Quantification of the Effects of Noise on Speech Recognition

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Abstract

Objective: The objective of the study was to compare the signal to noise ratio required for 50% performance (SNR-50) between individuals having normal hearing with those having different types, degrees of hearing loss and configurations of audiograms. In addition, the efficacy of the noise reduction algorithms in hearing aids, in terms of SNR-50 measure, was studied. Further, the relationship between the SNR-50 and a self-assessment scale of hearing handicap was evaluated.

Method: The unaided SNR-50 was obtained in 44 ears of individuals with normal hearing and 103 ears of individuals with hearing impairment. In individuals with hearing impairment, the SNR-50 was obtained in aided condition, with and without the use of noise reduction. The SNR loss was computed using SNR-50. The participants were administered a part of the self-assessment of hearing handicap scale that was relevant for perception of speech in the presence of background noise.

Results: The SNR-50 was significantly better in individuals with normal hearing than those with hearing impairment. Further, in individuals with hearing impairment, the SNR-50 was significantly better with the use of noise reduction in hearing aid, except in participants with moderate sensorineural and sloping hearing loss groups. It was also recognized that the SNR-50 could be used to a certain extent to predict the performance of the individuals with hearing impairment in daily life situations.

Conclusion: The SNR-50 is a useful and time saving measure to establish the performance of an individual in the presence of background noise. Thus, this measure should become a part of the routine clinical evaluation.

Key words: SNR-50, SNR loss, noise reduction, self-assessment scale

Quantification of the Effects of Noise on Speech Recognition

Background

Individuals with sensorineural hearing loss often report of difficulty in understanding speech in the presence of noise. Keith and Tallis (1972) reported deterioration in the speech recognition scores in individuals with normal hearing and those with hearing impairment in the presence of white noise. In individuals with normal hearing, the scores reduced by approximately 52% from quiet to a condition with a signal-to-noise ratio (SNR) of -8 dB. The scores reduced by 57% and 67% for the listeners with high frequency hearing loss and flat hearing loss respectively.

In routine speech audiometry, the speech reception threshold (SRT), speech identification or recognition scores (SIS or SRS) and the uncomfortable loudness level (UCL) are established in quiet. However, these measures may not reflect all the problems faced by individuals with hearing impairment in real life. This is because in real life, an individual will often have to understand speech in the presence of background noise.

Today, most audiological evaluations of listeners with hearing impairment focus on maximum speech recognition ability (PB-Max). During speech audiometry, the speech material is typically presented in quiet environments to maximize the potential for the highest speech recognition score. However, performance in the absence of background competition is often a poor predictor of a listener's recognition ability in noise (Carhart & Tillman, 1970). Further, noise appears to have different effects on the speech recognition ability, even in individuals with similar magnitudes of hearing loss, configurations and etiologies (Crandell, 1991; Feng, Yin, Kiefte, & Wang, 2010;). Hence, it was construed that a study on the effect of noise on speech recognition ability and the effect of noise reduction strategy in hearing aids in reducing this problem would throw more light on effectiveness of such algorithms in hearing aids. The relevant literature has been given under the following headings:

1. Speech identification in noise as a function of type, degree and configuration of hearing loss
2. Signal to noise ratio (SNR) required for 50% performance (SNR-50)and SNR loss
3. Signal to noise ratio required for 50% performance (SNR-50) in individuals with normal hearing and hearing impairment

4. Tests for measuring speech in noise performance
5. Speech in noise tests vs. Self-assessment tools
6. Use of noise reduction algorithms in hearing aids

1. Speech identification in noise as a function of type, degree and configuration of hearing loss

Individuals with hearing impairment usually report that in the presence of noise, although they can hear the speech, they have difficulty in understanding the speech. There have been studies which report of differences in the speech in noise performance depending on the type, degree and configuration of hearing loss (Bilger & Wang, 1976).

Nabelek and Mason (1981) established the word identification scores of individuals with flat and sloping configurations of sensorineural hearing loss using the modified rhyme test. The test was conducted in unaided and aided conditions, with ear level devices, using five signal-to-noise ratios, i.e., quiet (+30 dB), +10 dB, +5 dB, 0 dB and -5 dB. The authors reported that there was a significant decrease in the word identification scores as the signal-to-noise ratio decreased. There were more individual differences seen in the group with sloping audiogram configuration than the group with flat audiogram configuration group.

Pekkarinen, Salmivalli, and Suonpaa (1990) studied the effect of noise on word discrimination by individuals with normal hearing and those with hearing impairment. The participants included 106 Finnish speaking adults who were grouped into six groups; four groups of individuals with different configurations of sensorineural hearing impairment, one group of individuals with conductive hearing impairment and a group of normal hearing adults. A word list containing bisyllabic and trisyllabic words was used. The testing was conducted in quiet and at the three signal-to-noise ratios, of -13, -8 and -3 dB. The word recognition testing was conducted at 30 dB above the speech reception thresholds of the individuals. It was found that as the noise level increased, the subjects with sensorineural hearing loss showed poorer scores than individuals with normal hearing or those with conductive hearing loss. Subjects with a high frequency loss with a cut-off of 1 kHz had similar scores in noise as those with sloping or flat hearing losses whereas subjects with high frequency losses with a cut- off of 2 kHz discriminated speech in quiet and moderate levels of noise as well as the subjects with normal hearing. It was only at high noise levels that they showed significantly poor speech identification as compared to those with normal hearing. Individuals with normal hearing and individuals with conductive hearing loss obtained similar scores in quiet and with moderate levels of noise. However at high noise levels, subjects with conductive hearing loss achieved better scores than individuals with normal hearing.

