values of P2 in quiet condition are shorter when compared to that in noise condition. Stated differently, the P2 latencies in all the three groups were prolonged by the addition of white noise.

Table 4.6: *Mean, Standard Deviation (in brackets) and p value of P2 latency across three groups, in quiet and in noise conditions.*

Parameter	***Condition***	***Group A***	***Group B1***	***Group B2***
P2 latency (ms)	*In quiet*	157.34 (7.25)	207.40 (11.35)	193.07 (10.44)
	In noise	182.58 (10.81)	226.88 (11.93)	217.02 (10.56)
	p	0.00*	0.01*	0.00*

Note: * indicates significant difference at 0.05 level of significance

The results of two way repeated measures of ANOVA revealed that there was no interaction between the groups and conditions [F (2, 21) =1.688, p>0.05]. There was a significant main effect of conditions on P2 latency [F (1, 21) =290.02, p<0.05] and there was a main effect of the groups [F (2, 21) =53.92, p<0.05] as well.

Bonferroni's multiple comparison test results showed that all the three groups (p<0.05) are significantly different in quiet condition. The latency of P2 in the Group B1 and Group B2 participants are significantly prolonged in quiet condition than Group A participants. In addition within Group B, the participants in Group B1 had longer P2 latencies compared to Group B2 participants. In noise condition, there is no significant difference among Group B1 and Group B2 (p>0.05). Nonetheless, there is a difference between the Group A and Group B participants (p<0.05).

Thus, it can be stated that for participants in Group B1 and B2, though the P2 latencies were significantly different in quiet condition, the latency was not significantly different under noise condition. In other words, the P2 latency in individuals with moderate hearing loss (Group B2) is prolonged to a greater extent compared to individuals with mild hearing loss (Group B1). Therefore, the results suggest that effect of white noise increases with increase in the degree of hearing loss.

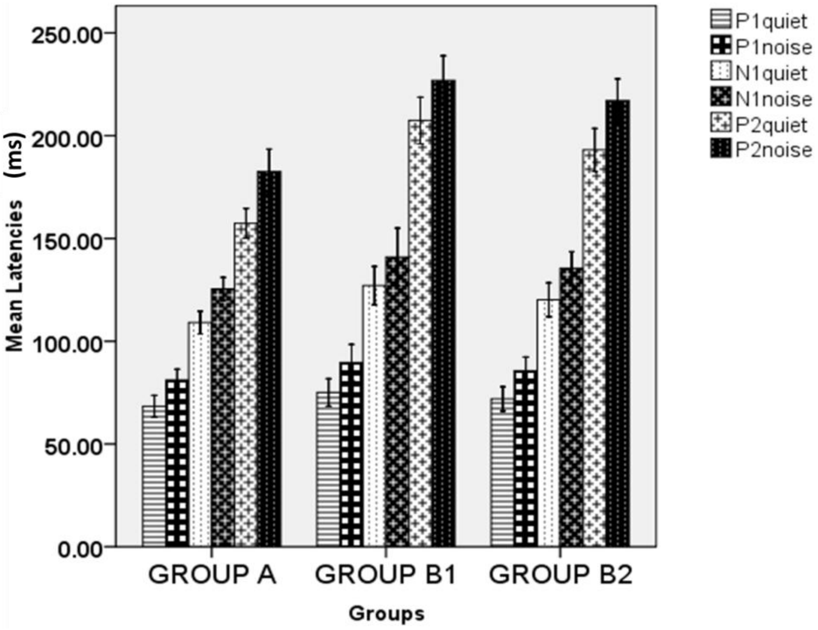

Figure 4.1: Mean and standard deviation (+/- 1 SD) for ALLR parameters (P1, N1 & P2 in ms) under quiet and at 0 dB SNR across three groups.

As it is seen in the Figure 4.1, the mean latencies of all the peaks namely P1, N1 and P2 are prolonged in the presence of noise for all the groups. On the other hand, the latency shift in the presence of noise was greater for P2 than N1 peak. Thus, the influence of noise was greater for P2 latency.

Auditory processing of natural /da/ stimuli, at the cortical level is negatively affected by the presence of white noise, as indicated by smaller amplitude (N1-P2 complex) and increased latencies for ALLR components (P1, N1, & P2). These findings are in agreement with Martin and Stapells (2005), who investigated the effect of background noise on CAEPs in individuals with normal hearing. They used /ba/ and /da/ speech sounds to elicit the responses and they concluded that the latencies were significantly prolonged in the presence of noise compared to that in quiet condition.

Since N1 and P2 are obligatory potentials, the presence of noise at 0 dB SNR decreases the audibility of the stimulus and hence it leads to prolonged latencies in the presence of noise (Martin & Stapells, 2005). Another reason for the prolonged latencies could be due to pronounced disruption of the timing features in cortical processing, when encoding rapidly presented acoustic signal that have been masked by noise (Wible, Nicol, & Kraus, 2005; Chandra & Barman, 2009).

The participants with hearing loss did not perform equivalent to those with normal hearing as showed by ALLR latencies in quiet condition, even after providing appropriate amplification. It must be noted that the ALLRs were recorded in aided condition for Group B whereas unaided condition for Group A.

The prolongation of latencies of P1, N1 and P2 in individuals with hearing loss (Group B1 & B2) could be due to the physiological changes such as damaged hair cells and auditory nerve fibers which result in elevated thresholds and broadened tuning curves that may affect the place and timing cues that are encoded throughout the auditory system. Further, the prolongation of latencies may also be influenced by the delay in the processing of the stimuli through the hearing aid. Therefore, in addition to hearing aid processing, damaged mechanisms in the peripheral auditory system might probably modify the signal before it reaches the brain (Souza & Tremblay, 2006). Hence, these individuals are not performing similar to individuals with normal hearing, under quiet condition.

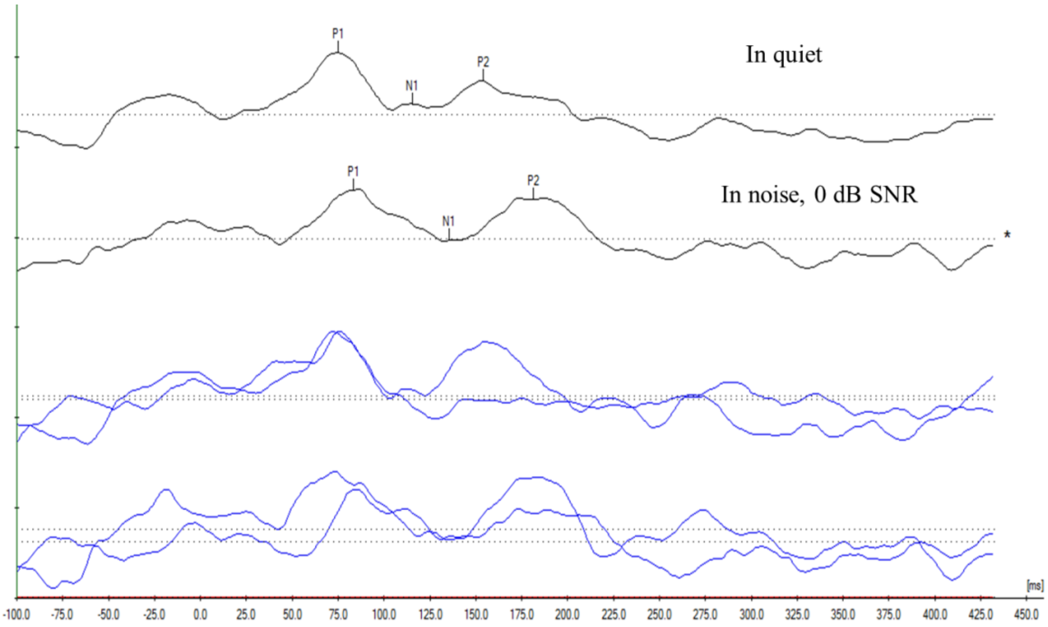

Figure 4.2: The ALLR waveform of a participant with normal hearing obtained under quiet and in noise. The upper single waveform represent the weighted add of the two individual waveforms in 5µv/ div visual scale.

