Effect of Gain and Digital Noise Reduction on hearing aid in Low annoyance and High annoyance groups

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This Dissertation is submitted as partfullfillment
for the Degree of Master of Science in Audiology
University of Mysuru, Mysuru

MAY, 2015

Certificate

This is to certify that this Masters dissertation entitled '**Effect of gain and digital noise reduction on hearing aid in low and high annoyance groups**' is a bonafide work in part fulfillment for the degree of Master of Sciences (Audiology) of the student with Registration Number 13AUD015. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other Universities for the award of any Diploma or Degree.

Mysuru,
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Declaration

This Masters dissertation entitled **'Effect of gain and digital noise reduction on hearing aid in low and high annoyance groups'** it is the result of my own study and has not been submitted to any other university for the award of any other Diploma or Degree.

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May, 2015

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Abstract

Objective: The present study assesses the effect of Digital Noise Reduction and gain on Most Comfortable Level, Background Noise Level, Acceptable Noise Level and Speech in Noise Ratio 50 from within and between low and high annoyance groups. In addition, combined effect of DNR and gain was investigated on MCL, BNL, ANL and SNR 50 from within and between low and high annoyance groups.

Method*:* A blinded randomized one shot post comparative with repeated measures research design was used to investigate the effect of DNR and gain on MCL, BNL, ANL and SNR- 50 from within and between low and high annoyance groups. Two experiments were performed. In experiment-1 only five participants were involved on whom deviation of gain from user and precriptive gain was obtained. This helped to assign the gain variation in experiment-2. Eight listeners in low annoyance group and twelve listeners in high annoyance group were participated in the study. In experiment-2, ANL and SNR-50 was obtained in aided condition with varying gain from prescriptive target gain in activating and deactiving DNR in hearing aid.

Results: It was found that the ANL and SNR-50 score was better in -3 dB gain in DNR activated condition than compared to DNR 'off' condition. It was also found that ANL and SNR-50 score was better in low annoyance group individuals compared to high annoyance group individuals. Overall, the results reveal that the annoyance level was reduced in -3 dB gain below the prescriptive formula in DNR activated condition for both low and high annoyance groups.

Conclusion: Annoyance level reduced for both groups of participants by activating DNR in hearing aid and also reducing 3 dB gain from prescribed target.

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Chapter 1

Introduction

Individuals with cochlear hearing loss frequently complain that their hearing aids are of limited benefit. Most of the adults who use hearing aids complain of difficulty to understand speech in the presence of noise (Cord, Surr, Walden, & Dyrlund, 2004). Kochkin (2002) reported that naïve hearing aid users initially find it difficult to listen due to the constant noise generated in hearing aid leading to rejection of hearing aid. Even with well fitted hearing aids, some of the users do not perform well and or though they perform well with their aid, background noise makes them feel annoyed (Hawkins & Yacullo, 1984)

Thus, one of the common performance related complain with the hearing aid is annoyance created by background noise (Kirkwood & Soulsby, 2005). In literature, there is a mixed opinion with regard to the benefit from the hearing aid. The users may benefit from hearing aid in quiet condition. However in presence of noise, there are equivocal reports on benefit of hearing aids. Alcantara, Moore, Kuhnel and Launer, (2003) reported that users are benefitted with the hearing aid even in the presence of noise. Whereas, Gustafsson and Arlinger (1994) documented controversial evidence that the hearing aid users are unable to comprehend the message in the presence of noise. In such circumstance, the clinicians tend to increase the gain with the premise that signal level become relatively more than the noise level.

In some condition where older adults preferred user gain of 10 to 15 dB lesser than prescriptive gain provided by NAL formula (Leijon, Eriksson, Mangold & Bech-Karlson,1984). They justified their result of lesser gain preferred by study participants is because of binaural fitting. In another condition where the older adults in the initial fitting may seek higher gain though the amplification provided by prescriptive formula. Meenakshi and Rajalakhsmi (2006) reported that participants user gain was high compared to that of prescriptive gain. Although the perception might improve with increase in gain, but at the same time annoyance level also increases (Nabelek, Tampas, & Burchfield, 2004). This is because the noise level increases in relation to the increased gain (Billings, Tremblay, & Miller, 2011). Further, to the external noise in the environment, same amount of gain is provided which is supposed to be given to the speech signal alone. It appeared that there is a equivocal findings on deviation of user and target gains. Thus, in the present study of experiment-1 the deviation between preferred and prescribed gains are documented to establish assignment of gain variations for the experiment -2.

Kochkin (2002) reported that about 22 % of hearing aid users reject their hearing aid because of background noise. To overcome this problem the hearing aid manufactures implemented noise reduction algorithm in the hearing aid circuitry (Schum & Donald, 2003). The noise reduction algorithm separate the speech (higher modulation depth) from noise (low modulation depth) through identifying the inherent modulation depth in the signals. To the separated signal the gain is provided to the speech having higher modulation depth. Oliveira, Lopes, and Alves (2010) reported that activation of DNR in hearing aid significantly improved perception of speech in the presence of noise. However, noise was not removed from the hearing aid. That is, even after activation of noise reduction circuit in hearing aid some amount of residual noise is still be persist. With this residual noise there might be annoyance to the hearing aid users. To quantify the annoyance level accurately, a subjective measurement of acceptable noise level was utilized in the present study.

Acceptance noise level is a measure of the willingness to accept background noise while listening to speech (Nabelek, Tucker, & Letowski, 1991). Acceptance noise level is calculated by taking the difference between the most comfortable level (MCL) for running speech and the maximum background noise level (BNL) that a listener is willing to accept. The ANL ranges between -3.5 and 27 dB (Plyler, Alworth, Rossini, & Mapes, 2011) which is measured reliably (Nabelek, Tampas, & Burchfield, 2004). It predicts hearing aid user for an accuracy of about 85 % of the time (Freyaldenhoven, Plyler, Thelin, & Muenchen, 2008).

The ANL is not affected by age (Branstrom, Lantz, Nielsen, & Olsen, 2011), gender of the speaker and language (Branstrom, Lantz, Nielsen, & Olsen, 2011), part time and full time hearing aid users (Freyaldenhoven, Plyler, Thelin, & Muenchen, 2008), naïve and experienced users (Nabelek, Tampas, & Burchfield, 2004), type of background noise level (Nabelek, Tucker & Letwoski, 1991) and no relation between speech perception and annoyance level (Nabelek, Tampas, & Burchfield, 2004). However, the acceptable noise level is of central origin, which was confirmed by electophysiological measures (Tampas & Harkrider, 2006). Nabelek, Freyaldenhoven, Tampas, Burchfield and Muenchen, (2006) reported that those individuals who accept more background noise have smaller ANL value and tend to be a good hearing aid users. Lowery (2008) conducted study on the effect of digital noise reduction on ANL. It was found that 4 dB reduction from their original ANL value after activation of digital noise reduction. However, there is a dearth of literature on the effect of DNR and gain on acceptance of noise and speech reception threshold in noise on low and high annoyance groups. The following research question is put forth: How the annoyance level and speech perception in noise varied in low and high annoyance group by activating and deactivating DNR at varied gain? Further, it is hypothesized that the decrease in gain and activation of digital noise reduction in hearing aid have no effect on annoyance level and speech perception in noise on either low annoyance or in high annoyance group.

1.1. Need for the study

In clinic it was observed that two kind of response are drawn from varying gain at the time of fitting hearing aid. In one set of individuals though the speech perception ability is favorable with prescribed gain they reject their hearing aid because of background noise. It can be predicted that these individuals accept less annoyance from the background noise level and require hearing aid having the option of noise reduction circuit. In another set of individuals, who are benefitted with the amplification device by compromising the presence of noise in the hearing aid. It appear to infer that these individuals accept more annoyance level and can manage hearing aid without having option of noise reduction circuit. Thus, before coming into conclusion, there is a need to study the effect of noise reduction and gain in the hearing aid on individual who are annoyed from background noise from those who are not annoyed. The most reliable way to measure the patient annoyance is through acceptable noise level. Thus, knowing the annoyance level, the clinician can think before prescribing gain especially to those who do not accept more noise. It will also help the clinician to objectively prove and counsel the importance of noise reduction circuit in the hearing aid for those individuals who accept less noise.

1.2. Aim of the study

The aim of the study was to investigate the effect of digital noise reduction and gain on annoyance level and speech perception in noise on low and high annoyance group.

1.3. Objectives of the study

The following objectives were formulated

1. To compare between DNR activated and deactivated conditions on Most Comfortable Level, Background Noise Level, Acceptable Noise Level and Speech to Noise Ratio 50 from within and between low and high annoyance groups.
2. To compare between prescribed gain and -3 dB; and -5 dB gain on Most Comfortable Level, Background Noise Level, Acceptable Noise Level and Speech to Noise Ratio 50 from within and between low and high annoyance groups.
3. To compare combined effect of DNR and gain on Most Comfortable Level, Background Noise Level, Acceptable Noise Level and Speech to Noise Ratio 50 from within and between low and high annoyance groups.

Chapter 2

Review of Literature

The study was focused to investigate the effect of DNR and gain on ANL and SNR 50 on low and high annoyance groups. In connection to above, relevant studies related to topic are reviewed and it is categorized in the following sections.