Harris and Swenson, (1990), studied the effect of noise on the speech recognition abilities of individuals with normal hearing and those with mild and moderate to severe sensorineural hearing impairment. A total of 30 subjects, with 10 in each group were considered for the study. The speech recognition was measured in quiet and in the presence of speech spectrum noise at an SNR of +10 dB. Results indicated that there was a decrease in the speech recognition performance in quiet and noise as the severity of hearing loss increased. Further, the speech recognition performance in noise was significantly poorer than the performance in quiet for each of the three groups.

2. Signal to noise ratio (SNR) required for 50% performance (SNR-50) and SNR loss

Individuals with similar audiograms need not have the same SNR loss. The extent of problem an individual faces in the presence of noise or the SNR loss is not measured in routine clinical evaluations. Such a measure needs to be established since there is no straight forward correlation between the audiogram and the SNR loss (Plomp & Mimpen, 1979; Smoorenburg, 1992). The popular tests that measure the speech recognition in noise include the Hearing in Noise Test (HINT) and Speech in Noise (SIN) test. However, these are time consuming, and hence not too suitable for clinical use (Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004).

According to Fabry (2005), a measure that is becoming popular to evaluate the effect of noise on speech is the SNR loss which is derived from the SNR-50. The degree to which the signal of interest is audible above the interfering noise at a given point of time is quantified as the signal to noise ratio. Improvement of the SNR leads to improvement in the individual’s ability to recognize speech in a background of noise. SNR loss is the dB increase in signal to noise ratio required by an individual with hearing impairment to understand speech in noise as well as an individual with normal hearing. This is a measure of how well patients perform in real world listening situations. Technological variations in a device are required based on the degree of SNR loss. Fabry (2005) has summarized the technological needs for individual with different degrees of SNR loss which is given in Table 1.

Table 1: *Technological needs for individuals with different degrees of SNR loss*

SNR loss	*Degree of SNR loss*	*Technology Needs*
0-2 dB	Normal	Omni-directional microphone
2-7 dB	Mild SNR loss	Fixed/ Adaptive Directional Microphones
7-15 dB	Moderate SNR loss	Adaptive/Fixed Directional Microphones
>15 dB	Severe- profound SNR loss	FM systems

A person with normal hearing requires an SNR of 0-2 dB to perform correctly 50% of the time. Most of the standard audiological tests do not assess the extent of SNR loss an individual has. From Table 1 it can be inferred that knowledge of the person's unaided SNR loss is an important factor in the hearing aid selection process. This is because two individuals with the same pure tone audiogram may have different SNR loss and may thus benefit from different technological variations in hearing aids (Beattie, Barr & Roup etal., 1997).

Walden and Walden (2004) reported a study to predict the success using hearing aids in everyday living. In their study, the relationship between various demographic and audiometric measures with two measures of hearing aid benefit was investigated. The audiometric measures used were pure tone average (PTA), unaided articulation index (U-AI), aided articulation index (A-AI), unaided QuickSIN (U-QSIN), aided QuickSIN (A-QSIN) and word recognition scores in quiet using the NU-6 word list. The demographic variables were age and experience with current hearing aids. The International Outcome Inventory for Hearing Aids (IOI-HA, Cox & Alexander, 2002) and the Hearing Aid Usefulness Scale (HAUS, Walden & Walden, 2004) were administered to obtain the benefit from hearing aids on a follow-up visit. Results revealed that the unaided and aided SNR loss obtained from the QuickSIN were shown to be the best predictors of hearing aid success in daily living. There was a significant interaction of these scores with age. Thus, it has also been documented that the SNR-50 can be used to predict hearing aid success.

3. Signal to noise ratio required for 50% performance (SNR-50) in individuals with normal hearing and hearing impairment

It has been reported in literature that individuals with sensorineural hearing loss show markedly reduced speech recognition in noise compared to listeners with normal hearing (Cohen & Keith, 1976; Plomp & Mimpen, 1979). Noise is known to have a different effect on the speech recognition ability of individuals with the same hearing loss magnitudes, configurations and etiologies.

Dirks, Morgan, and Dubno (1982) studied a procedure to quantify the effects of noise on speech recognition in individuals with normal hearing and those with mild to moderate sensorineural hearing loss. They used an adaptive procedure to determine the SNR-50 for monosyllabic as well as spondaic words. It was observed that as speech level increased, the SNR required for 50% performance increased slightly. The reason given for this was the upward spread of masking. Further, a majority of the subjects with hearing impairment required SNRs that were more than those required by the subjects with normal hearing to achieve 50% performance. The authors also studied the difference in SNR for a 70.7%, 50% and 29.3% performance. The relative performance was noted to be similar for all the three criteria.

Dubno, Dirks, and Morgan (1984) also studied the effect of age in addition to mild hearing loss on the SNR-50 measurement. The subjects were divided into four groups- individuals <44 years with normal hearing, individuals <44 years with mild sensorineural hearing loss, individuals >65 years with normal hearing and individuals >65 years with mild sensorineural hearing loss. The SNR-50 was measured using an adaptive procedure. The results indicated that as a function of age, there was a decrease in the SNR-50 even though there was equivalent performance in quiet. Further, the performance of individuals with mild sensorineural hearing loss was significantly poorer than their normal hearing counterparts.