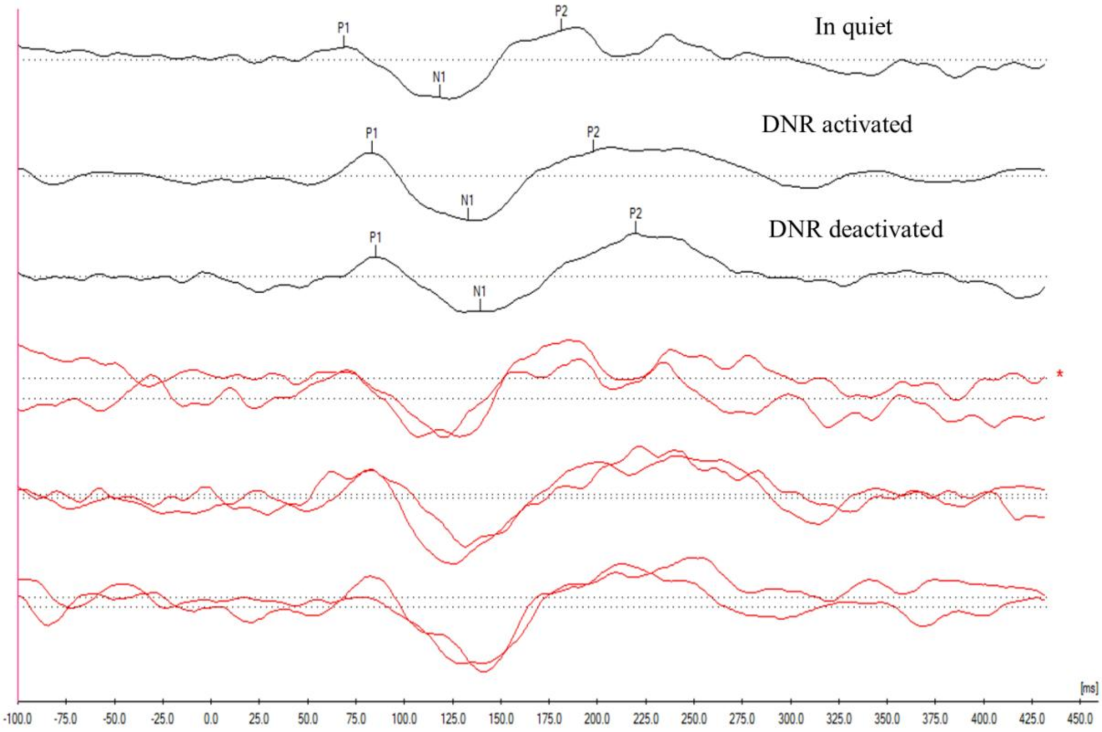

Figure 4.3: The ALLR waveform of a participant with hearing loss obtained under quiet, under noise with DNR activated and deactivated. The upper single waveform represent the weighted add of the two individual waveforms in 5µv/ div visual scale.

iv) Effect of 0 dB SNR white noise on the amplitude of N1-P2 complex

Table 4.7 shows the mean and standard deviation of N1-P2 amplitude, as it can be seen the amplitude has significantly deteriorated due to the presence of noise. The impact of white noise on the amplitude was comparable across all the three groups. Thus, the noise not only prolongs the latencies of the ALLR peaks but also reduces its amplitude.

Table 4.7*: Mean and Standard Deviation (SD) and p values of N1-P2 amplitude across three groups in quiet and noise conditions.*

Parameter	***Condition***	***Group A***	***Group B1***	***Group B2***
N1-P2 amplitude (µv)	*In quiet*	3.48 (1.01)	4.67 (1.33)	5.62 (0.72)
	In noise	2.32 (0.95)	3.13 (0.44)	4.03 (0.85)
	p	0.00*	0.02*	0.01*

Note: * indicates significant difference at 0.05 significance level

The results two way repeated measures ANOVA revealed that the interaction between the group and conditions was not significant [F (1, 21) =0.788, p>0.05]. But, there is a significant main effect of condition [F (1, 21) =79.37, p<0.05] and group [F (1, 21) =10.623, p<0.05] on N1-P2 amplitude.

Hence the data was subjected to Bonferroni's multiple comparisons test. The results indicated that there is no significant difference between the Group A and Group B1 (p> 0.05) and also Group B1 and Group B2 (p> 0.05) but there is difference among Group A and Group B2 (p< 0.05) under quiet condition. None of the groups were significantly different in noise condition.

Stated differently, the N1-P2 amplitude obtained under quiet condition was significantly reduced for Group A. It must be noted that, the ALLRs for Group A were recorded by giving noise to the non-test ear (NTE), through the insert receiver from the audiometer, as the NTE had normal hearing sensitivity. Whereas for most of the participants in Group B1 and Group B2 the ALLRs were recorded without insert receiver, since the other ear also had hearing loss. So this presence of the insert receiver might have probably caused stimulus transduction artifacts as the transducer producing current in the insert receiver, was proximal to the body or electrode components (Van Campen, Sammeth, Hall, & Peek, 1992; Campbell, Kerlin, Bishop, & Miller, 2012). Therefore, this reason could be attributed to the reduction in amplitude for Group A participants.

Further, there was a reduction of N1-P2 amplitude in the presence of noise at 0 dB SNR in all the three groups. These results are in consonance with the findings reported by Martin and Stapells (2005); and Chandra and Barman (2009). They investigated the effect of noise on CAEPs by using /ba/ and /da/ speech stimulus. Their results indicated that the amplitude of N1-P2 reduced significantly in the presence of noise.

Since ALLR is an exogenous potential, the components of ALLR namely P1, N1 and P2 depend on the characteristics of the stimulus. Hence, the presence of noise decreases the audibility of the stimulus leading to a reduction in N1-P2 amplitude (Martin & Stapells, 2005; Chandra & Barman, 2009).

4.2 Effect of DNR on Speech Recognition Scores (SRS), Auditory Late Latency Responses (ALLR) and perceptual quality rating in participants with hearing loss

The SRS and components of auditory late latency responses (ALLR) obtained under noise at 0 dB SNR, with DNR activated and deactivated conditions, for participants in Group B1 (N=7) and Group B2 (N=7), were tabulated for statistical analysis, to find out the differences between two conditions, if any.

4.2.1 Effect of DNR on SRS in both Group B1 and Group B2

To examine the effect of the DNR in hearing aid on speech recognition scores in individuals with hearing loss, Group B1 and Group B2 were considered. Descriptive statistics was done to obtain the mean and standard deviation for the two aided conditions i.e., when DNR was activated and when DNR was deactivated. A look into the mean values, as shown in Table 4.8, indicates that the speech recognition scores of words in 'DNR activated' condition are greater than in 'DNR deactivated' condition. Hence, it revealed that there is improvement in the speech recognition scores on activation of DNR.

Table 4.8: *Mean and standard deviation values (in brackets) of SRS obtained in quiet and under noise at 0 dB SNR, with DNR activated and deactivated condition, across two groups participants with hearing loss*

	Condition	*Group B1*	*Group B2*
SRS	*Quiet*	20.86 (0.90)	19.86 (0.69)
	DNR deactivated	17.00 (1.15)	16.14 (1.06)
	DNR activated	17.86 (0.90)	17.29 (1.38)

The results of two way repeated measure ANOVA revealed that there was no interaction between the conditions and the groups [F (1, 12) =0.923, p>0.05] as well as no main effect of group [F (1, 12) = 1.463, p>0.05]. However, there was main effect of conditions [F (1, 12) = 45.231, p<0.05].

Bonferroni's multiple comparison tests was done to obtain pair-wise comparison of different condition (quiet, DNR activated & DNR deactivated). The results showed that the mean speech recognition scores obtained under quiet condition are significantly different from those obtained in noise, with DNR activated condition [F (1, 12) =45.231, p<0.05]. Hence the results suggest that, the implementation DNR processing did not improve the scores to the extent equivalent to that obtained under quiet condition.