1. Speech perception in older adults with hearing loss
2. Estimation of annoyance towards noise using ANL
3. Preferred and prescriptive gain
4. Effect of hearing aid gain and noise level
5. To account speech perception in noise and annoyance level by activating digital noise reduction in hearing aids

2.1. Speech perception in older adults with hearing loss

Cochlear hearing impairment individuals often complain to understand speech, especially in background noise. Frequency selectivity is usually reduced in individuals with cochlear hearing loss. Whereas, in advanced age accompanied by hearing loss temporal resolution is likely to be impaired in them. There are several studies (Festen, 1987; Glasberg et al., 1987; Moore & Glasberg, 1988; Glasberg & Moore, 1989; Festen & Plomp, 1990; Plomp, 1994; Glasberg & Moore, 1992; Festen, 1993; Nilsson et al., 1994; Moore, 1995; Grant & Walden, 2013) conducted on speech recognition in cochlear hearing loss at different SNRs. Individuals with cochlear loss required higher SNR level to achieve same performance of normal hearing individuals. In addition, difference in SRT for normal and hearing-impaired individuals varies greatly depending on the nature of the background sound. If the background noise used as speech-shaped noise then SRTn difference between normal and hearing-impaired individuals ranged from 2 to 5 dB (Glasberg & Moore, 1989; Plomp, 1994). Whereas, in other background noise such as single competing talker, time-reversed talker or an amplitude-modulated noise the difference in SRTn can be much larger, ranged from about 7 dB up to about 15 dB (Souza & Turner, 1994, Peters, Moore & Baer, 1996). Thus, speech recognition in noise from cochlear hearing loss varies based on type of background noise in which it masks the temporal and spectral content of speech. Further, in case of informational masking such as single talker and four talkers babble hearing-impaired individuals fails to take advantage of ‘‘dips’’ in the competing voice. These dips may be of two types: temporal and spectral. Temporal dips are momentary fluctuations in overall signal to noise ratio, especially during brief pauses in speech or during production of low energy sounds. In the region of temporal dips the signal strength is found to be relatively higher than that of background noise, this allows brief ‘glimpses’ to be obtained from the target speech. The spectral dips arise because the spectrum of the target speech is usually different from that of the background speech measured over any short interval. Although parts of the target spectrum may be completely masked by the background, other parts may be hardly masked at all. Thus, parts of the spectrum of the target speech may be ‘‘glimpsed’’ and used as cue to follow speech in competing noise. Van Tassel (1993) reported possible factors in the reduction of speech recognition in noise. Cochlear hearing loss subjects have broadened auditory filters. Wider auditory filters do not mean that it removes information from speech rather; it impedes the transfer of spectral and temporal information. It can be expected that spectral peaks and valleys in stimulus are smoothed out in those individuals with SNHL. In addition, upward spread of masking is common i.e., the higher frequency components of speech are masked by the higher amplitude of vocalic sounds or maskers of low frequencies, which is found to be one of confronting factors in SNHL. It was also speculated that that only few auditory filters are available for analysis but noise accompanied with stimulus taxes these available filters such that noise accumulates in functioning filters leading to reduced recognition in lesser SNRs.

To summarize, hearing-impaired individuals gained much less advantage from spectral and temporal dips to recognize speech in background noise than compared to normal hearing individuals. If the spectral and temporal content of noise is closer to the target speech stimulus then its effect on speech recognition is exacerbation.

2.2. Estimation of annoyance towards noise using ANL

Acceptable noise level is the measure of whether the subject is able to put up with noise while simultaneously listening to speech at their most comfortable listening level (Nabelek et al, 1991). This method of quantifying background noise acceptance is termed "acceptable noise level" (ANL). Based on acceptance towards noise ANL classified into three. Individuals who receive ANL values of <7 dB, > 13 dB and between 7 dB and 13 dB were termed as low, high and average ANL groups, respectively. Nabelek et al. (1991) demonstrated that the clinical consequences of ANL on hearing impaired individuals. Those who received low ANLs (< 7 dB) tend to accept more noise, with high potential to become successful hearing aid users. Conversely, hearing impaired individuals with high ANLs (>13 dB) tend to accept less noise relative to their counterparts. They are less likely to become successful hearing aid users and are considered as problematic with the usage of hearing aid. It was noted from literature that some of the variables influence and other variables affect the values of ANL.

2.2.1. Language.

Goldman (2009) reported that ANL increased significantly using reversed or unfamiliar language as speech signal compared to intelligible speech. In a similar line of study by Olsen, S. Ø., Lantz, J., Nielsen, L. H., and Brännström, K. J. (2012) reported that non semantic versions of ANL generate unreliable results that cannot predict hearing aid use. In a recent study done by Lu-Feng Shi, Gabrielly Azcona, and Lupe Buten (2015), examined the ANL using speech passage of different languages and their babbles in multi-talkers as background noise. Participants included were 55 adult listeners between age range from 19 to 41 years, in which 15 English monolingual, 16 Russian–English bilingual, and 24 Spanish–English bilingual listeners. They found that Russian- English bilingual's listeners yielded significant higher ANL values (by 4–5 dB) than the other listeners. All listeners, regardless of their language background, yielded significantly higher ANL values with the Spanish than the English signal, although the difference was negligible. The language of the babble significantly interacted with the number of talkers, but only in Russian-English bilinguals, for whom 12-talker Spanish babble yielded higher ANL values by 1.5 dB than 12- talker English babble. This finding supports the notion that ANL is either language independent. Thus, in the present study the syntactically and semantically structured Kannada passage was used to obtain ANL.

2.2.2. Type and preference of noise.

Nabelek et al (1991) found no effect of noise type on ANL. This was supported by following study by Rowley and Nabelek (1996) designed experiment in which confronting variables of noise was constructively varied and its effect on ANL was observed. They found mean ANL difference yielded between 12 speaker babble and steady state speech shaped noise but this did not reach significance. Since there was no effect of background noise on ANL speech shaped noise available in the audiometer was used.

2.2.3. Presentation level.

Studies related to effect of presentation level of speech signal on ANL was reviewed in this section. Freyaldenhoven, Plyler, Thelin, and Hedrick, (2007) measured ANL by varying the presentation level from 40 dB HL to 75 dB HL in normal hearing and hearing impaired individuals. Participants were 24 normal hearing subjects and 46 hearing impaired subjects. The results revealed that global ANL (i.e., ANL averaged across speech presentation levels) or ANL growth (i.e., the slope of the ANL function) varied between groups but did not show significant difference. In yet another study by Recker and Edwards (2013) studied the effect of presentation level with the speech fixed at different levels (50, 63, 75, or 88 dB A) on ANL in normal hearing and hearing impaired listeners was studied. Listeners were asked to adjust the level of the background noise to the maximum level at which they were willing to listen while following the speech, whhich was fixed at particular intensity. In second part of the same experiment, noise level was fixed at different levels (50, 60, 70, or 80 dB A). In this task listeners were made to adjust the level of the speech to the minimum, preferred, or maximum levels at which they were willing to listen to speech, at fixed level of noise. Results showed that varying presentation level either by fixed level of speech or noise did not show any change in the growth of ANL. Thus in the present study the speech was presented at speech recognition threshold and noise was presented at 30 dBA.

2.2.4. Gender.

Nebelek et al (1991) utilized female speakers to record speech. They took male and female participants and ANL was estimated on them using female voice. Results revealed that there was no significant difference between male and female groups. In this study speech recorded by female was considered but still the question remained unclear on gender related speech on ANL. Rogers, Harkrider, Burchfield, and Nabelek (2003), assessed the effect of gender on ANL utilizing male and female speech passages. Twenty-five male and 25 female participants were considered for the study. Though male group had high MCL and maximum acceptable background noise level than for those of female group for both male and female voiced speech passages, it did not reach significant difference. Hence in the present study the male voice speech passage was used to obtain ANL. Further, grouping was not made based on male and female participants.

2.2.5. Monaural v/s binaural listening condition.

Freyaldenhoven et al. (2006) assessed the ANL in 39 individuals using hearing aids monaurally or binaurally. There was no change in the ANL in binaural condition when compared to monaural condition. In some of the participants the monaural ANLs were better than the binaural condition. The possible contributions were inter-aural differences in the ANL leading to deterioration in the ANL. Hence, it was recommended to use monaural amplification in such participants. However in the present study, audibility in both ears were lessened by fitting the hearing aid and ANL was obtained from binaural listening condition.

2.2.6. Aided v/s unaided condition.

Agarwal and Manjula (2008) studied the difference in ANL in aided and unaided conditions. Participants were adults having mild, moderately severe and severe SNHL; and mixed hearing loss. The results revealed that there was no difference between unaided and aided ANL among the participants. Thus, in present study based on ANL participants were classified based on ANL. Whereas, aided ANL were estimated by changing gain and DNR in hearing aids.

2.2.7. Hearing aid users.

Nabelek, Freyaldenhoven, Tampas, Burchfield, and Muenchen, (2006) measured ANL in 191 hearing aid users who were classified into three groups such as full time users, part time users and non-users. The results of regression analysis could predict the hearing aid use with 85% accuracy. That is those individuals who used hearing aid full time were able to accept more noise than their counterparts. Hence in the present study only naïve hearing aid users are considered to assess the effect of gain and DNR on ANL values.