The above mentioned studies were conducted in individuals with sensorineural hearing impairment. Hsieh, Lin, Ho, and Liu (2009) studied the effect of conductive hearing impairment on the scores of the Mandarin-Hearing in Noise Test (M-HINT). 32 subjects with unilateral and bilateral conductive hearing loss were included in the study and 20 subjects with normal hearing served as the control group. The authors used the Taiwan version of the M-HINT which was an adaptive test which measured the reception threshold for sentences (RTS) in quiet and noise. The RTS was the presentation level at which half the sentence was identified correctly. The RTS in quiet was 22.3+/-2.2, 29.9+/-3.5 and 50.2+/- 6.8 dB (A) for the control, unilateral and bilateral groups respectively. It can be observed that the RTS was poorer for the unilateral group than the control group; and even poorer for the bilateral group than the control and unilateral groups. For the unilateral group, the RTS was significantly higher than the control group irrespective of whether the noise came from the front, normal side and affected side. For the bilateral group, the SNR was significantly elevated when the noise came from the front, right or left side. These results revealed that there was reduced speech discrimination ability in noise even in individuals with conductive hearing impairment.

From the studies reported in literature, it can be observed that individuals with sensorineural and conductive hearing loss obtained a higher SNR-50. However, these studies mostly considered individuals with mild hearing losses. Investigation is warranted on SNR-50 in higher degrees of hearing loss.

4. Tests for measuring speech in noise performance

There are several tests which assess the speech recognition abilities in the presence of noise. Taylor (2003) reviewed the types of speech in noise tests and discussed their inclusion in the routine test battery. These tests are: 1) Fixed SNR tests - those that measure a percent correct at a fixed SNR. This type of test has been typically used to compare the aided and unaided scores at fixed SNRs. The disadvantage of this procedure is that it is difficult to assess where to fix the SNR. Further, there can be a ceiling or floor effect observed with such fixed SNR tests. 2) Adaptive SNR tests are those that measure the speech to noise ratio while the intensity level of the speech or noise is varied. These tests can also be conducted in the earphone condition. These tests are important in diagnosing the SNR loss.

Some of the other tests that are used to measure speech perception in noise include the Connected Speech Test (Cox, Alexander, & Gilmore, 1987); the City University of New York topic related sentences (Boothroyd, Hanin, & Hnath, 1985) and the Speech Perception in Noise test (Kalikow, Stevens, & Elliot, 1977). These tests assess the speech recognition ability in noise at a fixed level and are thus subject to ceiling and floor effects (Nilsson, Soli & Sullivan, 1994). An alternate test that has been described is the Signal-to-Noise Ratio-50 (SNR-50) which is defined as the presentation level necessary for the listener to recognize the speech materials presented correctly 50% of the time.

The technique usually used to assess the SNR-50 is an adaptive procedure where the presentation level of the stimulus is either increased or decreased by a fixed amount, depending on the listener's ability to repeat the material correctly (Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004). Over some trials, the level of the following stimulus is increased if the response to the current stimulus is incorrect and the level of the following stimulus is decreased if the response to the current stimulus is correct.

Nilsson, Soli, and Sullivan (1994) developed a test to assess the SNR-50 using sentences. The advantage of this type of test is that whole sentences are used. However, it is disadvantageous because a greater number of sentences are required when the key word scoring method is used. Besides, the testing time would increase. Killion and Villchur (1993) also developed a sentence test which was called the Sentence in Noise test (SIN). However, these tests are too lengthy to be used for clinical purposes. Thus, the need arose for a speech in noise test which was less time consuming.

Killion, Niquette, Gudmundsen, Revit, and Banerjee (2004) developed a quick speech in noise test which was a shortened version of the Speech in Noise (SIN) test (Etymotic Research, 1993). First, the level of a female talker relative to that of four-talker babble was adjusted to produce 50% scores in individuals with normal hearing. Then, those sentences-in-babble that produced lack of equivalence or a high degree of variability in scores were discarded. The final lists were those that measured the SNR where the listener is required to understand 50% of key words in sentences in a background of babble. According to the authors, a single QuickSIN list took around one minute for administration and provided an estimate of SNR accurate to +/-2.7dB at the 95% confidence level.

5. Speech in noise tests vs. Self-assessment tools

There are several audiological tests such as pure tone audiometry, immittance evaluation, auditory brainstem response which assess different functions of the hearing mechanism. These tests quantify the loss of hearing sensitivity, difficulty in speech recognition, and the presence and extent of site of lesion (if any). However, these tests do not quantify the impact of hearing loss on an individual. The extent to which hearing loss affects individuals in their day to day function cannot be predicted based on the audiogram alone. To evaluate this degree of handicap that an individual with hearing impairment experiences in the real world situations, a self assessment tool may be required. It has been shown that these questionnaires correlate significantly with the pure tone audiogram (High, Fairbanks & Glorig, 1964; Schow & Tannahill, 1977). However, there has been a lack of agreement among authors about the correlation between the questionnaires and speech identification (Tyler & Smith, 1983; Rowland, Dirks, Dubno, & Bell, 1985; Hawes & Niswander, 1985).

Tyler and Smith (1983) compared the performance of sentence identification in noise and two hearing handicap questionnaires. The sentence tests used were CID sentences in the presence of continuous speech spectrum shaped noise at 0 dB SNR, and Bamford Kowal Bench sentences in noise. The questionnaires used were the Social Hearing Handicap Index (SHHI) given by Ewerstein and Nielsen (1973) and the Hearing Measurement Scale (HMS) given by Noble and Atherly (1970). All the sentence tests show significant negative correlations with both questionnaires, i.e., the poorer the sentence in noise performance, the higher the hearing handicap. They concluded that the high first order correlation between the questionnaires and the sentence in noise tests offer support for the notion that questionnaires can be used to quantify hearing handicap.