Figure 4.4 depicts the mean and standard deviation SRS obtained under quiet, 0 dB SNR condition with DNR deactivated and activated across two groups. It should be noted that the maximum speech recognition score is 25.

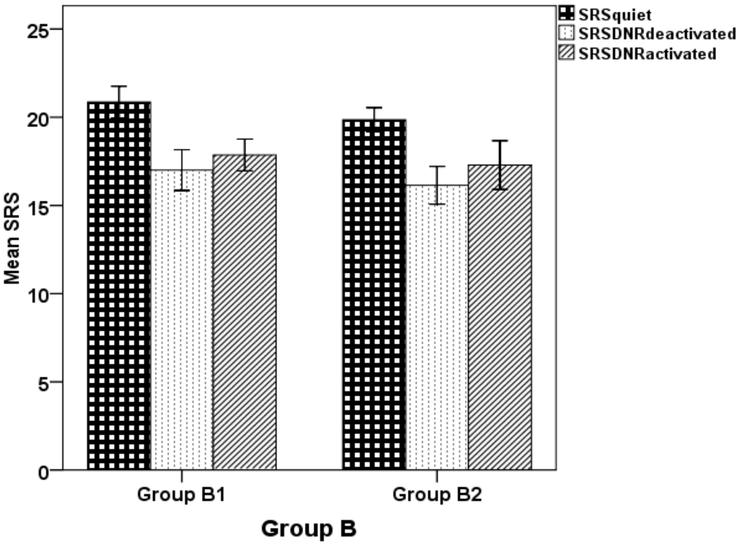

Figure 4.4: Mean and standard deviation (+/- 1 SD) for SRS (max. scores = 25) obtained in quiet condition, with DNR deactivated and activated condition for both the Group B1 and Group B2.

As it is obvious from the Figure 4.4, the activation of DNR in the hearing aid led to slight improvement in the speech recognition scores. However, the studies reported in literature (Boymans, Dreschler, Schoneveld, & Verschuure, 1999; Alcantara, Moore, Kuhel, & Launer, 2003), revealed that the scores were similar across the activated and deactivated conditions. The discrepancies between the studies could be attributed to the speed of gain reduction, how fast the DNR is capable of reducing the noise and also the magnitude of gain reduction, degree to which noise suppression occurs. As well as differences in experimental method such as the type of competing signal and type of test stimuli used, may play a role. The present study used the DNR which capable of suppressing noise to moderate degree, competing signal was white noise and also words as test stimuli. On the other hand, Alcantara, Moore, Kuhel, & Launer, (2003) used four different type of competing signal as well as low redundancy sentences as test stimuli. Whereas in Boymans, Dreschler, Schoneveld, & Verschuure, (1999) study, they used modulation based DNR but the hearing aid used for the present study had frequency based DNR algorithm (Figure 4.7)

However, the SRS of words were as not good as obtained in quiet condition, in individuals with hearing loss. This could be attributed to the degradation caused by the background noise, causing the scores to worsen compared to quiet condition. To explain, the activation of DNR will also allow some amount of background noise which may distort the stimuli. Thus, the DNR algorithm needs to be more effective in suppressing the background noise.

Stated differently, the SRS obtained under DNR activation is a little greater compared to DNR deactivated condition. Further, these differences in the scores obtained in DNR activated and deactivated condition was larger (though not significant) for Group B2, in comparison to Group B1. Thus, this result suggests that the DNR is more beneficial to participants with moderate hearing loss (Group B2). However, the implementation of DNR in hearing aid processing improves the SRS in both the groups.

4.2.2 Effect of DNR on P1, N1 & P2 latencies and amplitude of N1-P2 complex in both Group B1 and Group B2

To examine the effect of DNR on latencies of ALLR components Group B1 and Group B2 are considered. Each subject served as their own controls. The ALLRs were recorded in aided conditions for both Group B1 and B2. The latencies of the LLR peaks with the DNR deactivated compared to the DNR activated condition, reveal the effect of DNR.

Descriptive analysis was done to obtain mean and standard deviation of P1, N1 and P2 latencies and amplitude of N1-P2 complex obtained in quiet and noise conditions, for the two groups of participants (Table 4.9). The mean of P1, N1 and P2 latencies across the two condition shows that, the latencies recorded under DNR activation are significantly shorter in relation to the latencies obtained under DNR deactivated condition. But the amplitude of N1-P2 complex was not different across the two conditions (DNR activated and deactivated).

Two way repeated measure ANOVA was done to find the main effect of group and two conditions under three dependent variables (P1, N1, & P2). The results showed that there is no statistically significant interaction between the groups and condition; as well as there was no significant difference between the two groups. In other words, the impact of DNR on the latencies of LLR components was same across the two groups of individuals with mild and moderate hearing loss (Group B1 and Group B2).

Also, two way repeated measure ANOVA was done to find the main effect of group, conditions and the interaction between the group and condition on N1-P2 complex. The results revealed that there is no significant interaction of group and conditions [F (1, 21) =1.076, p>0.05]; and also no main effect of condition [F (1, 12) =0.195, p>0.05] on N1-P2 complex. But, there was a main effect of group on N1-P2 amplitude [F (1, 12) =7.552, p<0.05].

Table 4.9: *Mean, standard deviation (SD) and p value of P1, N1 and P2 latencies and amplitude of N1-P2 complex, across two groups (Group B1 and Group B2), under DNR deactivated and activated condition.*

Components of LLR	***Conditions/p***	***Group B1***	***Group B2***
P1 (in ms)	*DNR deactivated*	89.60 (8.83)	85.62 (6.67)
	DNR activated	81.87 (7.61)	81.19 (5.62)
	p	0.02*	0.01*
N1 (in ms)	*DNR deactivated*	140.98 (14.03)	135.51 (8.05)
	DNR activated	134.71 (15.77)	130.48 (8.57)
	p	0.08*	0.00*
P2 (in ms)	*DNR deactivated*	226.88 (11.93)	217.02 (10.56)
	DNR activated	219.81 (11.84)	206.46 (9.41)
	p	0.02*	0.01*
N1-P2 Amplitude (µv)	*DNR deactivated*	3.13 (0.44)	3.039 (0.83)
	DNR activated	4.03 (0.85)	4.264 (0.90)
	p	0.683	1.00

Note: * indicates significant difference at 0.05 significance level

Table 4.9 revealed that there was a significant effect of DNR on the latencies of P1, N1 and P2, whereas there was no statistically significant difference obtained for the amplitude of N1-P2 complex under two conditions.

The Figure 4.5 and Figure 4.6 represent the P1, N2 and P2 latencies across quiet condition and noise condition with DNR activated and deactivated conditions, for Group B1 and B2.