2.3. Preferred and prescriptive gain

It was found that real ear insertion gain from prescriptive target always deviates from patient user gain at least in some frequencies. Byrne and Tonisson, (1976) reported standard deviation of 8 dB in user gain than compared to prescriptive gain in individuals who had same hearing thresholds. For first time hearing aid users it is preferred to consider some of the factors such as age and configuration of hearing loss. Leijon, Lindkvist, Ringdahl, and Lsraelsson, (1990) compared preferred insertion gain in naive and experienced hearing aid users. It was reported that the amount of previous hearing aid use has no relation with the preferred gain. However, it was predominantly noted in clinic that naive hearing aid users prefer to use lesser gain than experienced hearing aid users. The observation made in clinic is consonance with literature reports. Byrne and Cotton (1988) who compared preferred and target gain on 44 naive hearing aid users. It was noted that three frequency average of preferred gain was less by approximately 1 dB when compared to target gain. Leijon, Eriksson, Mangold and Bech-Karlson (1984) found that older adults preferred user gain 10 to 15 dB lesser than prescriptive gain provided by NAL formula. They justified their result of lesser gain preferred by user is because of binaural fitting. In extending their previous study by involving older adults who were fitted with hearing aid in one ear, they documented 6 to 5 dB less preferred gain than compared to a NAL prescriptive gain. From the above studies of data suggests that preferred gain of the older adults falls below prescriptive target. In yet another similar study by Meenakshi and Rajalakhsmi (2006) who utilized different prescriptive formula to compare between target and preferred gain. A total of 20 individuals were considered in the study within the age range of 23 to 56 years. 10 subjects had gradual sloping (PTA=53 dB) and 11 subjects had steeply sloping hearing loss (PTA=59 dB). Real ear insertion gain was measured for prescriptive gain and preferred gain. The results revealed that the REIG was lower for preferred gain compared to prescriptive gain for 4k and 8k Hz and mean preferred gain was greater at 1kHz, 2kHz and 3kHz when they did it on DSL-i/o formula. Whereas, when they used NAL-NL1 formula they found that the REIG was increased across frequency in preferred gain than prescriptive gain. The equivocal result was noted between preferred and prescriptive gain. Thus, in the present study the deviated gain from preferred and prescribed gain was documented from study participants. This data was considered to set the appropriate gain in hearing aid to run the experiment 2.

2.4. Effect of hearing aid gain and noise level

When we look at the waveform of aided speech some amount of noise was always accumulated with it. This ambient noise generated contributed by the operation in hearing aid circuit. Therefore, hearing aid amplify signal of interest in which ambient noise generated by noise also present in it. Billing, Tremblay and Miller (2011) studied effect of hearing aid gain and resulting SNR in the ear canal on the latency and amplitude of cortical auditory evoked potentials. Nine normal hearing individuals were taken for the study. A 1 kHz tone was used in which intensity was varied in two conditions. In first condition (unaided), the absolute intensity was varied from 40 to 70 dB in step of 10 dB step size. In another condition (aided), a 40 dB signal was delivered to a hearing aid to provide the same output of absolute intensity level. This was done by changing the gain from 0 dB to 40 dB in step size of 10 dB change in gain. They recorded evoked potentials at cortical level and measured SPL generated in the ear canal. The results revealed that, the aided CAEPs were smaller and delayed relative to unaided CAEPs. It was also noted that noise level was increased linearly with increased in gain. From these findings, they proved the notion that hearing aids modify stimulus characteristics such as SNR. Thus, in the present study the gain of hearing aid was varied and obtained annoyance level from low and high ANL groups.

2.5. To account annoyance level and speech perception in noise by activating and deactivating from digital noise reduction in hearing aids

Majority of the patients complain poor speech in noise perception through the hearing aids. Aided SNR-50 may give better picture on outcome of the hearing in daily life situation. SNR 50 is the signal to noise ratio required to obtain 50% of speech reception threshold. Boymans and Dreschler (2000) measured SNR-50 on individuals with SNHL across different conditions. Target speech stimulus was delivered from 0^0azimuths and the noise was delivered from 90^0, 180^0 and 270^0. The performance was compared with the DNR on and off conditions with and without enabling the directional microphone in hearing aid. They found improvement of SNR-50 in activation of noise reduction but the significant difference was found by enabling the directional microphone with DNR ‘on’ condition than other experimental conditions. In the similar line of experiment by Alcantra, Moore, Kuhnel and Launer (2003) who evaluated the effectiveness of noise reduction in a digital multichannel compression hearing aid, eight experienced bilaterally hearing aid wearers with moderate sensorineural hearing loss were included. Two programs were enabled in the hearing aid. In one program DNR was activated and in another program DNR was deactivated. Participants were blinded regarding the program present in hearing aid. They were asked to regularly use each program for duration of three months period. Each participant was tested for speech recognition thresholds in different SNRs in 4 background noise (steady noise and noises with spectral or temporal dips) from both settings/programs in hearing aid. They found that speech recognition threshold was found to be better in DNR ‘on’ condition than compared to DNR ‘off’ condition. This infer that modern hearing aids commonly employ digital noise reduction (DNR) algorithms and this will provide improved speech understanding in noise. In addition, apart from better improvement of speech in noise, different processing strategies in hearing aid also provide relaxed listening or increased ease of listening. Mueller, Weber, and Hornsby (2006) assessed the effect of digital noise reduction (DNR) on ANL. Twenty two adults fitted with 16 channel wide dynamic range compression hearing aid were considered for the study. All the hearing aids had DNR having modulation based on wiener filter type of DNR algorithms. The ANL was assessed in DNR-on and DNR-off condition. The results obtained showed a significant reduction in ANL (4.2 dB) when DNR-on condition compared to DNR-off condition. The similar line of experiment by Agarwal and Manjula (2008) involved individuals who had different types and degrees of hearing loss, in whom the effect of DNR on ANL was studied. The performance of individuals with moderate to severe degree of SNHL or mixed hearing loss was compared between the aided condition with DNR ‘off’ and DNR ‘on’. There was a significant improvement in ANL in the DNR ‘on’ condition. Further, activating the DNR and also enabling the option of directional microphone improves the signal level. In this processing strategy accumulated noise level in amplified speech is reduced. To support the above notion Yu-Hsiang Wu and Elizabeth Stangl (2013) investigated the combined effect of DNR and directional microphone on acceptable noise level. Twenty five adults with sensorineural hearing loss participated in the study. They found that with deactivating the DNR, the ANL was increased by 1.5 dB, whereas activating the DNR, ANL reduced by 2.8 dB. In addition, activating DNR and enabling option of directional microphone reduced the ANL by 2.8 dB. They concluded, when the hearing aid was switched from linear to WDRC mode, listeners perceived a noisier sound image, whereas activating the DNR with directional microphone perceived noisiness was reduced. It is clear from literature that DNR activation reduces the annoyance level.

This section of review shed the light on DNR activation with enabling microphone improves speech recognition threshold and reduce the annoyance level by considerable amount. However there a need to know how activation of DNR along with varying gain in hearing aid effects the annoyance level and speech perception skills in low and high ANL groups.

Chapter 3

Method

A one shot post test only and single blinded randomized repeated measures with comparative research design was utilized to investigate the effect of digital noise reduction and gain on MCL (most comfortable noise), BNL (Background noise level), ANL (Acceptable noise level) and SNR 50 (Signal to noise ratio) on individuals of low and high annoyance groups.

3.1. Participant inclusion criteria

A total of twenty participants with in age range from ≥ 60 to ≤ 75 having acquired bilateral mild to severe sloping sensorineural hearing impairment were involved. Those study participants suffering from hearing loss is operationally defined as ≤ 30 dB HL at 0.25 kHz to ≤ 2 kHz and ≥ 55 to ≤ 75 dB HL from 4 kHz to 8 kHz (Pittman, & Stelmachowicz, 2003). The speech recognition score was ≥ 70 % (Dirks, & Wilson, 1969). All participants had normal middle ear status as indicated by ‘A’ type tympanogram. Each participant had adequate speech and language skills and fluent in speaking Kannada. The participants had normal cognitive scores in the mini mental status examination. None of them had previous experience with hearing aid. Further, participants had no complain of neurological, psychological, cognitive or otological problems.

3.2. Test Environment

Testing was carried out in a sound treated double room situation. The noise levels were within the permissible limits as per ANSI (S3.1; 1991).

3.3. Instrumentation

The following instruments and speech materials were used to select the participants for the study and also to collect the data from them.

1 A calibrated diagnostic two channel audiometer with head phones used to measure the hearing sensitivity and speech identification scores. Bone vibrator was utilized to obtain bone conduction thresholds. Loud speaker was employed to obtain MCL, BNL, ANL and SNR 50**.**

2 A calibrated immittance meter comprised of both tympanometry and acoustic reflexometry tests were used to evaluate the status of the middle ear.

3 Biologic Navigator pro (version 7) an auditory evoked potential instrument was used to record the auditory brainstem response (ABR) at the two repetition rates i.e., 11.1 /sec and 90.1/sec to rule out space occupying lesion.

4 Compact disk player was used to play the recorded Kannada Passage to obtain the MCL and ANL; and recorded standardized sentences to obtain SNR 50.

5 Receiver in the canal digital hearing aid having an option to switch on and off the noise reduction circuit was used.

6 Fonix 7000 hearing aid analyzer was used to obtain prescriptive and preferred gain at the ear canal level from study participants.

Speech materials

1. Phonemically balanced (PB) word lists in Kannada developed by Yathiraj and Vijayalakshmi (2005) was used, to find out the closed set speech identification score.
2. Kannada passage (Sairam & Manjula, 2002) was used to obtain MCL, BNL and ANL.
3. A standardized five lists of Kannada sentences were used to obtain SNR 50.

3.4. Stimulus preparation for SNR 50

Ten lists of standardized Kannada test developed by Geetha et, al (2014) were selected. Each sentence comprised of five target words. The root mean square (RMS) of each sentence was identified and then noise was added at desired SNR. To generate speech shaped noise MATLAB software was used. The ten sentences were concatenated and then sent through Fast Fourier Transformers (FFT). The output of spectrum was then converted back to dot wave from inverse FFT. The ten sentences were mixed with speech shaped noise at different signal to noise ratios ranging from +12 dB to -6 dB SNR in 2 dB step size.

3.5. Procedure

The following procedures were utilized to select the study participants and also to collect the data from them.

3.5.1. Participants Selection Criteria.

A. Pure tone thresholds at octave frequencies from 0.25 kHz to 8 kHz in air conduction and 0.25 kHz to 4 kHz in bone conduction was obtained using the modified Hughson and Westlake procedure (Carhart & Jerger, 1959).

B. A one list among six lists of phonetically balanced word developed by Yathiraj and Vijayalakshmi (2005) was selected and presented through headphone. Each list consists of 25 words. Each participant was asked to repeat the word heard. The correctly identified word was assigned a score of one mark and incorrect response was identified as zero. Further, the correct score was averaged and converted into percentage.