Rowland, Dirks, Dubno, and Bell (1985) compared the results of speech recognition in noise with the ‘understanding speech’ subsection of the Hearing Performance Inventory. The signal to noise ratio required to obtain 50% speech recognition was obtained. It was reported that the listeners with hearing impairment required a higher SNR-50 than those with normal hearing even at the high level of 80 dB SPL, which was attributed to the low sensation level of the SPIN sentences relative to threshold. The performance on the self-assessment scales and the speech recognition task differentiated between the listeners with normal hearing and those with hearing impairment. However, for the group with hearing impairment, the correlation between the speech recognition scores and the self-assessment scale was poor.

Hawes and Niswander (1985) compared the Hearing Performance Inventory (HPI) with the spondee threshold, measures of most comfortable loudness level, monosyllabic discrimination - in quiet and in noise, and conversational level monosyllabic discrimination. The correlation of the HPI with the discrimination in noise was slightly higher than that in quiet, although this was not significantly different. Also, the correlation of the HPI scores with the discrimination measures was higher than with the sensitivity measures. In general, they concluded that the amount of difficulty a client reports is often inconsistent with that predicted from the audiogram. The Social Adequacy Index (SAI), a measure of the degree of hearing handicap which takes into account the speech audiometry findings, was calculated for the quiet and noise situations and these scores were correlated with the HPI. The SAI-Noise score correlated most highly with the HPI scores. The hearing handicap scales offer a method of systematically assessing the impact of the hearing loss.

Smits, Kramer, and Houtgast (2006) compared the speech reception thresholds in noise and the self-reported hearing disability. The diotic speech in noise performance of the subjects was recorded over the telephone. It was observed that out of five questions in the questionnaires, a single question could be used to predict the hearing status category corresponding to the results of the speech in noise test correctly in the 62% of the cases. Also, the use of all the five questions allowed for 69% of the subjects to be classified correctly. They have reported a median SNR loss to be 2.2 dB for men and 1.2 dB for women in the 60-64 year age group and 5.0 dB for men and 3.6 dB for women in the 80-84 year age groups. Thus, they reported that the type and degree of hearing loss, configuration of audiogram are some of the variables that affect the SNR loss. Thus, it can be noted that the speech identification in noise correlates with a single question or a particular sub-section of the hearing handicap inventory.

6. Use of Noise Reduction Algorithms

One of the most frequently stated complaints by individuals with hearing impairment is difficulty hearing in the presence of background noise. Most of the hearing aids, which are typically fitted in the low priced group, have only omni-directional microphones. This means that the background noise will also be amplified along with the speech and therefore the SNR will remain the same. However, the performance will decrease in comparison to the unaided due to factors like upward spread of masking and distortion provided by the hearing aids (Plomp, 1978). A study by Kochkin (2000) states that 18% of individuals with hearing aids do not use them, 17% return their hearing aids and 20% of individuals report of dissatisfaction with the device.

Current day hearing aids have implemented several techniques to try to overcome this difficulty. Some of them are binaural amplification, reduction of low frequency amplification, directional microphones and digital noise reduction. Noise reduction in hearing aids has been studied extensively over the past decade (Boymans & Dreschler, 2000; Alcantra, Moore, Kuhnel, & Launer, 2003; Ricketts & Hornsby, 2005; Peeters, Kuk, Lau, & Keenan, 2009; Kuk, Peeters, Lau, & Korhonen, 2011). At present, most noise reduction algorithms use digital signal processing to acoustically analyze the incoming signal and alter the gain requirement or output characteristic according to some predetermined rule (Stelmachowicz, Lewis, Nishi, McCreery, & Woods, 2010).

Boymans and Dreschler (2000) measured the effects of a digital hearing aid on speech recognition in noise for active noise reduction and directional microphone system in individuals with sensorineural hearing loss. Speech recognition in noise was measured in speech babble noise as well as a low frequency car noise from three different locations, 90°, 180° and 270° azimuths. The SNR-50 was estimated using 20 lists of sentences. The subjects' preference was also taken using paired comparisons where they were asked to listen to standard speech fragments and report which program they preferred given a choice that they would have to listen to it all day. A Dutch version of the APHAB questionnaire was also administered so as to compare the different settings of the hearing aid. The results indicated that the setting with directional microphone showed a statistically significant lower SNR than the setting without it. The setting with the noise reduction also showed a lower SNR than the setting without it. However, this difference was not significantly different. In terms of the subjective preference, the subjects preferred the directional microphone setting more than the noise reduction setting. The preference for noise reduction was 10-20% higher than the setting without either directional microphone or noise reduction. The SNRs obtained were lower with the car noise than the speech noise. But there was no difference in the subjective preference in both the types of noise.

Alcantra, Moore, Kuhnel, and Launer (2003) evaluated the noise reduction system in a multichannel digital hearing aid. The participants included eight individuals with bilateral moderate sensorineural hearing loss. The subjects were provided with the hearing aids with two programs, one with and one without noise reduction, for a period of three months. Following this three month period, the SNR-50 was measured using different types of noise, steady noise and noise with spectral and temporal dips. The SNR-50 was markedly lower for the aided condition than the unaided condition, with not much difference in the performance with and without noise reduction. The SNRs were lower in the presence of noise with dips than the steady noise and this was more evident in the aided conditions. This showed that amplification helped individuals to hear in the presence of dips.