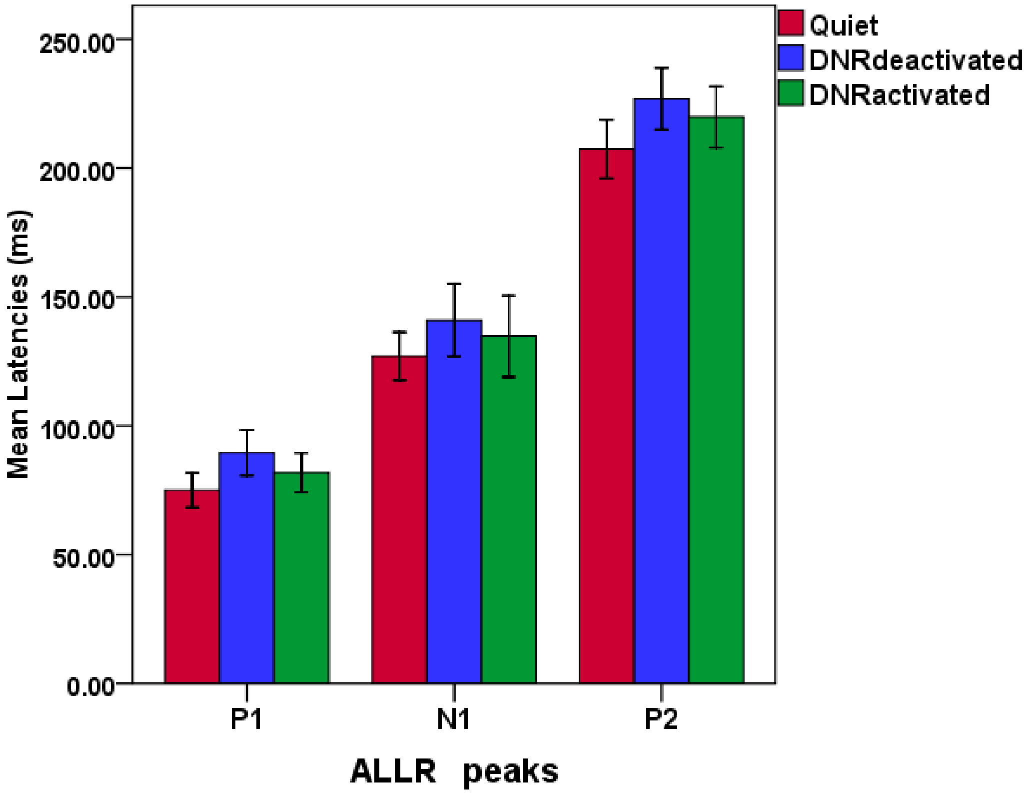

Figure 4.5: Mean and standard deviation (+/- 1 SD) for ALLR components (P1, N1 & P2) under quiet and at 0 dB SNR, with DNR deactivated and activated conditions for Group B1

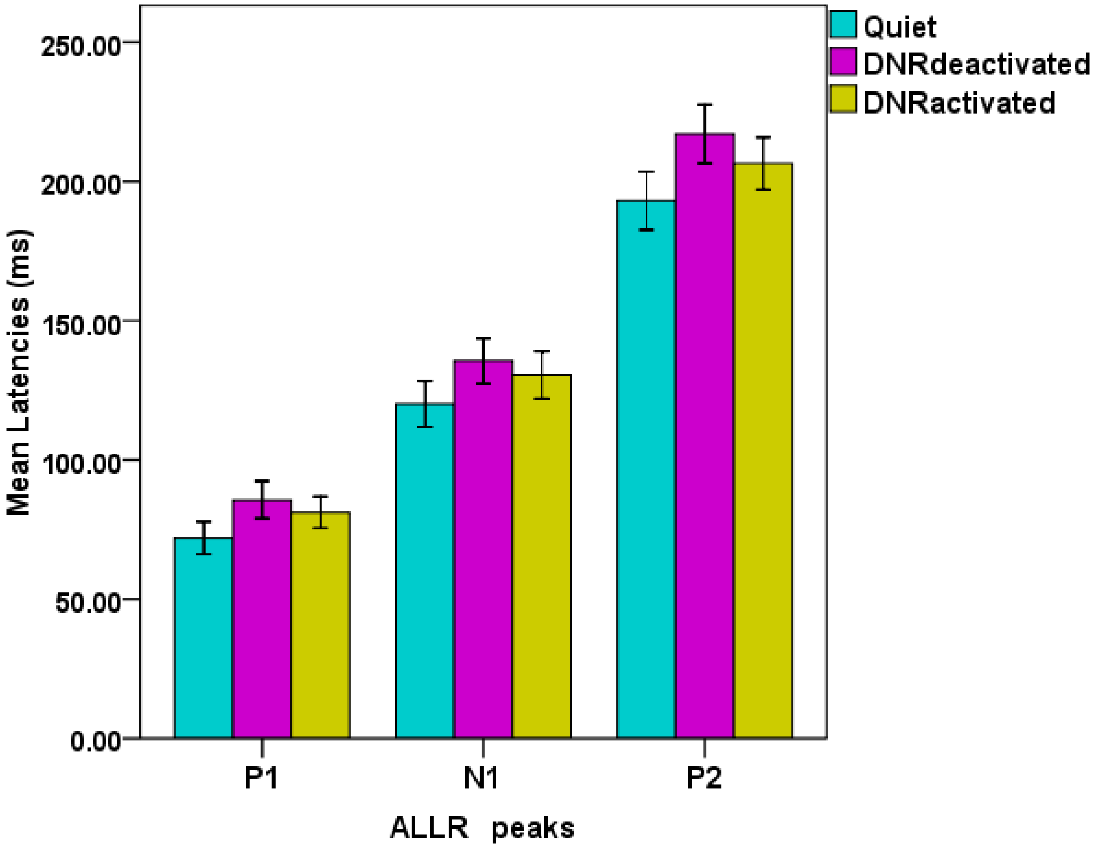

Figure 4.6: Mean and standard deviation (+/- 1 SD) for ALLR latency (P1, N1 & P2) under quiet and at 0 dB SNR with DNR deactivated and activated condition, in Group B2.

As it is displayed in the Figure 4.5, Figure 4.6 and Figure 4.3, the activation of DNR has reduced the prolongation of latencies in comparison to the latencies obtained under deactivated DNR condition. As reported in literature, the morphology of P1, N1 and P2 latencies is driven by the signal-to-noise ratio. As the SNR increases, the latencies of P1, N1 and P2 reduce (Billings, Tremblay, Steckera, & Tolina, 2009). Since the activation of DNR reduces further deterioration of the latencies caused by the noise, the DNR might probably be enhancing the SNR. However, the improvement obtained in the latencies under DNR activation was not comparable to the latencies obtained in quiet condition.

The electroacoustic coupler measurements were done to investigate the gain changes across frequencies under quiet condition and under noise with DNR activated and deactivated conditions. An external input, natural /da/ stimulus in quiet and noise was routed through the auxiliary input of the audiometer to Fonix 7000. This was picked up by the hearing aid with / without DNR being activated. The output from the hearing was measured by Fonix 7000. Figure 4.7 depicts the electroacoustic measurements obtained for /da/ in quiet (curve 3), /da/ in DNR deactivated condition (curve 2) and /da/ in DNR activated condition (curve 1).

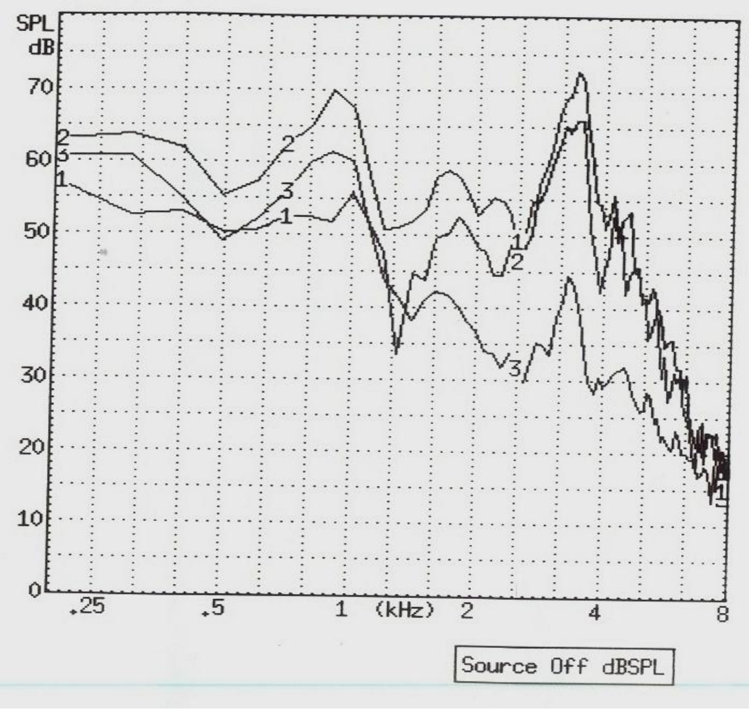

Figure 4.7: The electroacoustic measurements obtained for /da/ in quiet (curve 3), /da/ in DNR deactivated condition (curve 2) and /da/ in DNR activated condition (curve 1).