C. Tympanometry was carried out with a low probe frequency of 226 Hz and pressure rate was varied from 200/600 daPa. In addition, the ipsilateral and contralateral acoustic reflex thresholds were measured for 0.5 kHz, 1 kHz, 2 kHz and 4 kHz tones in octave frequencies by varying the intensity of stimulus in 5 dB-steps to observe changes in acoustic admittance.

D. ABR testing was carried out to rule out any space occupying lesions. Initially the electrode site were cleaned with the help of skin preparing gel. Electrodes were then placed on the three recording sites (non inverting electrode on the Cz, inverting electrode on the mastoid test ear and forehead as ground) with the conduction paste and then fixing them with the help of a surgical tape. The electrode impedance was checked and it was ensured that the impedance at each electrode site is less than or equal to 5KΩ and the inter electrode impedance should be within 2 KΩ. ABR was carried out with the click stimulus delivered through insert ear phone (ER-3 A). A 1500 sweeps of click stimulus having duration of 100 µs were presented in rarefaction polarity at the repetition rate of 11.1/ sec at 90 dBnHL. A band pass filter setting of 0.01 kHz to 3 kHz was used to capture the response with an pre-stimulus time window of -5 ms and post stimulus window of 10 ms. Those waveform having potential below the artifact rejection of ± 27 µV was averaged. The similar procedure was carried out for the repetition rate of 90.1/sec. The V peak difference from the two repetition rates should be less than 0.8 to rule out space occupying lesion.

E. Acceptable noise level (ANL) is the participant willingness to accept the background noise while listening to speech. The procedure of ANL is adopted by Nabelek, Tucker, and Letowski (1991). Each participant was seated comfortably in front of loudspeaker at a distance of one meter. To calculate ANL involves two steps i.e., obtaining the most comfortable level and the background noise level. In step 1, the standardized Kannada passage (Sairam & Manjula, 2002) was presented at the level of SRT, which was obtained at the time of audiological evaluation. The level of the Kannada passage was increased linearly and when level approximately reach the MCL then +1 Up (no response) -2 dB (response) step size was utilized to obtain the MCL. In the presence of speech passage at the MCL, the speech babble noise was presented at 30 dB HL then the level of noise was increased till the participant can able to put up with noise with no annoyance and follow the message. The level at which the individual is able to accept the background noise while listening to speech is the background noise level (BNL). The ANL was calculated by the formula MCL-BNL=ANL. This procedure was repeated twice and averaged. The score of ANL between <1 dB to ≤ 7 dB was considered as low annoyance group. However, those participants who received the ANL score ≥ 13 dB was considered as high annoyance group.

3.6. Experiment-1

A total of five participants who satisfied the participant inclusion criteria were involved. This experiment was conducted to establish the deviation of gain by subtracting the preferred gain from that of prescriptive gain as a function of frequencies (at octave frequencies from 0.25 kHz to 4 kHz).

3.6.1. Programming the hearing aid.

Hearing aid was connected to HiPro which is in turn connected to computer in which NOAH and hearing aid specific software were installed. The participant hearing threshold was entered in audiogram module. Through the hearing aid software, the hearing aid was detected. The prescriptive formula NAL-NL1 was selected to prescribe gain appropriate to the participant hearing loss. The first fitting option with acclimatization two was selected for programming the hearing aid.

3.6.2. Real ear insertion gain measurement was performed to obtain prescriptive and preferred gain.

The participant was seated at 1 meter distance from loudspeaker at 0^0 azimuth. The probe microphone of the Fonix 7000 system was inserted into the ear canal of the participant. The probe tip detached from probe unit was marked 5 mm past the end of the doom of RIC hearing aid. Later the probe tip was attached to probe unit and inserted into the ear canal till the marking of probe tube was visible at tragal notch. The levelling was done once the probe tube was inserted into the ear canal. The real ear unaided response (REUR) was measured by presenting digi speech at 65 dB SPL. The output SPL at the level of ear canal was measured at octave frequencies from 0.25 kHz to 4 kHz. Then RIC hearing aid was placed into the ear canal without changing the position of probe tube.

The real ear aided response (REAR) was measured for the digi speech at 65 dB SPL. The output SPL at the level of ear canal after placing the hearing aid at the ear canal was measured at octave frequencies from 0.25 kHz to 4 kHz. The Fonix 700 hearing aid analyzer automatically calculates the real ear insertion gain (REIG) at octave frequencies from 0.25 kHz to 8 kHz by subtracting REAR from REUR. Later, it was ensured that REIG was almost matched to the prescriptive target. The insertion gain at octave frequencies from 0.25 kHz to 4 kHz was noted down, this response is *prescriptive gain*. In addition, the ling six sounds were used to obtain the preferred gain, in which the probe tip and hearing aid was in the same position. These recorded ling six sounds were presented at 65 dB SPL at random order. Each participant was instructed to judge the loudness and clarity of these sounds informally and asked to report the same. Depending on the participant's response the gain with respect to the spectrum of each sound was programmed. Further, the REIG obtained for the *preferred gain* set in individual's hearing aid at octave frequencies from 0.25 kHz to 4 kHz were documented.

3.7. Experiment-2

In Experiment 2, a total of twenty participants who satisfied the criteria in the subject selection criteria were involved. Based on ANL scores two groups were made. In *low annoyance group*, eight participants received score less than 7. In *high annoyance group* twelve participants secured score of greater than 13. The MCL, BNL and ANL of each participant from two groups are tabulated in Table-1. The data of aided ANL and aided SNR 50 were obtained from each participant of low and high annoyance groups who are fitted with binaural RIC hearing aids. The procedure of ANL was explained earlier. However, procedure of SNR 50 is given below.

Table 3.1. *Averaged response of each component of ANL obtained from participants of two groups*

Groups →	*Low annoyance group*			*High annoyance group*		
Parameters →	*MCL*	*BNL*	*ANL*	*MCL*	*BNL*	*ANL*
	59	53	6	64	47	17
	62	57	5	77	60	17
	56	49	7	74	48	26
	53	48	5	60	43	17
	44	40	4	56	39	17
	50	43	7	56	38	18
	54	51	3	61	34	27
	59	52	7	62	39	23
				47	33	14
				64	50	14
				62	47	15
				69	53	16
Mean (SD)	54.62 (5.75)	49.12(5.48)	5.5 (1.21)	62.66(8.10)	44.25(8.05)	18.41 (4.44)
Range			3-7			14-27
Intra-class correlation			0.98			0.96

3.7.1. SNR 50.

Ten sentences embedded at different SNRs were randomized. Each sentence was presented bilaterally at the MCL. The participant was instructed to repeat the sentence heard. The SNR level at which the testing started (L) and number of recognized target words in each sentence was noted down. The total number of target words from all sentences were added (T). In addition, the total number of words per decrement (W) and SNR decrement step size in each sentence (d) was noted down. The obtained values was substituted to the given equation adapted by Spearman-Karber to determine SNR 50 % (Finney, 1952). The below equation is used to calculate the SNR 50.

$$\textbf{50 \% point} = L + (0.5*d) - d\,(T)/\,W$$

3.8. Listening condition

The receiver in the canal hearing aid was programmed according to the prescriptive gain, where the gain in the hearing aid was almost matched to prescriptive target (Gain 1) and digital noise reduction circuit was switched off. An aided ANL and SNR 50 were obtained from each study participant. The procedure was repeated by decreasing the gain in the hearing aid for G2 and G3 conditions.

1. G 2 : -3dB below the target gain
2. G 3 : -5 dB below the target gain / 2 dB gain below G2.

The entire procedure was repeated by activating the digital noise reduction circuit in the hearing aid. Further, in each participant the experimental conditions were single blinded and randomized. That is none of the study participants was unaware of the experimental conditions.

Statistical analyses

1. Descriptive statistics was carried out to determine the mean and standard deviation of MCL, BNL, ANL and SNR50 in DNR 'on' and "off" conditions at different gains from low and high annoyance groups.
2. A two way repeated measures [DNR 'on' and 'off' conditions; and 3 gain conditions (prescriptive, -3 ,-5) with between subject factor as groups was conducted on each dependent variable to determine the effect of DNR and gain from low and high annoyance groups.
3. Paired samples t tests were performed as a post hoc to see in which gain or in DNR caused significant difference in each dependent variable.
4. MANOVA was done to know the significant difference between groups in each experimental condition.

Chapter 4

Results

The aim of the first experiment was to investigate the amount of deviation of gain across frequencies between preferred and prescriptive gain. The data of preferred and prescriptive gain was descriptively analyzed at each frequency. The second experiment was taken up to investigate the effect of digital noise reduction and gain in hearing aid on MCL (Most comfortable level), BNL (Background noise level), ANL (Acceptable noise level) and SNR 50 (Speech to noise ratio 50) in low and high annoyance groups. The data of MCL, BNL, ANL and SNR 50 in DNR 'on' and 'off' conditions at different gains (prescriptive gain, -3dB gain, -5dB gain) from two groups were subjected to statistical analyses. The Statistical Package for Social Sciences (SPSS) software (version 17) was utilized to carry out the statistical analyses. The analyses performed under each objective are reported. Before performing inferential statistical analyses we conducted Kolmogorov-Smirnov normality test and Levene's homogeneity test for the data of experiment-2. The result revealed the data of each experimental condition is normally distributed ($p>0.05$) and homogenous between groups ($F<2$).

4.1. Experiment -1

4.1.1. To compare between preferred and prescriptive gain in study participants.

Descriptive analysis was performed for target gain and user gain from frequencies 0.5 kHz to 4 kHz (in octaves) . Over all mean scores of preferred gain was lesser than compared to prescriptive gain when real ear insertion gain was measured. At 0.5 kHz and 2 kHz the amount of gain deviates were relatively less than compared to other two frequencies 1 kHz and 4 kHz (Figure -1). At 0.5 kHz the gain deviates with in range of 0 to 6 dB. Where as at 1 kHz the difference between user gain and target gain range between 6 to 12 dB. At 2 kHz and 4 kHz the deviation between preferred and prescriptive target gain found to have a range of 0 to 9 dB and 10 to 17 dB, respectively.

