The Effect of Digital Noise Reduction (DNR) in Hearing Aids on Auditory Late Latency Response, Speech Recognition Ability and Quality

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Abstract

The present study aimed to investigate the effect of Digital noise reduction (DNR) on auditory late latency response (ALLR), speech recognition ability (SRS) and quality of speech. The data were collected from 10 individuals with normal hearing and 14 individuals with hearing loss. The results revealed that there was a negative 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 there was a slight improvement in SRS on activation of DNR. The improvement brought about by the DNR was not enough to bring the scores to that obtained under quiet condition. The DNR activation minimizes the effect of background noise by reducing the prolongation of the latencies of ALLR peaks. Nonetheless, the amplitude of N1-P2 complex remained unchanged by the activation of DNR. Further, there was no relationship between the SRS and N1-P2 amplitude in quiet and noise. However, there was no correlation between the morphology ratings and SRS obtained under DNR activated and deactivated condition. In addition, DNR significantly improved the 'Loudness','Clarity', 'Naturalness' and 'Overall impression' ratings for the speech through the hearing aid. The quality ratings also appears to be 'acceptable to excellent reliability' between the two sessions on the three parameters namely 'Loudness', 'Clarity' and 'Overall impression'. Overall, the effect of white noise was greater for individuals with hearing loss. Participants with moderate hearing loss are affected by noise to a greater degree compared to those with mild hearing loss.

Keywords: *DNR, ALLR, SRS and quality of speech.*

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 a 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). Thus, listening in background noise presents a challenge that often leads to communication breakdowns.

In addition, successful communication in difficult listening environments will depend on 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 are a few studies which have recorded the CAEPs in individuals with normal hearing. However, there is a dearth of literature on the cortical auditory evoked potentials associated with encoding signal in individuals with hearing loss. The results of such studies indicate that the latencies are more sensitive indicators of these masking effects than amplitudes (Whiting, Martin, & Stapells, 1998; Billings et al, 2009). 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 stimuli (/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

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listening levels, distortion caused by limited bandwidth of the hearing aid (Plomp, 1978). Therefore, there are a variety of signal-processing techniques in hearing aids 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 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 studies have shown equivocal results on the sound quality of speech output by the implementation of DNR in hearing aids. 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 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).

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 et al, 2003). However, there is a dearth of literature that reports on the effect of DNR in hearing aids on electrophysiological measures.

The studies revealed that the cortical potentials are sensitive to the relative intensity of the signal with respect to noise rather than the absolute level (Kaplan-Neeman, Kishon-Rabin, Henkin & Muchnik 2006; Whiting et al, 1998; Billings et al, 2009; Chandra & Barman, 2009). A few studies have reported that cortical responses may differ from expected when recorded via sensory devices (e.g., hearing aids), this has given an impetus for additional studies examining auditory evoked responses recorded with hearing aids.

However, there is a dearth of studies in background noise done in population with perceptual difficulties such as those with hearing impairment or older adults. CAEPs may give potential information on the signal-in-noise difficulties experienced by these groups. The findings of such a 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 was taken up to explore whether the signal-to-noise ratio improved by the DNR is measurable at the level of cortex.

The primary purpose of the study was to compare the aided performance in terms of speech recognition scores (SRS), auditory late latency response (ALLR) and the quality of speech of the participants, with and without the digital noise reduction (DNR) being activated. Another purpose of the study was to compare the effect of masking noise in individuals with normal hearing and hearing loss on SRS and components of ALLR.

Method

The null hypothesis of the present study was that there was no significant difference between the SRS, ALLR and quality of speech output with DNR activated and deactivated. Repeated measures research design was used to test the null hypothesis.

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 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 $\geq$ 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. 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 the 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 42.4 years).

Instrumentation

A calibrated two-channel diagnostic audiometer Madsen OB922 (version 2) with TDH-39 headphones housed in MX-41/AR ear cushions and a bone vibrator, Radio ear B-71 was used to carry out pure tone audiometry. A loudspeaker (Martin Audio, C115) placed at 45 degree azimuth, at one meter distance from the aided ear of the participant, was used for presenting the test stimuli. A calibrated GSI-Tympstar (version 2) immittance meter was used to rule out middle ear pathology. Bio-logic Navigator Pro EP system was used to record ALLRs using dB electronics loudspeaker.

A four channel digital behind-the-ear hearing aid was chosen for the study. According to the manufacturer's specifications, the frequency range of this hearing aid was from 100 Hz to 6800 Hz. 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.