As shown in Figure 4.7, the curve 1 where the /da/ is given in noise with DNR activated had differential gain reduction for low frequencies and high frequencies. The maximum gain reduction was seen at the low frequencies when compared to high frequencies. Also the curve 1 (DNR activated) is not equivalent to the gain curve obtained under quiet condition (curve 3). Thus, the distortions of the stimuli caused by the activation of DNR which is evident through the acoustic measure could be attributed to the reduction in speech recognition scores and delay in ALLR latencies seen under DNR activated condition in comparison to quiet condition, in participants with hearing loss (Group B1 & B2).

4.2.3 Perceptual Quality Rating

Perceptual quality ratings were given by the participants in Group B only. Four parameters for the judgements of quality of speech output in aided conditions were evaluated based on participants rating of quality in two conditions, with deactivated and activated DNR, in hearing aid. Within each condition, the four perceptual parameters (loudness, clarity, naturalness, and overall impression) of quality were rated on a ten-point rating scale.

i) Perceptual Quality Rating across Two Conditions (DNR activated and deactivated) between Two Groups partcipants hearing loss (Group B1 & Group B2)

Descriptive statistics was done to obtain the mean and the standard deviation for four perceptual parameters under two conditions (DNR deactivated & activated) for two groups of participants. Table 4.10 gives the mean and standard deviation values of the quality ratings on four perceptual parameters with DNR deactivated and activated condition.

Table 4.10: *Mean and standard deviation (in brackets) values of four perceptual parameters of quality obtained with DNR activated and deactivated conditions, across the two groups*

Groups	**Parameters of quality**	***Rating on a 10 - point scale***	
		DNR deactivated	***DNR activated***
Group B1	*Loudness*	6.71 (0.75)	8.00 (0.57)
	Clarity	6.86 (0.69)	8.57 (0.53)
	Naturalness	6.86 (0.90)	7.57 (0.53)
	Overall impression	7.00 (1.00)	8.14 (0.6)
Group B2	*Loudness*	5.57 (0.53)	7.57 (0.97)
	Clarity	5.71 (0.75)	7.86 (0.37)
	Naturalness	6.14 (1.06)	7.71 (0.48)
	Overall impression	6.43 (0.97)	8.57 (0.53)

It can be noted from Table 4.10 that the mean values of quality ratings is greater when the DNR was activated compared to when the DNR was deactivated, on all the four parameters. Mann-Whitney U test was performed to compare the differences quality ratings between the two group of participants (Group B1 & Group B2) on a ten-point rating scale. This was done since the data was ordinal.

Table 4.11: *Results of the Mann-Whitney U test across the two conditions (with activated & deactivated DNR) for four parameters of quality, between the two groups (Group B1 & Group B2).*

Conditions	***Parameters of Quality***	***/Z/***	***Significance (2- tailed)***
DNR deactivated	*Loudness*	-2.550	0.011*
	Clarity	-2.353	0.354
	Naturalness	-1.344	0.019*
	Overall impression	-1.014	0.019*
DNR activated	*Loudness*	-0.926	0.179
	Clarity	-2.343	0.591
	Naturalness	-0.537	0.310
	Overall impression	-1.214	0.225

Note: * indicates significant difference at 0.05 significance level

As shown in the Table 4.11, results of the Mann-Whitney U test showed significant difference in perceptual parameters namely ‘Loudness’, ‘Naturalness’ and ‘Overall impression’ when DNR was deactivated between two groups (Group B1 & Group B2). Thus, the results of perceptual quality ratings are disscussed separately for Group B1 and Group B2. The mean values in Table 4.10 shows that the participants with mild hearing loss (Group B1) rated the quality under DNR deactivated, significantly better than those with moderate hearing loss (Group B2), except for the ‘Clarity’ pararmeter. For the ‘Clarity’ parameter, both the groups (Group B1 & Group B2) did not signficantly differ in ratings. Also, these groups where not significantly different when the DNR was activated.

This result suggests that the difference in the ratings obtained in DNR activated and deactivated condition is greater for Group B2 (Figure: 4.9) than Group B1(Figure: 4.8), as Group B1 participants rated the ‘Loudness’, ‘Clarity’ and ‘Overall impression' parameters higher in DNR deactivated condition. In other words, the annoyance caused by the noise under DNR deactivated condition is less disturbing for participants in Group B1 and hence the ratings given are more favourable and vice versa for Group B2 participants. Therefore, it can be infered that DNR implementation in hearing aid is more benificial for participants with moderate hearing loss (Group B2) than those with mild hearing loss (Group B1).

i) Perceptual Quality Ratings across DNR Activated and Deactivated Conditions, for Group B1

Figure 4.8 depicts the mean and standard deviation of quality ratings for four perceptual parameters for Group B1, under the two aided conditions. The maximum score rating obtained for any parameter is '10' and the minimum was '0'.

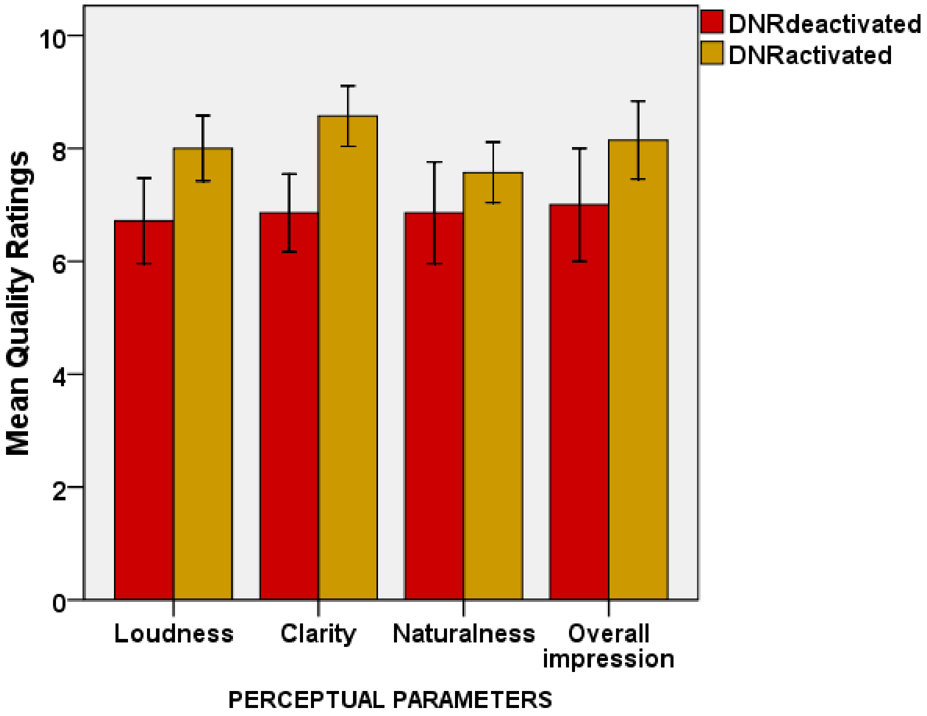

Figure 4.8: Mean and standard deviation (+/- 1 SD) for perceptual quality ratings (max.=10, min.=0) with DNR activated and deactivated conditions, for Group B1.

Wilcoxon Signed-Rank test was done for the pair-wise comparison of DNR activated and deactivated conditions, to evaluate the significance of difference (if any) between the two conditions, for Group B1.

Table 4.12: *Results of the Wilcoxon Signed-Rank test across two conditions (with activated & deactivated DNR) for four quality parameters, for Group B1.*

Quality parameters with DNR deactivated and activated conditions	***/Z/***	***Significance (2- tailed)***
Loudness	-2.041	0.041*
Clarity	-2.401	0.016 *
Naturalness	-1.890	0.059
Overall impression	-1.633	0.102

Note: * indicates significant difference at 0.05 level of significance

As it can be inferred from the Table 4.12, the results of the Wilcoxon Signed-Rank test showed that there is a significant difference between two perceptual quality parameters (Loudness and Clarity) ratings obtained in DNR deactivated and DNR activated condition, in Group B1.