Table 4.1. *The preferred and prescribed gain in in octaves frequencies (0.5 kHz to 4 kHz) from five participants*

	Prescriptive gain (dB)				*Preferred gain (dB)*				*Difference (dB)*			
Frequency (kHz)	*0.5*	*1*	*2*	*4*	*0.5*	*1*	*2*	*4*	*0.5*	*1*	*2*	*4*
Subjects												
1	16	29	30	24	15	17	30	14	1	12	0	10
2	11	21	20	21	8	11	16	3	3	10	4	17
3	3	11	30	21	3	5	24	10	0	6	6	11
4	10	22	30	23	6	12	21	18	4	10	9	15
5	6	13	20	21	0	9	14	9	6	4	6	12

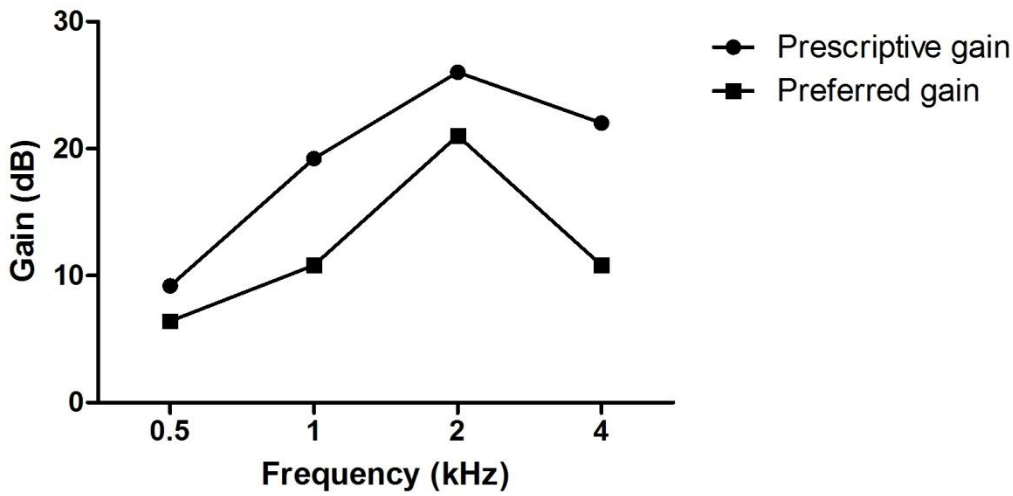

Figure-4.1. Representing average prescriptive and preferred gains as a function of frequencies from 0.5 to 4 kHz in octaves.

4.2. Experiment -2

4.2.1. To compare MCL between DNR 'on' and 'off' conditions at each gain from two groups of study participants.

The mean MCL and standard deviation from two groups of participants were tested under digital noise reduction (DNR) 'on' and 'off' conditions at 3 different gains (prescriptive gain, -3 dB and -5 dB) are tabulated in Table -2. In low annoyance group the mean MCL was reduced in DNR 'off' condition than compared to DNR 'on' condition at prescriptive gain and -5 dB gain. Whereas, at -3 dB gain MCL was reduced in DNR 'on' condition than compared to DNR 'off' condition. Besides, in high annoyance group, the MCL was reduced in DNR 'on' condition than compared to DNR 'off' condition at -3 dB gain and -5 dB gain. However, at prescriptive gain the MCL reduced in DNR ‘off’ condition than compared to DNR ‘on’ condition. It was also observed that in both low and high annoyance groups, the value of MCL at -3 dB gain was decreased compared to -5 dB gain and prescriptive gain, whereas, at -5 dB gain the MCL was increased compared to -3 dB gain and prescriptive gain, when the DNR was activated in hearing aid. From both groups, in DNR ‘off’ condition, the MCL increased with reduced gain. In addition, the MCL was higher in high annoyance group than compared to low annoyance group in both DNR on and off conditions at each gain.

Table- 4.2. *Mean and standard deviation of MCL at each gain for DNR ‘on’ and ‘off’ conditions obtained from two groups of study participants.*

Conditions →	*DNR ‘on’*						*DNR ‘off’*					
Gain →	*Prescriptive gain*		*-3dB gain*		*-5dB gain*		*Prescriptive gain*		*-3 dB gain*		*-5 dB gain*	
Groups ↓	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Low annoyance (N=8)	37.10	8.62	36.10	11.12	40.37	14.13	36.20	12.21	36.50	10.28	40.00	11.33
High annoyance (N=12)	48.00	11.75	47.75	6.53	51.01	11.23	46.00	2.90	49.50	9.95	54.58	7.14

To evaluate the effect of DNR and gain on MCL from two groups, a two way repeated measures ANOVA [DNR ‘on’ and ‘off’ conditions; and three gains (prescriptive, -3,-5) with between subject factor as groups (low and high annoyance) was carried out. The result revealed a significant main effect of gain [$F(2, 36) = 10.37$, $P = 0.000$], such that value of MCL increased with reduced gain. In addition, a significant main effect of group [$F(1, 18) = 409.70$, $P = 0.000$] was observed in which the MCL reduced in low annoyance group than compared to high annoyance group. Further, interaction effects were found to have no significant difference. Since, there was no difference in MCL between DNR ‘on’ and ‘off’ conditions, the data were combined and compared between gains in each group.

In addition, to evaluate the gain (Figure-2) at which caused significant difference in MCL, a post hoc analysis was conducted using paired samples t-test with corrected mean to control type I error. This was done in each group. Three paired samples t test were conducted separately in two groups to see the effect of gain on MCL. Thus, the alpha value yielded 0.016 instead of 0.05. In low annoyance group, though the mean MCL increased with reduced gains the result of paired samples t tests were revealed no significant difference between gains. However, in high annoyance group, it was noted that MCL was significantly increased at -5 dB gain than compared to prescriptive gain ($t(23) = -4.10$, $p = 0.000$) and at -3 dB gain, respectively ($t(23) = -3.02$, $p = 0.006$). Although the MCL increased at -3 dB gain than compared to prescriptive gain, it did not reach significant.

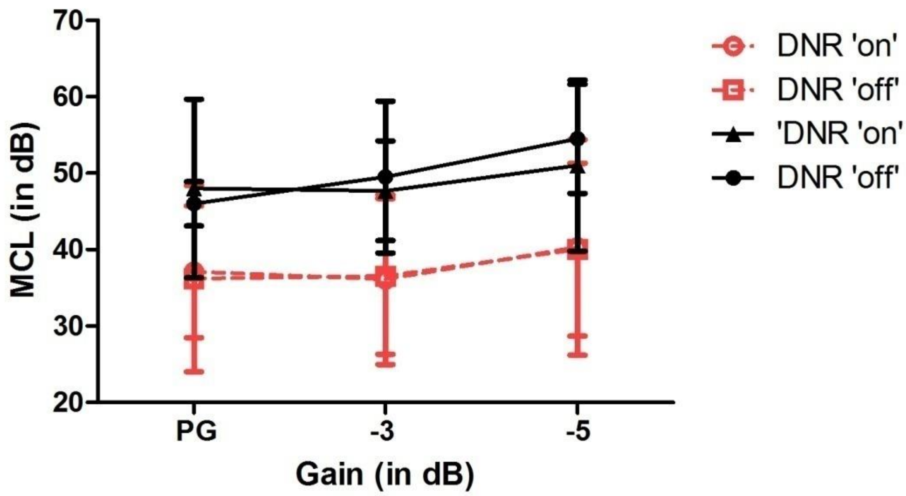

Figure-4.2. Representing most comfortable level as a function of gain. Red circle and square with dotted line represents MCL obtained from low annoyance group from DNR on and off conditions respectively. Filled trigangle and circle with solid line represents MCL obtained form high annoyance group from DNR on and off conditions respectively.

Further, to determine the groups in which caused significant difference in MCL at different gains, a MANOVA was conducted. The result of MANOVA showed that there was a significant difference between groups at prescriptive gain [F (1, 38) =9.78, P=0.03], -3 dB gain [F (1, 38) =17.35, P=0.000] and -5 dB gain [F (1, 38) =10.49, P=0.001], such that the MCL reduced in low annoyance group than compared to high annoyance group.

4.2.2. To compare BNL between DNR 'on' and 'off' conditions at each gain from two groups of study participants.

The mean BNL and standard deviation from two groups of participants in DNR 'on' and 'off' conditions at 3 different gains (prescriptive gain, -3 dB and -5 dB) are tabulated in Table -3. In both low and high annoyance groups, the BNL was increased with decrease in gain in each DNR 'on' and 'off' condition. It was also observed that the BNL was higher in DNR 'on' condition than compared to DNR 'off' condition at each gain in both high and low annoyance groups. In addition, the BNL was higher in low annoyance group than compared to high annoyance group at each gain in both DNR 'on' and 'off' conditions.

Table-4. 3. *Mean and standard deviation of BNL at each gain for DNR 'on' and 'off' conditions obtained from two groups of study participants.*

Condition →	*DNR 'on'*						*DNR 'off'*					
Gain →	*Prescriptive gain*		*-3dB gain*		*-5dB gain*		*Prescriptive gain*		*-3 dB gain*		*-5 dB gain*	
Groups ↓	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Low annoyance (N=8)	31.60	8.53	33.50	10.71	34.5	13.60	29.75	12.39	32.00	10.47	33.75	11.9
High annoyance (N= 12)	30.90	13.51	31.70	7.90	34.25	13.16	28.58	10.13	31.20	10.27	34.15	6.98

To evaluate the effect of DNR and gain on BNL from two groups, a two way repeated measure ANOVA [DNR ‘on’ and ‘off’ conditions; and 3 gain conditions (prescriptive, -3 ,-5) with between subject factor as groups (low and high annoyance) was carried out. The result revealed a significant main effect of gain [F (2, 36) = 5.00, P= 0.012], such that increased BNL was observed with reduced gain. In addition, main effect of group on BNL was found significant [F (1, 18) = 10.37, P= 0.05], in which higher BNL was seen in low annoyance group than compared to high annoyance group. Further, it was noted that there were no significant interaction effects. The data of BNL between DNR ‘on’ and ‘off’ conditions were combined to see in which gain caused significant in each group.