Test material

Phonemically balanced (PB) bi-syllabic word lists in Kannada (Yathiraj & Vijayalaksmi, 2005) were used to find out the speech recognition scores. The judgement of sound quality rating scale was developed by Gabrielsson, Schenkman, and Hagerman (1988), originally with eight dimensions related to sound quality, was adapted for the study.

Recording and Preparation of /da/ Stimulus and Kannada Passage

The Consonant-Vowel (CV) token /da/ was uttered 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 the personal computer, via a hand-held unidirectional microphone (AHUJA, AUD-101XLR) placed 10 cm away from the lips of the speaker. The recorded stimulus was digitized using a 32-bit processor at 44,100 Hz sampling frequency. The /da/ stimulus was uttered thrice with an approximate duration of stimulus being 250 ms. Goodness test of /da/ stimulus was carried to see which of the /da/ stimulus was natural, by presenting the stimuli to five individuals 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 individuals with normal hearing for the Goodness test and they rated the passage to be highly intelligible.

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

Test Procedure

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

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, so that the gain was adjusted according to each participant.

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.

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 in omni-directional mode with the volume control deactivated. The hearing aid chosen had two programs. Program 1 of the hearing instrument had speech in quiet program, wherein 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. This was repeated for each test ear and for each participant.

Phase II: Behavioural Testing

The Speech Recognition Scores (SRS) and Perceptual quality rating were collected from each test ear of each participant.

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 45^0Azimuth 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.

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.

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 loud speaker. 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.

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 such that the SNR was 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 participants were instructed to rate the quality on a 10-point rating scale in terms of loudness, clearness, naturalness and overall impression. For loudness, a rating of 9 was given when speech output through the hearing aid is sufficiently loud. In contrast, 0 was given if the speech was very loud /faint. For clearness, a rating scale of 9 was given when the speech was clear and distinct; whereas for blurred and distorted speech, the rating was 0. For naturalness, a higher rating was given when the speech sounded as if there was no hearing aid, i.e., natural. The overall impression is the output of speech with little distortion, giving rise to speech that was very similar that in quiet condition.

For this, the participants were asked to rate on a 10-point rating scale, where 0 is very poor and 9 is excellent. The rating of speech was done while listening to a recorded passage, through the hearing aid with DNR being activated and deactivated, only 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 or more than one day.

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 1. The recording was done twice in each test condition to check for the replicability of the ALLR and weighted average of two recordings was taken.

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 the 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.

Analysis of ALLR

The latency of the wave P1, N1 and P2 and amplitude of N1-P2 complex, in the two recordings 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

Table 1: Table 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)

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 waveforms, under the DNR activated and deactivated conditions, on a 5-point rating scale. Where 0 was used for 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.

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

Results

All the statistical tests were performed using Statistical Package for Social Science software (version 16.0). The Shapiro-Wilk's test of normality was used to assess whether the sampling distribution between means was normal (Howell, 2008). Normality needs to be checked for each of the independent variables for each of the sample groups. The results showed that, most of the parameters were normally distributed, thus parametric tests were administered. However, the SRS data for Group A did not follow the normal distribution.

Effect of Noise (0 dB SNR) on SRS

Descriptive statistics was done on the 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 compute the mean and standard deviation. The results are outlined in Table 2.

Table 2: Mean and standard deviation (in brackets) values of SRS (Max score: 25) obtained in quiet condition and in noise at 0 dB SNR, in the three groups

	Total correct scores		
Conditions	Group A	Group B1	Group B2
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 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. The results of two-way repeated measures ANOVA 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 main effect of condition [$F(1, 21) = 468.26$, $p<0.05$] and the group [$F(2, 21) = 70.837$, $p<0.05$].

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

Effect of Noise (0 dB SNR) on ALLR

The mean and standard deviation were obtained for latencies of P1, N1 and P2 and amplitude of N1-P2 complex, under quiet and noise condition, using descriptive statistics. The results showed that latencies of P1, N1 and P2 were significantly prolonged and there was reduction of N1-P2 amplitude in the presence of noise at 0 dB SNR in all the three groups. The effect the noise on P1 latency is similar across 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). In addition, 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, this suggested that the effect of noise increases with increase in the degree of hearing loss.

Table 3: Mean and standard deviation (in brackets) of the difference values of SRS, across three groups

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

Effect of DNR on SRS

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 in Table 4, indicates that the SRS of words in 'DNR activated' condition are greater than in 'DNR deactivated' condition. Hence, there is slight improvement in the speech recognition scores on activation of DNR.