From Table 4.10 and Figure 4.8it can be inferred that, the activation DNR signal processing improved the perceptual quality of speech output for two parameters namely ‘Loudness’and‘Clarity’. Although there is difference between the ratings obtained in DNR activated and deactivated conditions, for the parameters namely ‘Naturalness’ and ‘Overall impression’, they are not statistically significant.

It must be noted that, the participants were asked to rate ‘10’ (higher score) if the loudness of the speech was comfortable level, in contrast ‘0’ was given when the signal was faint or too loud. Thus, DNR signal processing signficantly improves the Clarity of speech output and the loudness of speech such that it is comfortable.

For Group B1, it can be inferred from the findings of the present study that individuals with mild hearing loss, find the digital noise reduction algorithm benificial when listening in background noise. Though the ‘Naturalness’ and ‘Overall impression’ of the speech output with DNR signal processing remained to be not statistically different. This could be attributed to the milder form of hearing loss and also due to lack of acclimatization to the aided speech, as all the participants were naïve hearing aid users (Ovegard, Lundberg, Hagerman, Gabrielsson, Bengtsson & Brändström, 1997).

ii) *Perceptual Quality Ratings across DNR Activated and Deactivated Condition, for Group B2*

Figure 4.9 depicts the mean and standard deviation of ratings for four perceptual parameters for Group B2, under the two aided conditions namely DNR activated and deactivated. It may be noted that the maximum score obtained for any parameter is ‘10’ and the minimum score is ‘0’.

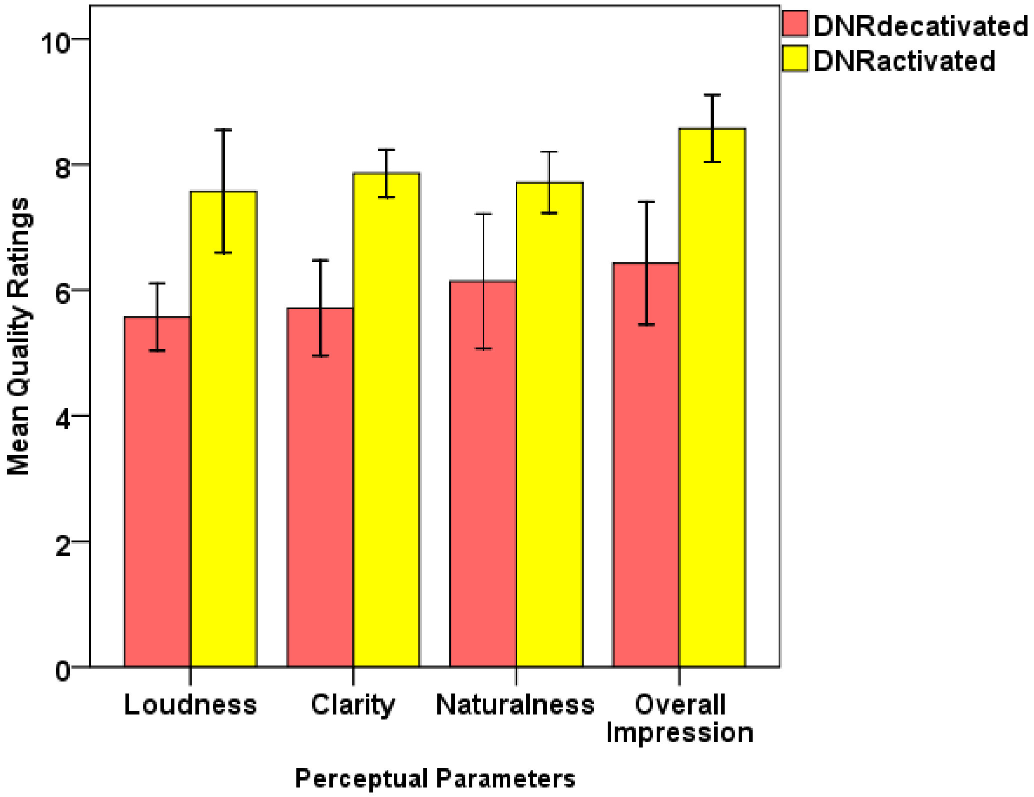

Figure 4.9: Mean and standard deviation (+/- 1 SD) for perceptual quality ratings (max.=10, min.=0) with DNR activated and deactivated condition for Group B2.

For Group B2, Wilcoxon Signed-Rank test was done for the pair-wise comparison for DNR activated and deactivated condition, to obtain the significance of difference between the two condition, if any. As it can be observed from the Table 4.13, activating the DNR significantly improved the ratings for ‘Loudness’, ‘Clarity’, ‘Naturalness’, and ‘Overall impression’ parameters.

Table 4.13: *Results of the Wilcoxon Signed-Rank test across two aided conditions (with & without DNR activated) for four quality parameters, for Group B2.*

Quality parameters with DNR deactivated and activated conditions	***/Z/***	***Significance (2-tailed)***
Loudness	-2.392	0.017*
Clarity	-2.414	0.016*
Naturalness	-2.232	0.026*
Overall impression	-2.392	0.017*

Note: * indicates significant difference at 0.05 level of significance

It can be inferred that for Group B2, that the 'Overall impression' of the hearing aid in background noise condition was rated the best than all other parameters, when DNR was activated. Comparable ratings were obtained for all other perceptual parameters, when the DNR was activated. In all the four perceptual parameters of quality ratings, the activated DNR signal processing appears to be significantly better than the deactivated DNR condition, when listening to background noise of 0 dB SNR.

The results of the current study is in accordance with the studies reported in literature, which report on implementationof DNR in hearing aid leads to improvement in sound quality (Boymans, Dreschler, Schoneveld, & Verschuure, 1999; Ricketts & Hornsby, 2005).

4.3 Test Re-Test Reliability On Perceptual Quality Rating Across Two Conditions Two Groups (Group B1 & Group B2) of participants with hearing loss

Test re-test reliability on quality rating was analyzed using Cronbach alpha, the inter-class correlation statistics for the ratings obtained in the two sessions. This was done to measure the internal consistency estimate of reliability of test scores. Cronbach’s alpha is a coefficient of reliability and it normally ranges from 0 to 1, where 0.9 indicate excellent internal consistency and < 0.5 unacceptable internal consistency.

i) *Test-retest reliability on perceptual quality rating under DNR deactivated condition.*

To assess test-retest reliability, descriptive statistics was done to obtain the mean and standard deviation for all the four perceptual parameters for the two sessions. The data from the two groups of partcipants with hearing loss were combined to obtain the mean and standard deviation and the Cronbach alpha.

Table 4.14 : *Mean and standard deviation of quality ratings on four parameters of quality with DNR deactivated, for two sessions, for participants with hearing loss.*

Groups	***Perceptual parameters***	***Session 1***	***Session 2***
Group B	*Loudness*	6.20 (0.91)	6.10 (1.19)
(DNR deactivated)	*Clarity*	6.30 (0.94)	6.00 (1.15)
	Naturalness	6.70 (1.05)	6.50 (0.70)
	Overall impression	7.00 (0.94)	7.10 (0.99)

As it is obvious from Table 4.14, the differences in the ratings scores were not significantly different between the sessions.

Table 4.15: *Cronbach Alpha (A) value and reliability when the DNR was deactivated for four quality parameters for Group B.*

Cronbach alpha	***Loudness***	***Clarity***	***Naturalness***	***Overall impression***
A	0.8	0.9	0.7	0.8
Reliability	Good	Excellent	Acceptable	Good

Table 4.15 indicates that the reliability between the two sessions for all the four parameters of quality ranged from acceptable to good reliability or internal consistency.

ii) Test re-test reliability on perceptual quality rating under DNR activated condition.

Descriptive statistics was done to obtain the mean and standard deviation for all the four perceptual parameters of quality for two sessions for Group B. The two groups of partcipants with hearing loss were combined to obtain both the mean, standard deviation and the Cronbach alpha.