Peeters, Kuk, Lau, and Keenan (2009) compared the directional microphone and noise reduction algorithms on eighteen adults with bilateral symmetrical sensorineural hearing loss. They conducted both objective and subjective measurements of speech in noise performance. As a part of the objective measurements, they assessed the SNR-50 using HINT sentences. The subjective measure of speech in noise performance was measured using the Accepted Noise Level (ANL). The highest Background Noise Level (BNL) is that at which the subject can no longer tolerate the noise without becoming tense or tired. The ANL is the difference between the BNL and the most comfortable level (MCL) for speech in quiet while the subject listens to running speech. HINT and ANL testing were completed under four hearing aid conditions: (1) omnidirectional microphone only (2) omnidirectional with speech enhancer (3) fixed directional microphone only and (4) fixed directional microphone with speech enhancer. The results indicated that both the directional microphone and noise reduction algorithm improved the speech performance in noise. Higher benefits were reported with the directional microphone. There was a moderate correlation observed between the HINT and ANL for all the conditions. Thus, it was reported that there was a significant improvement in the speech performance in noise using both directional microphones as well as noise reduction algorithms, and both the HINT and ANL methods could be used to assess this benefit for speech in noise performance.

Quintino, Mondelli, and Ferrari (2010) studied the speech perception and benefit obtained when hearing aids were used with directional microphones and noise reduction algorithms in individuals with bilateral mild to severe sensorineural hearing loss. The individuals wore four different types of hearing devices; completely in the canal (CIC) devices, in the canal (ITC) devices, behind the ear (BTE) devices with omnidirectional microphone, and BTE devices with directional microphone. All the devices were also equipped with noise reduction algorithms. SNR-50 was measured using sentences to assess the speech perception in the presence of noise. The benefit was determined using the Abbreviated Profile of Hearing Aid Benefit (APHAB) and satisfaction was using the International Outcome Inventory for Hearing Aids (IOI-HA). The SNR-50 obtained was lower in the groups with CIC, ITC and directional BTE hearing aids, although no significant difference was obtained between the groups. Similar results were obtained with the APHAB scale. The authors did not report differences in results with and without the noise reduction algorithm. Similar results were obtained by Ricketts and Hornsby (2005). However, the subjects in their study reported better sound quality when the digital noise reduction algorithm was switched on than when it was switched off.

DiGiovanni, Davlin, and Nagaraj (2011) studied the effects of transient noise reduction (TNR) on the speech intelligibility in individuals with hearing impairment. Transient noise reduction algorithms are those which are specifically designed to reduce the effects of transient noise without distorting the speech signal. Seventeen adults who had mild to severe sensorineural hearing loss were included in the study. HINT sentences were presented in quiet and in noise in a total of six conditions. The conditions were sentences presented in quiet, sentences mixed with multi-talker babble, sentences with door slam (transient noise), sentences with chair clangs (transient noise), sentences mixed with multi-talker babble and door slam, and sentences mixed with multi-talker babble and chair clang. Following each test condition, the individuals rated the overall speech understanding, overall sound comfort and overall sound quality on a 11-point rating scale. The score in the quiet condition was nearly 100%. In the transient only or multi-talker babble only conditions, the score ranged from 71.6 to 84.9%. There was an average drop of 42.4% from the transient alone conditions and babble alone conditions to the transient plus babble conditions. The authors reasoned that the effects of the transients would be directly additive to the reduced intelligibility with the multi-talker babble alone, given that the two stimuli differ in their temporal characteristics. ANOVA results revealed a small but significant effect of the processing (transient noise reduction activated versus deactivated) and a significant effect of the condition. Results of the subjective ratings revealed that there were higher sound quality ratings for TNR activated for all the conditions. Thus, TNR appears to offer a step in improving the listening experience for hearing aid users.

Kuk, Peeters, Lau, and Korhonen (2011) studied the effect of maximum power output and noise reduction on the speech recognition in noise. Eleven adults with moderately flat, severe hearing loss were recruited for the study. They compared the performance of the individuals on HINT using two types of noise reduction (NR) algorithms, the NR-classic (NR-C) and the NR-speech enhancer (NR-SE), and with the noise reduction algorithm switched off. The NR-C reduces gain in each channel where the noise is identified by an amount which is determined by the level of the input signal. The NR-SE estimates the speech intelligibility index (SII), from the noise spectrum and then reduces the gain. The results revealed that there was a significant improvement in the scores when the noise reduction was switched on with either NR-C or NR-SE algorithms compared to the noise reduction switched off. However, there was no significant difference between the two types of noise reduction algorithms.

Thus, it can be observed that there are equivocal findings regarding the benefit on performance in the aided with and without noise reduction. In the present study, the effect of noise reduction in hearing aids on speech perception in the presence of noise is being evaluated using the SNR-50 and SNR loss.

Need for the Study

Evidence shows that individuals with hearing impairment demonstrate markedly reduced speech recognition scores in the presence of noise compared to individuals having normal hearing (Cohen & Keith, 1976; Leshowitz, 1977). During routine clinical evaluations, the speech is usually presented in quiet. However, the performance in the absence of any form of background competition is a poor predictor of the speech recognition ability in noise (Carhart & Tillman, 1970). It is important to assess speech recognition in noise as it gives more information about the real world situations that an individual with hearing impairment faces.

In the present day, there are hearing aids with features such as directional microphones and noise reduction algorithms. It has already been established in literature that the speech recognition performance in noise improves in the directional microphone mode. However, there are equivocal findings in literature on noise reduction algorithms. Boymans and Dreschler (2000) reported no significant difference in all the subscales of APHAB with and without noise reduction. Similar results were obtained by Alcantra, Moore, Kuhnel, and Launer (2003) who tested speech recognition thresholds in noise and estimated the ratings of sound quality and listening comfort, in the aided conditions with and without noise reduction. Ricketts and Hornsby (2005) have also reported that the presence of digital noise reduction did not impact speech recognition in noise. However, better sound quality has been reported by individuals when the noise reduction processing was used (Boymans & Dreschler, 2000; Ricketts & Hornsby, 2005). DiGiovanni, Davlin, and Nagaraj (2011) studied the effect of transient noise reduction algorithm on speech intelligibility and ratings by hearing aid users. They reported a significant improvement in speech intelligibility when the transient noise reduction was activated but there was no significant improvement in the subjective ratings. Peeters et al., (2009) and Kuk et al., (2011) also report of significantly better performance in the presence of noise when the noise reduction algorithm was used.