Table 4: Mean and standard deviation values (in brackets) of SRS (Max score: 25) obtained in quiet and under noise at 0 dB SNR, with DNR activated and deactivated condition, across Group B1 and Group B2

	Total correct scores	
Condition	Group B1	Group B2
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)

Effect of DNR on ALLR

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 with hearing loss (Table 5). The mean latencies of P1, N1 and P2 across the two conditions shows that, the latencies recorded under DNR activation were 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).

Table 5: 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
Pl (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*

Effect of DNR on perceptual quality ratings

The mean and standard deviation for four perceptual parameters under two test conditions (DNR deactivated & activated) for two groups was computed using descriptive statistics. Table 6 gives the mean and standard deviation values of the quality ratings on four perceptual parameters with DNR deactivated and activated condition.

It can be noted from Table 6 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 for both Group B1 and Group B2. The mean values show that in DNR deactivted condition, the participants with mild hearing loss (Group B1) rated the quality under DNR deactivated to be significantly better than those with moderate hearing loss (Group B2), except for the 'Clarity' pararmeter. For the 'Clarity' parameter, the two groups (Group B1 & Group B2) did not signficantly differ in their ratings. Also, these groups were 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 than Group B1, as Group B1 participants rated the 'Loudness', 'Clarity' and 'Overall impression' higher in DNR deactivated condition. In other words, the annoyance caused by the noise under the 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 inferred that DNR implementation in hearing aid is more benificial for participants with moderate hearing loss (Group B2) than for those with mild hearing loss (Group B1).

Mann-Whitney U test was performed to compare the differences in quality ratings between the two groups of participants (Group B1 & Group B2) on a 10-point rating scale. This was done since the data was ordinal. The results showed significant difference in ratings of the 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. Also, these groups were not significantly different when the DNR was activated.

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 and Group B2. For Group B1 participants, the results showed that there was a significant difference ($p<0.05$) between the ratings of two perceptual quality parameters (Loudness & Clarity) obtained in DNR deactivated and DNR activated conditions. Although there was a difference between the ratings obtained in DNR activated and deactivated conditions, for the parameters 'Naturalness' and 'Overall impression', they are not statistically significant.

For Group B2 participants, the results revealed that there was statisically significant differences ($p<0.05$) seen between the quality ratings of all the four perceptual parameters under DNR activated condition and DNR deactivated condition. The 'Overall impression'

Table 6: Table 6: Mean and standard deviation (in brackets) values of four perceptual parameters of quality obtained with DNR activated and deactivated conditions, across the two groups

		Rating on a 10 - point scale (0-very poor, 9-excellent)	
Groups	Parameters of quality	DNR de-activated	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 (0.60)
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)

of the quality through the hearing aid in background noise condition was rated the best compared to all other parameters, when DNR was activated. Comparable ratings were obtained for all other perceptual parameters, when the DNR was activated. It must be noted that the participants were asked to rate '9' (highest score) if the loudness of the speech was comfortable level; in contrast '0' was given when the signal was faint or too loud. Thus, the DNR signal processing signficantly improved the loudness of speech such that it is comfortable.

Test Retest Reliability

Test re-test reliability on quality rating was analyzed using Cronbach alpha, the intra-class correlation statistics for the ratings obtained in the two sessions. Cronbach's alpha is a coefficient of reliability and it normally ranges from 0 to 1, where 1 indicates excellent internal consistency.

The Cronbach Alpha was obtained across two sessions for four perceptual quality paramenters, under DNR activated and deactivated conditions. In DNR deactivated condition, the reliability between the two sessions for all the four parameters of quality ranged from acceptable to excellent reliability (Table 7).

Under the DNR activated condition, the tests re-test reliability for the three perceptual parameters viz., 'Loudness', 'Clarity' and 'Overall impression' revealed that there was a good to excellent reliability between the two sessions (Table 8).

Correlation

Spearman rank correlation co-efficient was obtained between N1-P2 amplitude and SRS, and between SRS and morphology ratings. The results indicated that, the no correlation was obtained between N1-P2 amplitude and SRS obtained in quiet and noise conditions in all the three Groups. The average of the morphology ratings given by two audiologists was tabulated for the statistical analysis. The results showed that there is no correlation obtained between SRS and morphology ratings in both activated and deactivated DNR conditions.