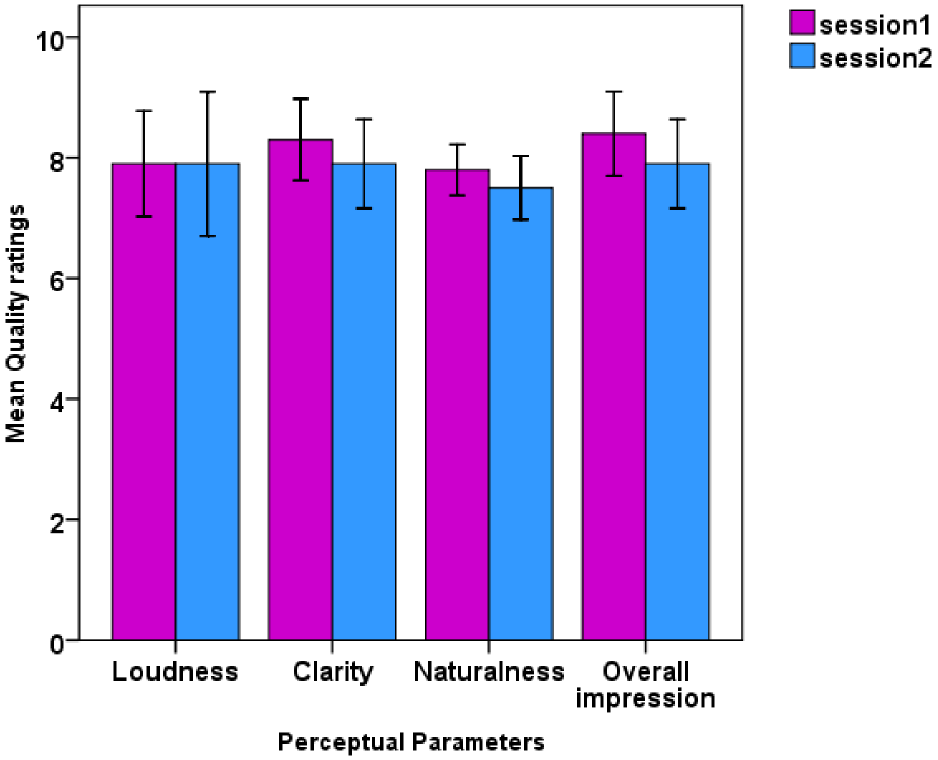

Figure 4.10: Mean and standard deviation (+/- 1 SD) for perceptual quality ratings with DNR activated in two sessions, for Group B.

As it is obvious from Figure 4.10, the differences in the ratings scores were not significantly different between the sessions.

Table 4.16 : *Mean and standard deviation of quality ratings on four parameters with DNR activated, for two sessions, for participants with hearing loss.*

Groups	***Quality parameters***	***Session 1***	***Session 2***
	Loudness	7.79	7.90
Group B		(0.80)	(1.19)
	Clarity	8.21	7.90
(DNR activated)		(0.57)	(0.73)
	Naturalness	7.64	7.50
		(0.49)	(0.52)
	Overall impression	8.36	7.90
		(0.63)	(0.73)

The Cronbach Alpha, the measure of reliability across two sessions for four perceptual quality paramenters was computed. The Cronbach Alpha was negative for the parameter 'Naturalness' because the sum of the individual item variances is greater than the scale variance, so the value is neagative. Hence the parameter 'Naturalness' was not considered for the test re-test reliability.

Table 4.17: *Cronbach Alpha (A) value when the DNR was activated for four quality parameters for Group B (Group B1+Group B2).*

Cronbach alpha	***Loudness***	***Clarity***	***Naturalness***	***Overall impression***
A	0.8	0.9	-	0.8
Reliability	Good	Excellent	-	Good

In DNR activated condition, the tests re-test reliability for the three perceptual parameters viz.,'Loudness', 'Clarity' and 'Overall impression' revealed that there is a good to excellent reliability or internal consistency between the two sessions.

4.4 Correlation between the SRS and N1-P2 amplitude, morphology ratings in Group A and Group B

Speech identification scores obtained with and without noise conditions were correlated with the N1-P2 amplitude obtained for participants in Group A and Group B. For participants in Group B1 and B2, the N1-P2 amplitude obtained with and without the activation of DNR was not correlated as there was no statistically significant difference obtained between the two conditions.

Spearman rank correlation co-efficient was obtained. The results are summarized in Table 4.18. As it is indicated, the correlation between N1-P2 amplitude and SRS obtained in quiet and noise conditions are not significant across all the three Groups.

Table 4.18: *Correlation coefficient value along with significance for N1-P2 amplitude and SRS obtained in quiet & noise conditions, for Group A, Group B1 & Group B2.*

Groups	***N-P2 amplitude and SRS in quiet***		***N-P2 amplitude and SRS in noise***	
	Correlation coefficient	***Sig. (2-tailed)***	***Correlation coefficient***	***Sig. (2- tailed)***
Group A	0.284	0.426	-0.353	0.317
Group B1	-0.227	0.625	0.075	0.873
Group B2	-0.139	0.766	-0.019	0.968

These results are in agreement with the study done by Chandra and Barman (2009). They studied the relationship between the speech identification scores and ALLR and found that the SRS obtained at 0 dB SNR did not correlate with the amplitude in individual with normal hearing. They attributed the lack of correlation between speech recognition scores and ALLR to the wide variability of latencies and amplitude of ALLR across the subjects. In addition, the components of ALLR are affected by a number of factors such as background EEG, impedance between the electrodes, sleep or drowsiness state etc., which might have led to poor correlation (Chandra & Barman, 2009). Hence, speech recognition scores will not only depend on generators of ALLR, but also on other factors.

The morphology rating was obtained for the ALLRs recorded under DNR activation and deactivation. The morphology ratings were given by two audiologists, the average of the ratings was tabulated for the statistical analysis. As shown in the

Table 4.19, there is no significant correlation obtained between SRS and Morphology ratings in both activated and deactivated DNR conditions.

Table 4.19: *Correlation coefficient value along with significance for morphology ratings and SRS obtained under DNR activated and deactivated conditions, for Group B1 & Group B2.*

	SRS in DNR deactivation		***SRS DNR activation***	
	Correlation coefficient	***Sig. (2-tailed)***	***Correlation coefficient***	***Sig. (2- tailed)***
Ratings in DNR deactivation	-0.129	0.660		
Ratings in DNR activation			-0.184	0.528

To summarize, the results of the study -

The results of the present study revealed that there is a significant effect of noise on the SRS, latencies of ALLR components (P1, N1 & P2) and the amplitude of N1-P2 complex. The results also suggest that the effect of white noise is greater for individual with hearing loss. Further, among individuals with hearing loss, the participants with moderate hearing loss (Group B2) are affected by noise to greater degree compared to individual with mild hearing loss (Group B1). These results are in agreement with the many studies reported in literature (Keith & Talis, 1972; Carhart, Tillman, & Greetis, 1969; Danhauer, Doyle, & Lucks, 1985) which state that the individuals with hearing loss are more susceptible to noise than individuals with normal hearing. This could be attributed to the reduced frequency selectivity and excessive upward spread of masking in individuals with hearing loss (Martin & Pickett, 1970; Trees & Turner, 1986).

The DNR signal processing minimizes the effect of background noise by reducing the prolongation of the latencies of ALLR peaks (P1, N1 & P2). However, the amplitude of N1-P2 complex remained unchanged by the DNR activation, in individuals with hearing loss. And also DNR processing will significantly improve the ‘Loudness’, ‘Clarity’, ‘Naturalness’ and the ‘Overall impression’ of the speech through the hearing aid with DNR activated condition. And the perceptual quality ratings appear to have acceptable to excellent internal consistency between the two sessions on all the three perceptual parameters namely ‘Loudness’, ‘Clarity’ and ‘Overall impression’. Further, there was no relationship between the SRS and the N1-P2 amplitude in quiet and noise condition and also no correlation was seen in the morphology ratings and SRS obtained under DNR activated and deactivated condition.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The purpose of the study was to investigate the effect of digital noise reduction (DNR) on speech recognition scores (SRS), auditory late latency response (ALLR) and quality of speech through hearing aid, in individuals with hearing loss; and to examine the effect of noise on SRS and ALLR in individuals with normal hearing and hearing loss. In addition, the study also aimed to assess the test-retest reliability of the quality ratings obtained under two sessions, in individuals with hearing loss. Also, another aim was to study the relationship between the SRS and the amplitude of N1-P2 complex.