Hence, there is a need for more studies to measure and quantify the speech recognition ability in the presence of noise in different types, degrees and configurations of hearing loss. Studies conducted earlier have considered individuals with sensorineural hearing loss. In addition to sensorineural hearing loss, the present study also compares the SNR-50 of individuals with normal hearing and conductive hearing loss. Further, studies conducted earlier have not focused on the effect of noise reduction algorithms on individuals with varying audiogram configurations. Hence, there is a need to evaluate if there is an effect of noise reduction on the SNR-50 of individuals with sensorineural hearing loss having either flat or sloping configuration of audiogram. The purpose of the present study was also to study the effect of noise reduction algorithms on the SNR-50 and SNR loss.

Aim:

To quantify the effects of noise on speech recognition in individuals with hearing impairment.

Objectives:

1. To compare the SNR-50 obtained in individuals with varying degrees and types of hearing loss with those having normal hearing
2. To compare the SNR-50 obtained in individuals with sensorineural hearing loss and conductive hearing loss
3. To evaluate the SNR loss obtained in individuals with normal hearing and those having hearing impairment in whom the unaided SNR-50 was measurable
4. To compare the SNR-50 in the unaided and aided conditions in the individuals with varying degrees and types of hearing loss
5. To compare the SNR-50 in the aided conditions with and without noise reduction algorithm
6. To compare the relationship between the SNR-50 and outcome measures related to speech perception in noise.

Method

The main objectives of the present study were to compare the SNR-50 and SNR loss in individuals having normal hearing and hearing loss. In the aided condition, this was evaluated with and without noise reduction, in individuals with hearing loss.To evaluate the objectives, following method was followed for data collection.

Participants:

The data were collected from a total of 147 ears of individuals in the age ranging from 15 years to 65 years. Of these, 44 ears had normal hearing (Group 1). The rest of the ears had hearing impairment (Group 2). Group 2 was divided into different sub-groups based on the type of hearing loss sensorineural or conductive. Sensorineural hearing loss was audiologically confirmed before testing.

Table 2: *Categorization of test ears in Group 2*

<table>
<tr><td colspan="8">Sensorineural hearing loss</td><td colspan="3">Conductive hearing loss (flat)</td></tr>
<tr><td colspan="6">Flat hearing loss</td><td colspan="2">Sloping hearing loss</td><td rowspan="3">Mild (N=10)</td><td rowspan="3">Moderate (N=10)</td><td rowspan="3">Moderately severe (N=10)</td></tr>
<tr><td colspan="2">Mild</td><td colspan="2">Moderate</td><td colspan="2">Moderately severe</td><td rowspan="2">(N=11)</td><td rowspan="2">(N=11)</td></tr>
<tr><td>N=8</td><td>N=8</td><td>N=8</td><td>N=11</td><td>N=8</td><td>N=9</td></tr>
</table>

All the participants were native speakers of Kannada language with acquired hearing loss, having abilities to perform on open-set speech recognition tasks. None of them had any complaints of any psychological or neurological problems. All the participants in Group 2 were naive hearing aid users. Informed consent was obtained from all the participants prior to the testing.

Equipment and Material:

- A calibrated diagnostic audiometer was used to obtain the pure tone air-conduction and bone-conduction thresholds, speech recognition threshold, speech recognition scores, uncomfortable level and the unaided and aided (only for Group 2) SNR-50.
- A calibrated middle ear analyzer was used to obtain the tympanogram and the acoustic reflex thresholds.
- NOAH software with Hi-Pro connected to the personal computer was used to program the four channel digital BTE hearing aid.
- Phonemically balanced (PB) test material in Kannada (Yathiraj & Vijayalakshmi, 2005) was used to obtain the speech identification scores and the signal-to-noise ratio-50 (SNR-50) values. This test material had four lists with 25 bi-syllabic words each.
- Self Assessment of Hearing Handicap (Vanaja & Nikam, 2000)

Test Environment:

Air conditioned, sound treated double room test suite was used to carry out all the audiological testing.

Procedure:

For each test ear, the hearing thresholds were established at 250, 500, 750, 1000, 1500, 2000, 3000, 4000 and 6000 Hz for air-conduction, and at 250, 500, 1000, 2000 and 4000 Hz for bone–conduction using modified Hughson-Westlake procedure. The speech recognition threshold was obtained using the procedure given by Tillman and Olsen (1973). The speech identification scores were obtained at 40 dB SL (re: SRT) using the PB word list in Kannada (Yathiraj & Vijayalakshmi, 2005). The number of correct recognition of words was noted for each test ear for each test condition. The uncomfortable level for speech in the test ear of the individual was also noted. A middle ear analyzer was used to obtain the status of the middle ear. This testing was common to both Group 1 and Group 2. These tests were done to confirm the inclusion criteria of the test ear.

The SNR-50 and SNR loss were obtained for the test ears using the procedure given below.