Discussion

The present results suggest that 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

Table 7: Cronbach Alpha (A) value and reliability when the DNR was deactivated for four quality parameters for Group B

Perceptual parameters	A	Reliability
Loudness	0.8	Good
Clarity	0.9	Excellent
Naturalness	0.7	Acceptable
Overall impression	0.8	Good

Table 8: Cronbach Alpha (A) value and reliability when the DNR was activated for four quality parameters for Group B

Perceptual parameters	A	Reliability
Loudness	0.8	Good
Clarity	0.9	Excellent
Naturalness	-	-
Overall impression	0.8	Good

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).

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. The reason for the prolonged latencies in the presence of noise, 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, 2004; Chandra & Barman, 2009).

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 accordance 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 and prolongation of latencies (Martin & Stapells, 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.

Furthermore, the results showed that 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 et al, 2003), indicated that the scores were similar across the activated and deactivated conditions. The inconsistency 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. Further, differences in variables such as the type of competing signal and type of test stimuli used may play a role. The present study used the DNR capable of suppressing noise to moderate degree, competing signal was white noise and also words as test stimuli. On the other hand, Alcantara et al, (2003) used four different types of competing signal as well as low redundancy sentences as test stimuli. Whereas, in Boymans et al's (1999) study, modulation based DNR was used. The hearing aid used in the present study had frequency- based DNR algorithm (Figure 1).

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 et al, 2009). Since the activation of DNR reduces further deterioration of the latencies caused by the noise, the DNR

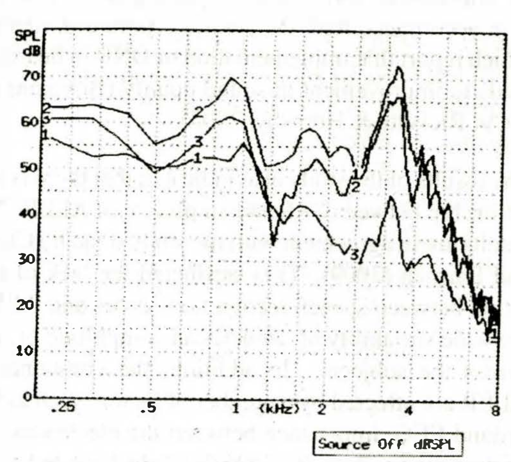

Figure 1: The electroacoustic measurements obtained for /da/ in quiet (curve 3), /da/ in DNR deactivated condition (curve 2) and /da/ in DNR activated condition (curve 1).

might probably be enhancing the SNR. However, this improvement obtained in the latencies under DNR activation was not similar 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. Natural /da/ stimulus was given in quiet and noise. This was picked up by the hearing aid with / without DNR being activated. The output from the hearing aid was measured by Fonix 7000.

As shown in Figure 1, 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 (SRS) and delay in ALLR latencies seen under DNR activated condition, in comparison to quiet condition, in participants with hearing loss (Group B1 & B2).

For the perceptual quality ratings in Group B1 participants, the 'Naturalness' and 'Overall impression' of the speech with and without the DNR activation were 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 naive hearing aid users (Ovegard, Lundberg, Hagerman, Gabrielsson, Bengtsson & Brandstrom, 1997).

DNR activation improved the sound quality of speech in terms of 'Loudness', 'Clarity', 'Naturalness' and 'Overall impression' for Group B2 participants. This result is in accordance with the studies reported in literature, which report that implementation of DNR in hearing aid leads to improvement in sound quality (Boymans et al, 1999; Ricketts & Hornsby, 2005).

The results of the study also indicated that there is no relationship between SRS and amplitude of ALLR. These results are in agreement with the study done by Chandra and Barman (2009). 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). Thus, speech recognition scores will not only depend on generators of ALLR, but also on other factors.

Conclusions

From the study, it can be concluded that implementing a frequency-based DNR will lead to slight improvement in scores of speech recognition, reduces the prolongation of ALLR peaks and also improves the sound quality of speech in the presence of noise. However, DNR is more beneficial to the participants with higher degree of hearing loss.

The results of the ALLR in the present study help in understanding how the signal is encoded at the cortical level, in the presence of noise in individual with normal hearing and hearing loss. Speech perception inferred through electrophysiological measures such as ALLR has two advantages. ALLR as 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. The DNR has improved the sound quality in the presence of noise, thus there is greater chance of using the hearing aid more often in day-to-day life, than rejecting the hearing aid.

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