Two groups of participants took part in the study. Group A consisted of participants with normal hearing sensitivity and Group B consisted of individuals with hearing impairment. Group B was further divided into two groups; Group B1 had participants with mild flat sensorineural hearing loss while Group B2 included participants with moderate flat sensorineural hearing loss.

For Group A, all the testing was done in unaided condition; whereas for Group B, the testing was done in aided condition. The study was conducted in three phases.

Phase I: The participants in both Group B1 and Group B2 were fitted with the hearing aid and the gain was optimized for the audibility of Ling’s six sounds. In addition, aided audiogram was also done to ensure adequate amplification.

Phase II: Behavioural testing was conducted to obtain the **SRS** in two test conditions i.e., in quiet and in noise at 0 dB SNR conditions for participants in Group A. Whereas, for participants in Group B, the SRS was obtained in quiet condition and under noise (0 dB SNR), with and without the activation of DNR in the hearing aid. In addition, perceptual **quality ratings** were obtained for four parameters viz., ‘Loudness’, ‘Clarity’, ‘Naturalness’ and ‘Overall impression’ under two aided conditions namely with and without DNR being activated for participants in Group B. Also, for assessing test **re-test reliability**; participants of Group B attended another session of perceptual quality rating.

Phase III: Electrophysiological testing included obtaining **ALLR** for natural /da/ stimulus, under quiet and noise (0 dB SNR) for participants in Group A, in unaided condition. While for Group B participants, the ALLR were recorded under three aided conditions - in quiet, in noise with and without DNR being activated.

Appropriate statistical analysis was carried out on the data obtained to verify the objectives of the study. Mean and standard deviation were obtained by using descriptive statistics. Shapiro Wilk’s test of normality was done to see whether the data distribution was normal. The data sample was found to be normally distributed and hence parametric test such as repeated measures ANOVA and Bonferroni’s multiple comparisons (if indicated) were performed. In addition, Mann-Whitney U test, Wilcoxon’s signed rank test and Cronbach alpha were used.

The summary of results of the present study is given under four main headings:

a. *The effect of noise on SRS and components of ALLR.*

The results revealed that the effect of noise on the speech recognition scores in all the participants was statistically significant ($p<0.01$). The SRS decreased in the presence of noise when compared to scores obtained in quiet condition in all the three groups. However, the SRS was greater for Group A participants when compared to Group B, under both quiet and noise conditions. But, the SRS obtained under two conditions were not different for Groups B1 and B2 ($p>0.05$). Likewise, even in electrophysiological measures, the addition of noise increased the latencies of P1, N1 and P2 and also reduced the amplitude of N1-P2. This effect of noise on latencies and amplitude of ALLR was seen in all three groups of participants. Further, the results also showed that the impact of noise was greater the individuals with hearing loss than normal hearing.

b. The effect of DNR on SRS, components of ALLR and perceptual quality ratings in individuals with hearing loss (Group B1 & B2)

The statistical test results showed that there was slight improvement in SRS on the activation of DNR in the presence of noise when compared to SRS obtained without DNR. Further, there was a reduction in prolongation of P1, N1 and P2 latencies by the DNR activation when compared to that obtained DNR deactivated condition. However, the activation of DNR did not increase the N1-P2 amplitude significantly, in both Groups (B1 & B2). On the other hand, there was no difference between the Group B1 and Group B2 across activated and deactivated DNR condition. Although the activation of DNR improved the speech recognition scores and the latencies of ALLR, this improvement was not equivalent to the SRS and latencies obtained in quiet condition.

For perceptual quality ratings, the mean ratings scores were significantly ($p<0.05$) higher for all the four parameters under DNR activated condition for participants in Group B2. Whereas for Group B1, the statistically significant differences were obtained only for ‘Loudness’ and ‘Clarity’. But for ‘Naturalness’ and ‘Overall impression’ parameter, though there were differences in the ratings obtained when the DNR was activated and deactivated, it was not statistically significant ($p>0.05$).

Also, there were statistically significant differences found between the two groups (Group B1 & Group B2) when the DNR was deactivated ($p<0.05$). The participants with mild hearing loss (Group B1) rated higher for the ‘Loudness’, ‘Naturalness’ and ‘Overall impression’ parameters under DNR deactivated, when compared to the ratings obtained for Group B2 participants. However, quality ratings of these groups were not different, under DNR activated condition. Thus, it can be inferred that, the difference in the ratings obtained between DNR activated and deactivated condition were lesser for Group B1 than Group B2. So this results suggest that the annoyance caused by the white noise was less disturbing for Group B1, whereas highly disturbing to Group B2 as indicated by the lower ratings. This could be because of lesser degree of hearing loss as the participants in Group B1 had mild hearing loss.

c. *Test re-test reliability of perceptual quality ratings between sessions were assessed under DNR activated and deactivated condition.*

The test re-test reliability measure, Cronbach alpha revealed that the perceptual quality ratings obtained between two sessions, across the four parameters had ‘excellent’ to ‘acceptable’ reliability.

d. *Correlation between the N1-P2 amplitude and SRS measure*

The results of the present study also showed that there was no correlation found between the N1-P2 amplitude and SRS obtained in quiet and noise condition for all the three groups of participants. Hence, speech recognition scores will not only depend on generators of ALLR, but also on other factors.

Also, there was no correlation between the morphology ratings and the SRS obtained under DNR activated and deactivated conditions.

From the present study, it can be concluded that the noise has a significant negative effect on SRS, on the latencies (P1, N1 & N2) as well as the amplitude (N1-P2) of ALLR in participants of all the three groups. Since N1 and P2 are obligatory potentials, the presence of noise at 0 dB SNR decreases the audibility of the stimulus and hence it leads to prolonged latencies and reduction in amplitude, by the presence of noise (Martin & Stapells, 2005). In addition, the SNR is the key contributor to ALLR characteristics, i.e., amplitude is increased and latency is decreased by increasing the SNR (Billings, Tremblay, Steckera, & Tolina, 2009), since the activation of DNR caused decrease in latencies of P1, N1 and P2 in relation to the latencies obtained under noise condition. DNR might have enhanced the SNR, which is reflected as decrease in latencies of P1, N1 and P2.

In summary, the activation of DNR –

- improves the speech recognition scores
- reduces further deterioration of P1, N1 and P2 latencies, and
- also improved sound quality in terms of 'Loudness', 'Clarity' 'Naturalness' and 'Overall impression' for Group B2 while only 'Loudness' and 'Clarity' for Group B1.

However, the effectiveness of DNR was not equivalent to the SRS and latencies of P1, N1 and P2 obtained under quiet condition. Further, there is a need of future research to validate the benefits of DNR, as the current study had small sample size (N=7) in each group.

5.1 Clinical implications

1. The results of the ALLR in the present study help in understanding how the signal is encoded at the cortical level, in presence of noise in individual with normal hearing and hearing loss.
2. Speech perception inferred through electrophysiological measures such as ALLR has two advantages. ALLR is an objective measure does not require the active participation of subjects and also the speech stimulus used to record ALLR is not language specific and hence can be used for wide range of population.
3. The outcome of the study tells us how the signal in noise (at 0 dB SNR) is encoded with activated and deactivated DNR processing.
4. The DNR has improved the sound quality in the presence of noise, thus there is greater chance of using the hearing aid in day-to-day life more often, than rejecting the hearing aid.

5.2 Future directions for research

- ✓ The study can be replicated using a large number of subjects, to validate the effect of the DNR using both electrophysiological measures and behavioural measures.
- ✓ At the cortical level, coding of signal in the presence of noise could be examined using different DNR algorithm such as ‘Modulation-based’ and ‘Frequency-based’ DNR.
- ✓ Further, the signal-to-noise ratio at which the DNR is more efficient could be investigated by recording ALLR at different SNRs.

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