Quantification of speech recognition in noise, SNR-50:

Signal to noise ratio-50 (SNR-50) was measured for each test ear. The level of speech, through audiometric loud speaker kept in front of the speaker (0^o Azimuth), was kept constant at 45 dB HL. The initial level of speech noise, through the same loudspeaker, was set at 30 dB HL. The level of noise was increased, in 5-dB steps, till the participant repeated two out of four (i.e., 50%) words being presented. From this level, the noise was varied in 2 dB steps in order to obtain a more precise level of speech noise at which 50% of the words were correctly repeated. At this point, the difference in intensity of speech and the intensity of speech noise, in dB, was noted as the SNR-50. The steps of the testing individuals with normal hearing and those with hearing impairment were as follows:

a) Individuals with normal hearing:

The SNR-50 was obtained only in unaided condition, with the speech at 45 dB HL and the speech noise varied from a starting level of 30 dB HL.

b) Individuals with hearing impairment:

For individuals with a hearing loss, unaided and aided SNR-50 were obtained.

i. Unaided SNR-50 was obtained at 45 dB HL for subjects with mild and moderate hearing loss.

ii. For the aided testing, a four channel digital BTE hearing aid was programmed for the test ear using the NOAH software loaded on a personal computer that was connected to a Hi-Pro. The client’s audiometric data were fed into the NOAH software. The hearing aid was initially programmed to ‘first-fit’ setting using the NAL-NL1 fitting formula, keeping the acclimatization level at 2. The gain was then optimized until the individual was able to repeat the Ling’s six sounds, five questions and five paired words. The hearing aid was programmed to this setting in two programs (P1 & P2). The only difference between P1 and P2 was that the P1 was without noise reduction and the P2 was with noise reduction activated. The aided SNR-50 was measured using the procedure as explained above with the presentation level for speech at 45 dBHL.

iii. The Self-Assessment of Hearing Handicap (Vanaja & Nikam, 2000) was administered on all the individuals with hearing impairment. This questionnaire had a three-point rating scale with a rating of '2' given for 'most of the time', a rating of '1' for 'sometimes' and a rating of '0' for 'seldom'. There were 12 questions which assess the difficulty that an individual faced in understanding speech in different situations. The questions included hearing speech in quiet, in several noisy environments, talking over the telephone, watching television and conversing with a group of people etc. There were eight questions which assessed the quality of life and two questions which assessed the detection of different sounds at two distances (6-8 feet and 18-20 feet). The last question was an open-ended question which required the participant to mention any other situation in which he/she had difficulty in hearing. Therefore, there were a total of 23 questions. The questionnaire is attached in Appendix I. The self-assessment of hearing handicap scale was used to assess the level of hearing handicap. It must be noted here that the part of the questionnaire, i.e., only 14 questions, which were associated with hearing in the presence of noise were included for the purpose of the study.

Estimation of SNR loss:

The SNR loss is the increased signal-to-noise required by an individual to understand speech in noise, as compared to performance by individuals with normal hearing. To evaluate this, the unaided SNR-50 at 45 dB HL is estimated for the individuals with normal hearing and those with mild and moderate hearing losses, wherever possible. The mean SNR-50 was calculated for each group. The mean SNR-50 of each group with hearing impairment was compared with the mean SNR-50 of the group with normal hearing to obtain the SNR loss.

To establish the SNR-50, speech was presented at 45 dBHL, and the speech noise level was kept at 30 dB below the level of speech. The stimuli were presented through the loud speaker located from 1 m distance at 45^{o} Azimuth. The level of speech noise was varied to find out the lowest level of speech noise at which the participant was able to repeat 50% of the words presented. At this point, the difference between the speech and the speech noise levels was considered as SNR-50.

SNR loss is the increased signal-to-noise ratio required by an individual to understand speech in noise, as compared to normal performance (Killion, Niquette, Gudmundsen, Revit, and & Banerjee, (2004). To illustrate this, a person with normal hearing requires about +2 dB SNR (i.e., target talker 2 dB louder than background babble talkers) to correctly repeat 50% of the key words. This is the SNR-50. A person with hearing impairment who requires the target speech to be 12 dB higher than the noise to achieve a 50% correct score would have a 10 dB SNR loss.

Thus, for individuals with normal hearing unaided SNR-50 was established and for individuals with a hearing loss, unaided and two aided (without noise reduction and with noise reduction enabled) SNR-50s were obtained. This data were utilized to calculate the SNR loss. Appropriate statistical analyses were performed to evaluate the objectives of the study.

Results and Discussion

The objectives of the study were to compare the SNR-50 and SNR loss obtained in individuals with varying degrees and types of hearing loss with those having normal hearing. In addition, the study also investigated the utility of SNR-50 in evaluating the effectiveness of noise reduction algorithm in hearing aids. The results and discussion are provided under different headings:

1. Comparison of unaided SNR-50in individuals with normal hearing and those with different hearing loss
2. SNR loss in the individuals with normal hearing and those with hearing loss in whom the unaided SNR-50 at 45 dB was measurable
3. SNR-50 in the aided and unaided conditions for the individuals with different degrees, types of hearing loss and configurations of audiogram
4. Aided SNR-50 with and without noise reduction
5. Unaided SNR-50 and the ratings on the self-assessment of hearing handicap questionnaire

Descriptive statistics and tests for evaluating the significant difference between the groups / conditions were conducted.

1. **Comparison of the unaided SNR-50 in individuals with normal hearing and those with hearing loss**

The mean, standard deviation and median of the unaided SNR-50 in the individuals with normal hearing and those with hearing impairment are displayed in Table 3. This is also displayed in Figure 1.