To further evaluate the gain (Figure-3) at which caused significant difference in BNL, a post hoc analysis was conducted using paired samples t-test with corrected mean to control type I error (0.016 instead of 0.05). Three paired samples t test were separately conducted for the two groups to see the effect of gain in BNL. In low annoyance group, the result of paired samples t tests revealed that at -5 dB gain the BNL were significantly increased compared to prescriptive gain (t (15) = -3.75, p = 0.002) and at -3 dB gain (t (15) = -3.66, p = 0.002). In addition, the value of BNL significantly increased at -3 dB gain than compared to prescriptive gain (t (15) = 3.02, p=0.009). In high annoyance group, it was noted that BNL was significantly increased at -5 dB gain than compared to -3 dB gain (t (15) = -3.75, p = 0.002) and prescriptive gain (t (15) = -3.75, p = 0.002), respectively. Though, increased BNL was noted at -3 dB gain than compared to prescriptive gain, this difference did not reach significant.

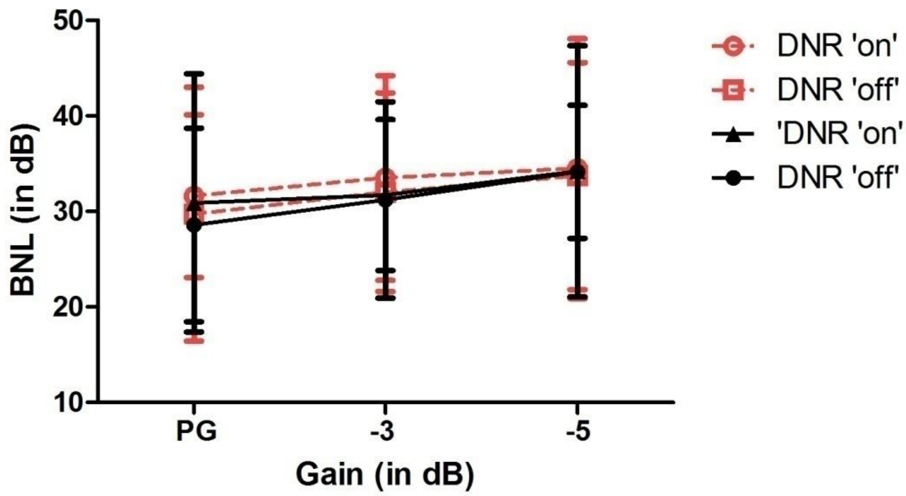

Figure-4.3. Representing background noise level as a function of gain. Red circle and square with dotted line represents BNL obtained from low annoyance group from DNR on and off conditions respectively. Filled trigangle and circle with solid line represents BNL obtained form high annoyance group from DNR on and off conditions respectively.

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Further, to determine the groups in which caused significant difference in BNL at different gains, a MANOVA was conducted. The results of MANOVA showed that there was no significant difference between groups such that the BNL was higher in low annoyance group than compared to high annoyance group, in each gain.

4.2.3. To compare ANL between DNR 'on' and 'off' conditions at each gain from two groups of study participants.

The mean ANL and standard deviation calculated for two groups under DNR 'on' and 'off' conditions at three different gains are tabulated in Table -4. In both low and high annoyance group, the ANL was decreased at each gain in DNR 'on' condition than compared to DNR 'off' condition. It was noted that each group, the ANL was decreased at -3 dB gain compared to prescriptive gain, whereas, the ANL was increased at -5 dB gain compared to -3 dB gain and prescriptive gain, in both conditions.

Table- 4.4. *Mean and standard deviation of ANL at each gain for DNR 'on' and 'off' conditions obtained from two groups of study participants.*

Condition →	*DNR 'on'*						*DNR 'off'*					
Gain →	*Prescriptive gain*		*-3dB gain*		*-5dB gain*		*Prescriptive gain*		*-3 dB gain*		*-5 dB gain*	
Groups ↓	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Low annoyance (N=8)	5.51	2.00	2.60	1.40	5.87	0.99	6.25	0.75	4.50	1.19	6.50	0.88
High annoyance (N=12)	17.21	4.90	13.41	2.20	19.81	5.30	17.41	4.46	14.71	2.63	23.30	5.10

To evaluate the effect of DNR and gain on ANL from two groups, a two way repeated measures ANOVA [DNR 'on' and 'off' conditions; and 3 gain conditions (prescriptive, -3 ,-5) with between subject factor as groups (low and high annoyance) was performed. The result revealed that there was a significant main effect of DNR [F (1, 18)

= 6.10, P= 0.024], such that ANL was reduced in 'on' condition than compared to DNR 'off' condition. In addition, a main effect of gain [F (1, 18) = 25.299, P= 0.000] was observed in which at -3 dB gain the ANL was relatively less than compared to prescriptive gain and -5 dB gain. In addition, main effect of group was noted [F (1, 18) = 124.02, P= 0.000] in which as expected ANL value was lower in low annoyance group than compared to high annoyance group. Further, no significant interaction effects were noted on ANL.

Though interaction effect of DNR* gain was not noted, a significant main effect was observed in DNR and as well as in gain on ANL. Thus, to evaluate ANL between DNR conditions at each gain, in both groups, a post hoc analysis was conducted using paired samples t-test with corrected mean to control type I error. Three paired samples t test were separately conducted for the two groups to see the effect of DNR on ANL, at each gain. In each group, the result revealed that though the ANL was lesser in DNR 'on' condition compared to that of DNR 'off' condition at each gain, this difference did not reach significant.

In addition, the effect of gain on ANL (Figure -4) was evaluated in each condition from both groups. Four sets of three paired samples t test were separately conducted to see the effect of gain in each condition ('on' and 'off') for the two groups. In low annoyance group, the result of paired samples t tests revealed that in DNR 'on' condition, there were no significant differences between gains. However, in DNR 'off' condition a significant differences were noted between prescriptive gain and -3 dB gain (t (7) = 3.52, p=0.010); and -3 dB gain and -5 dB gain (t (7) = -4.24, p=0.004), such that ANL was reduced at -3 dB gain compared to that of prescriptive gain and -5 dB gain, respectively. In high annoyance group, significant differences were observed between prescriptive gain and – 5 dB gain in DNR 'on' condition (t (11) = -3.71, p=0.003) and DNR off condition (t (7) = -4.38, p=0.001), such that ANL was reduced in perceptive gain than compared to -5 dB gain. Similarly, the ANL was reduced at -3 dB gain than compared to -5 dB gain, which was found to be significant in DNR on condition (t (7) = -4.38, p=0.001) and DNR off condition (t (7) = -5.99, p=0.000). It was noted that there was no significant difference between prescriptive gain and -3 dB gain on ANL, in each condition.

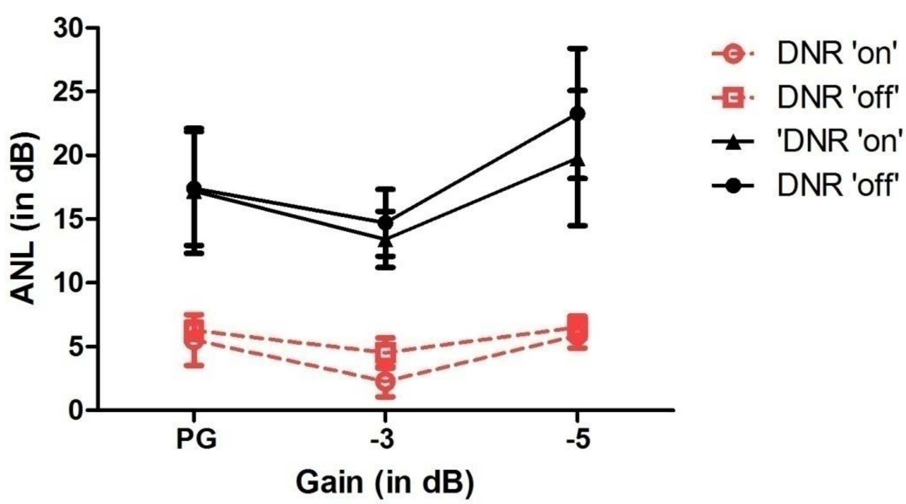

Figure -4.4. Representing ANL as a function of gain. Red circle and square with dotted line represents ANL obtained from low annoyance group from DNR on and off conditions respectively. Filled trigangle and circle with solid line represents ANL obtained form high annoyance group from DNR on and off conditions respectively.

4.2.4. To compare SNR 50 between DNR 'on' and 'off' conditions at each gain from two groups of study participants.

The mean and standard deviation of SNR 50 from two groups of participants tested under digital noise reduction (DNR) 'on' and 'off' conditions at three different gains (prescriptive gain, -3 dB and -5 dB) are tabulated in Table - 5. In both low and high annoyance groups, the SNR 50 was decreased at -3 dB gain compared to prescriptive gain, whereas, the SNR 50 was increased at -5 dB gain compared to -3 dB gain and prescriptive gain, when the DNR was 'on' in hearing aid. In DNR 'off' condition also it followed the same pattern. It was also observed that the mean SNR 50 was decreased in DNR 'on' condition compared to SNR 50 'off' condition, at each gain. This was true in both groups. In addition, the SNR 50 was lesser in low annoyance group than compared to high annoyance group at each gain in both conditions.

Table- 4.5. *Mean and standard deviation of SNR 50 for DNR 'on' and 'off' conditions at each gain obtained from two groups of study participants.*

Conditions →	*DNR 'on'*						*DNR 'off'*					
Gain →	*Prescriptive gain*		*-3dB gain*		*-5dB gain*		*Prescriptive gain*		*-3 dB gain*		*-5 dB gain*	
Groups ↓	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Low annoyance (N=8)	4.37	1.24	2.50	0.72	5.06	2.02	4.50	1.37	3.37	0.87	5.87	1.18
High annoyance (N=12)	5.50	2.74	4.50	2.51	6.16	2.98	6.20	2.47	5.60	1.55	7.12	2.44

To evaluate the effect of DNR and gain on SNR50 from two groups, a two way repeated measures ANOVA [DNR 'on' and 'off' conditions; and 3 gain (prescriptive, -3 dB gain, and -5 dB gain) with between subject factor as groups (low and high annoyance) was conducted. The result revealed a significant main effect of DNR [F (1, 18) = 11.80, P= 0.003] in which SNR 50 was reduced in 'on' condition than compared to 'off' condition. The main effect of gain was found significant [F (2, 36) = 23.97, P= 0.000] in which no tread was observed in SNR 50. In addition, main effect of group [F (1, 18) = 10.89, P= 0.004] was noted, such that SNR 50 was lesser in low annoyance group than compared to high annoyance group. Further, no interaction effects were found on SNR 50.

Though interaction effect of DNR* gain was not noted, a significant main effect was observed in DNR and as well as in gain on SNR 50. To further evaluate the SNR 50 between conditions at each gain in both groups, a post hoc analysis was conducted using paired samples t-test with corrected mean to control type I error. Three paired samples t test were separately conducted for the two groups to see the effect of DNR in SNR 50 at each gain. In both groups SNR 50 reduced in DNR 'on' condition than compared to 'off' condition at each gain, but this difference found significant at -5 dB gain (t (11) = -3.96, p = 0.002), in high annoyance group.

In addition, the effect of gain on SNR 50 (Figure-5) was evaluated in each condition from both groups. Four sets of three paired samples t test were separately conducted to see the effect of gain on SNR 50 for the two groups, in each condition (‘on’ and ‘off’). In low annoyance group, when the DNR was ‘on’ the SNR 50 was significantly reduced in -3 dB gain than compared to prescriptive gain (t (7) = 3.39, p = 0.010); and -5 dB gain (t (7) = -3.03, p = 0.013). In DNR ‘off’ condition, the SNR 50 was significantly reduced in -3 dB gain than compared to - 5 dB gain (t (7) = -4.67, p = 0.000). In addition, the SNR 50 was significantly reduced in prescriptive gain than compared to - 5 dB gain (t (7) = -3.59, p = 0.000). Further, in high annoyance group, SNR 50 was significantly reduced in -3 dB than compared to -5 dB in both DNR ‘on’ condition (t (11) = -3.76, p=0.000) and in ‘off’ condition (t (11) = -3 , p = 0.010). At prescriptive gain the SNR 50 reduced significantly than compared to – 5 dB gain in DNR ‘off’ condition (t (11) = -4.21, p = 0.001).

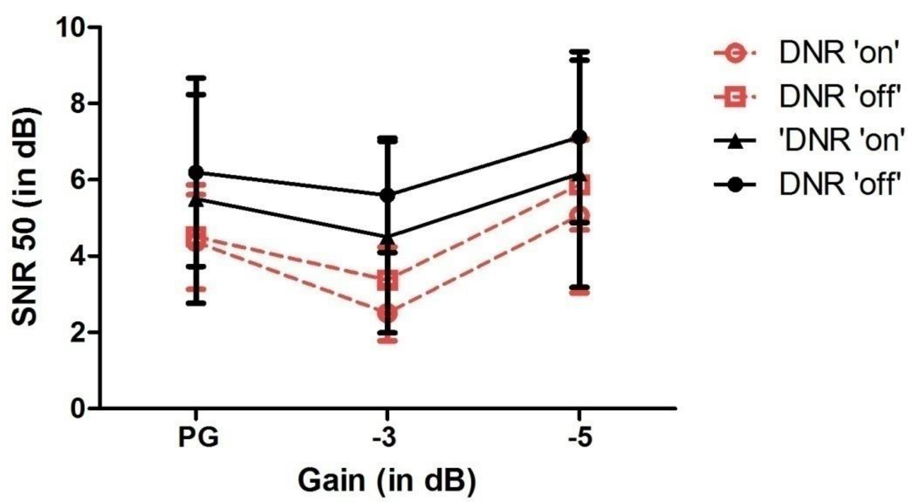

Figure -4.5. Representing SNR 50 as a function of gain. Red circle and square with dotted line represents SNR 50 obtained from low annoyance group from DNR on and off conditions respectively. Filled trigangle and circle with solid line represents SNR 50 obtained form high annoyance group from DNR on and off conditions respectively.

It was noted earlier that main effect of group on SNR 50 was observed. In order to know specifically under which experimental conditions caused significant difference between groups, a MANOVA was conducted. The result of MANOVA showed (Table - 6) that SNR 50 was significantly reduced in low annoyance group than compared to high annoyance group at -3 dB gain in both DNR 'on' and 'off' conditions.

Table 4.6. *MANOVA F ratio and p value for the SNR 50 obtained from two groups of study participants in each condition (DNR 'on' and 'off') at different gains (prescriptive gain, -3dB gain, -5dB gain).*

DNR 'on' Condition		
	F ratio	*P value*
Prescriptive gain	1.256	0.277
-3 dB gain	4.608	0.046
-5 dB SNR	0.830	0.374
DNR 'off' condition		
	F ratio	*P value*
Prescriptive gain	3.211	0.090
-3 dB gain	13.695	0.002
-5 dB gain	1.790	0.198

Chapter 5

Discussion

The purpose of the present study was to investigate the effect of gain and digital noise reduction on annoyance level and SNR 50 from low and high annoyance groups. The prescriptive gain was reduced from default setting by 3 dB and 5 dB, respectively. In addition, these gains were varied in activated and deactivated DNR conditions. The findings of the present study were discussed under the following objectives.

5.1. Experiment -1

In the present study, the real ear insertion gain measurement was performed. The mean scores of preferred gain was lesser compared to prescriptive gain at each frequency: This could be because that all the participants are naive hearing aid users and wore hearing aids on both ears. The results is in consonance with the research report of Leijon, Eriksson, Mangold and Bech - Karlson (1984), who found naive hearing aid older adult users preferred user gain of 10 to 15 dB lesser than prescriptive gain provided by NAL formula. In addition, while setting the user gain six ling's sounds and questions in Kannada language were used. However, to derive NAL NL-1 fitting formula, a component of normalization of speech was performed using English language speech sample. This discrepancy might have caused the deviation of around 5 to 15 dB gain between preferred and prescriptive gains. Our speculation is supported by study done by

Nisha and Manjula (2013) who found that the test done on Kannada language listeners needs lesser gain compared to the Indian English listeners. Further, they reported that lesser gain in low and mid frequencies were found compared to high frequencies due to frequent occurrence of vowels than consonants in Kannada language.

5.2. Experiment-2

5.2.1. Most comfortable noise level

Most comfortable level was compared between DNR 'on' and 'off' conditions at three different gains from two groups. The result revealed that MCL was decreased in DNR 'off' condition then compared to DNR 'on' condition at prescriptive gain and -5 dB. But in -3 dB gain, MCL was found to decrease in DNR 'on' condition than compared to DNR 'off' condition. However, these differences were failed to reach significant. This is because the participants on whom the effect of DNR was evaluated are naive hearing aid users. It appears to infer that amplified speech delivered from DNR activated or deactivated conditions would be same. This is because lack of experience towards distinguishing perceived residual noisiness in the amplified speech. Thus, this study shed light to sought another research question whether experienced hearing aid users can able to distinguish the perceived residual noisiness to adjust their MCL.

In addition, MCL was compared with respect to variation of gains from each group. The result revealed that mean MCL increased with decreased gain, this was true in each annoyance group. This is due to decrease in the audibility of speech with reducing gain from default prescriptive gain, such that from irrespective of group the participants asked higher intensity to reach their most comfortable level. Further, MCL was compared between low and high annoyance groups. The results revealed that MCL score in each gain reduced in low annoyance group than compared to high annoyance group. The results of the study are in consonance with the research report of Harkrider and Smith, (2005), who reported stronger afferent mechanism in low annoyance group; this mechanism could be sensitive enough to reach their MCL at lower intensity. Whereas, in high annoyance group due to their weaker afferent system the participants asked for higher intensity to reach their MCL.

5.2.2. Background noise level

When BNL was compared in terms of gain, in low annoyance group, the result revealed that at -5 dB gain the BNL were significantly increased compared to prescriptive gain and at -3 dB gain. In addition, the BNL significantly increased at -3 dB gain than compared to prescriptive gain. In high annoyance group, the BNL was significantly increased at -5 dB gain than compared to -3 dB gain and prescriptive gain. Further, BNL was increased at -3 dB gain than compared to prescriptive gain, but not signif icant. To conclude**,** in both low and high annoyance groups, the BNL was increased with decrease in gain in each DNR ‘on’ and ‘off’ condition. As expected the reason could be because of reduced audibility with reduction in gain. In addition, BNL was higher in DNR ‘on’ condition at each gain in both high and low annoyance groups. It was speculated that perceived annoyance and aversiveness towards noise decreases in amplified speech processed by DNR ‘on’ condition than DNR ‘off’ condition.

In addition, the residual noise in amplified speech was heard louder in DNR deactivated condition than compared to DNR deactivated. Palmer, Bentler and Mueller (2006) reported that perceived annoyance is influenced by audibility of noise. Thus, activation of DNR appears to have had a positive impact on the annoyance perception. Further, BNL was higher in low annoyance group than compared to high annoyance group in both DNR ‘on’ and ‘off’ conditions. The results of the study are in consonance with the research report of Harkrider and Smith (2005), who reported weaker efferent mechanism in high annoyance group, which reduced the capacity of inhibition. Thus, participants of high annoyance group are unable to put up more noise. This mechanism is conversely true in low annoyance group.

5.2.3. Acceptable noise level

Acceptable noise level decreased in DNR ‘on’ condition than compared to DNR ‘off’ condition. The results of the present study is in accordance to the research report of Mueller, Weber, and Hornsby (2006) who showed a significant reduction in ANL (4.2 dB) when DNR was in ‘on’ condition than compared to DNR-off condition. In addition perceived noisiness in amplified speech reduces in DNR activated condition (Lowery & Plyler, 2013). When DNR was activated the gain provided to noise accumulated in speech was reduced. First the speech and noise is going to be segregated based on modulation depth, such that acoustical property of noise has lesser amplitude variation to which gain assigned was lesser to the noise accumulated frequencies. Whereas, amplitude of speech signal vary across frequencies, in which the gain was assigned based on prescriptive formula. Thus, participants of present study tend to accept more annoyance in DNR 'on' condition than compared to that DNR 'off' condition.

In addition, when annoyance level was compared as a function of gain, it was noted that ANL was decreased at -3 dB gain compared to prescriptive gain. This result was found to be similar irrespective of groups in DNR activated or deactivated conditions. This is because during the operation of electronic circuit in hearing aid at times to amplify speech some amount of residual noise eventually generates. Thus, hearing aid modifies stimulus characteristics such as signal to noise ratios. But when gain of the hearing aid reduced the amount of residual noise generated decreases. This notion is supported by the research study of Billing, Tremblay and Miller (2011) who measured SNR of amplified speech at the ear-canal. They found that when gain in the hearing aid reduced the noise level was also decreased. Thus in the present study, annoyance level was reduced by reducing the gain in the hearing aid. Whereas, annoyance level was increased in -3 dB gain compared to that of -5 dB in both DNR 'on' and 'off' condition. This might be due to the audibility factor such that participants tend to accept more background noise and their MCL increased in – 5 dB gain than compared to -3 dB gain.

The ANL values remained within seven in low ANL group, whereas, the value in high ANL group remained greater than 13 irrespective of DNR activated or deactivated conditions with varying in gain. It appear to indicate that acceptance of noise is centrally driven. Even with advance in technology annoyance level was not reduced significantly. Further, the data has to be analyzed to accurately say how much the growth of annoyance reduced particularly in high and low annoyance group when DNR was activated in hearing aid at varied gain.

5.2.4. SNR-50

SNR-50 decreased in DNR 'on' condition than compared to DNR 'off' condition. This data suggest that DNR activation in hearing aid processing is capable of providing improved sound quality, for speech in noise. Thus, participants tend to obtain 50 % speech recognition at lesser signal to noise ratio in DNR 'on' condition. The results of the present study is supported by research study of Pittman (2013) who reported that modern DNR circuits can improve the signal to noise ratio (SNR) by up to 6 dB. In addition, SNR-50 reduced with decrease in the -3 dB gain compared to prescriptive gain. This is because the ambient noise level reduced with decreased gain in the hearing aid. Due to this the speech perception improved in presence of noise, such that 50 % speech recognition score obtained at lesser signal to noise ratio in- 3 dB gain than compared to prescriptive gain. However, in – 5 dB gain SNR 50 was increased compared to -3 dB gain and prescriptive gain. This could be due to reduced audibility in – 5 dB gain. Further, SNR-50 was better in low annoyance group than compared to high annoyance group, irrespective of experimental condition. This is due to stronger efferent mechanism in low ANL group, such that mechanism of inhibition withstands noise while listening to speech. Thus, low ANL group tend to have 50 % recognition scores at lesser signal to noise ratio than compared to high ANL group.

To conclude, in clinic it is observed that hearing impaired individuals expect that there should not be noise while listening to amplified speech. It is almost responsibility of clinician to counsel the patient regarding perceive noisiness in amplified speech to reduce the amount of rejecting hearing aid. It is preferred to first classify the hearing impaired individuals based on annoyance and then need to explain the effect of DNR activated condition in hearing aid on annoyance level and speech perception skills. Thus *null hypothesis is rejected*, as in current study annoyance level was reduced and SNR 50 reduced with decreasing the gain by 3 dB from prescriptive gain. Further, annoyance and speech perception in noise improved in DNR activated condition.

Chapter 6

Summary and Conclusion

The aim of study was to investigate the effect of digital noise reduction and gain on annoyance level and SNR -50 by low and high annoyance groups. Inorder to prove the aim of the study the following objectives were formulated. a) Effect of DNR and gain on MCL, BNL, ANL and SNR 50 from within and between low and high annoyance groups. b) Combined effect of DNR and gain on MCL, BNL, ANL and SNR 50 from within and between low and high annoyance groups.

The study was carried out in two experiments. In experiment- 1, deviation of gain from user and prescriptive gain was established from five particpants. In experiment-2, one shot post comparative with repeated measures research design was utilized. Twenty participants were involved in which eight individuals were in low annoyance group and twelve individuals were in high annoyance group. Each individual was measured for unaided acceptable noise level and SNR-50 in activating and deactivating DNR by varying gain (prescriptive, -3 dB, -5 dB).

Summary of the present study result are as follows.

Most comfortable level

- MCL was decreased in DNR ‘off’ condition then compared to DNR ‘on’ condition at prescriptive gain and -5 dB. But in -3 dB gain MCL was decreased in DNR ‘on’ condition than compared to DNR ‘off’. In both groups, MCL was decreased at -3 dB compared to -5 dB and prescriptive gain. However, this difference did not reach significant.

- When MCL was compared with respect to gain, in low annoyance group, mean MCL increased with decreased gain. In high annoyance group, mean MCL increased at -5 dB than compared to prescriptive gain and -3 dB. Inaddition, MCL increased at – 3 dB than compared to prescriptive gain.
- Further, when comparison is done between groups MCL found to be significantly decreased in low annoyance group than compared to high annoyance group.

Background noise level

- The BNL was increased with decreased gain in each DNR 'on' and 'off' condition for both groups. BNL was higher in DNR 'on' condition at each gain for both high and low annoyance groups.
- When BNL was compared in terms of gain, the result revealed that at -5 dB gain the BNL were significantly increased compared to prescriptive gain and at -3 dB gain for low annoyance group. In addition, the BNL significantly increased at -3 dB gain than compared to prescriptive gain. Whereas, for high annoyance group, the BNL was significantly increased at -5 dB gain than compared to -3 dB gain and prescriptive gain. BNL was increased at -3 dB gain than compared to prescriptive gain, but this failed to reach significant.
- BNL was higher in low annoyance group than compared to high annoyance group for both DNR 'on' and 'off' conditions.

Acceptable noise level.

- ANL was decreased at -3 dB gain compared to prescriptive gain and increased at -5 dB gain compared to -3 dB gain and prescriptive gain, in both DNR 'on' and 'off' conditions.
- ANL was reduced in DNR 'on' condition than compared to DNR 'off' condition but this difference failed to reach significant.
- Further, ANL was compared as a function of gain for low annoyance group. At -3 dB ANL was reduced compared to prescriptive and -5 dB. These difference in ANL by variation in gain did not reach significant difference. But in DNR 'off' condition there was significant difference between prescriptive gain and -3 dB gain, and also between -3 dB gain and -5 dB gain. In high annoyance group, ANL was significantly increased in -5 dB gain than prescriptive gain. However, at -3 dB ANL value reduced than compared to -5 dB gain which was found to be significant.
- ANL value was lower in low annoyance group than compared to high annoyance group.

Speech in noise -50

- In DNR on and off conditions in hearing aid, SNR 50 was decreased at -3 dB gain compared to prescriptive gain, whereas, the SNR 50 was increased at -5 dB gain compared to -3 dB gain and prescriptive gain. This was true for both groups.
- SNR 50 was lesser in low annoyance group than compared to high annoyance group at each gain in both conditions.

- In low annoyance group, when the DNR was ‘on’ the SNR 50 was significantly reduced in -3 dB gain than compared to prescriptive gain and -5 dB gain. Whereas, in DNR ‘off’ condition, the SNR 50 was significantly reduced in -3 dB gain than compared to - 5 dB gain. In addition, the SNR 50 was significantly reduced in prescriptive gain than compared to - 5 dB gain.
- In high annoyance group, SNR 50 was significantly reduced in -3 dB than compared to -5 dB in both DNR ‘on’ condition and in ‘off’ condition. At prescriptive gain the SNR 50 reduced significantly than compared to - 5dB gain in DNR off condition.

Over all, annoyance level was reduced and SNR 50 was decreased at -3 dB gain for low and high annoyance groups, irrespective of DNR activated or devativated condition. Clinically mean annoyance level was reduced at DNR activated than deactivated condition. To conclude, reduction in gain decrease the residual noise generated in hearing aid circuit. In addition, though the annoyance level did not significantly reduced by activation or deactivation of DNR in hearing aid, the perceived annoyance and aversiveness decreased. Due to which participants of both groups tend to accept more noise (BNL). Further, participants able to follow sentences at lower signal to noise ratio in DNR ‘on’condition than compared to DNR ‘off’ condition.

Implication of the study

- In knowing the annoyance level in those individuals who accept less noise helps the clinician to set the appropriate gain there by which rejection rate can be decreased.
- The study imply in counselling the participants regarding the importance of digital noise reduction in hearing aid at the time of purchasing the hearing aid in individuals who accept less noise

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