Table 3: *Mean, Standard Deviation and Median of the unaided SNR-50 in individuals with normal hearing and those with hearing loss of mild and moderate degrees*

Groups	*SNR-50*		
	Mean	*Standard Deviation*	*Median*
Normal Hearing (N=44)	-7.23	3.65	-7.00
Hearing Impairment (N=59)	1.22	6.98	-1.00

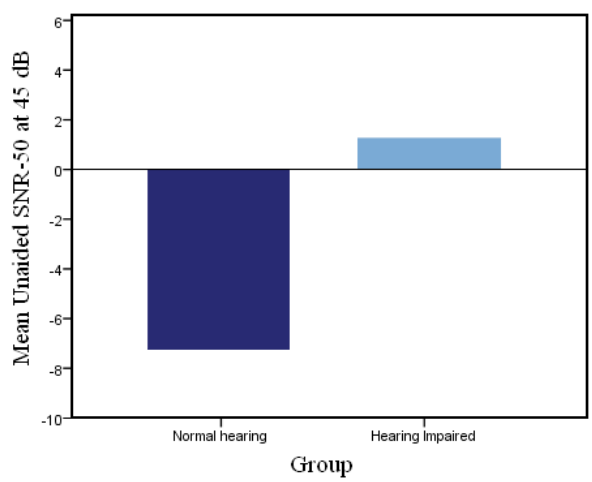

Fig 1: Mean unaided SNR-50 at 45 dBHL for individuals with normal hearing and those with mild and moderate hearing impairment.

It can be seen from Table 3 and Figure 1 that as expected, the unaided SNR-50 was much lower for the group with normal hearing than the group with hearing impairment. Here, it should be noted that lesser the SNR-50 or the more negative the value of SNR-50, the better the performance. That is, an individual performs well even when the difference between the noise and speech is less or when the noise level is higher than the speech level. Non-parametric test was used since the standard deviations were very high. That is, Mann Whitney U test was used to compare the performance between the two groups. This indicated that the SNR-50 was significantly lower in the group with normal hearing when compared to the group with hearing loss ($Z= -6.75$, $p<0.05$).

These results support the findings obtained by Dirks et al. (1982) and Dubno et al. (1984) who reported that the SNR-50 required by individuals with hearing loss was significantly higher than that required by individuals with normal hearing. The poor speech discrimination in noise by individuals with hearing loss can be attributed to poor temporal resolution with a resulting reduction in the ability to take advantage of the good signal to noise ratios (Zwicker & Schorn, 1982; Festen & Plomp, 1990). This could also be attributed to the reduction in redundancy of speech in the presence of noise (Hall, Buss, & Grose, 2008) and the inability of individuals with hearing impairment to utilize temporal fine structure cues which is more relevant to sensorineural hearing impairment (Moore & Moore, 2003; Buss, Hall, & Grose, 2004).

1.1 Unaided SNR-50 in individuals with sensorineural hearing loss and conductive hearing loss

The unaided SNR-50 was compared between individuals having sensorineural and conductive hearing loss. This comparison was done at a speech presentation level of 45 dB HL. The mean, standard deviation and median can be observed in Table 4. However, the SNR-50 was estimated when the speech was at 45 dBHL, for participants in whom it was feasible. The mean SNR-50 is also depicted graphically in Figure 2.

Table 4: *Mean, Standard Deviation and Median of the unaided SNR-50 of the normal hearing, sensorineural and conductive hearing loss groups*

		SNR-50		
		Mean	***Standard Deviation***	***Median***
Groups	***N***	***At 45 dB HL***	***At 45 dB HL***	***At 45 dB HL***
Normal hearing	44	-7.23	3.65	-7.00
Sensori-neural	27	2.30	8.48	-1.00
Conductive	16	-3.12	3.79	-2.00

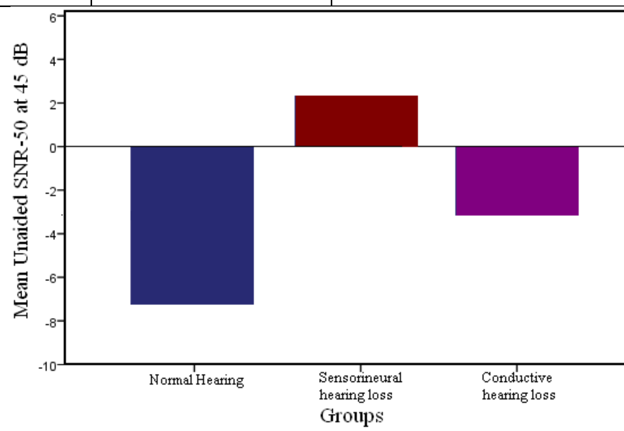

*Fig 2:*Mean unaided SNR-50 at 45 dBHL of individuals with normal hearing, sensorineural and conductive hearing impairment of mild and moderate degrees.

It can be observed from Table 4 that the SNR-50 was lesser for individuals with normal hearing than for those with hearing loss. In addition, the SNR-50 was lesser for individuals with conductive hearing loss than for those with sensorineural hearing loss.

The mean SNR-50 was lower for the conductive hearing loss group compared to the sensorineural hearing loss group. To see if this difference between the groups was significant, non-parametric Mann Whitney U test was used since the standard deviations were very high. The results indicated that there was no significant difference in the unaided SNR-50 between the individuals with conductive hearing loss and sensorineural hearing loss (Z= -1.58, p>0.05).

The results of the present study are in consonance with those obtained by Hseih et al. (2009) who reported significantly poor SNR-50 in individuals with unilateral and bilateral conductive hearing loss in comparison with those with normal hearing. This could be because the ability to hear speech in noise depends on the mechanisms related to central auditory processing.

This mechanism is compromised in individuals who have a long standing conductive and sensorineural hearing loss leading to auditory deprivation. This warrants further investigation. The results in the present study are partly in agreement with the findings reported by Pekkarinen et al. (1990) who reported significantly poor speech recognition by individuals with sensorineural hearing loss in comparison with individuals with conductive hearing loss. However, they reported that the speech recognition in moderate levels of noise showed no significant difference among listeners with normal hearing and those with conductive hearing impairment.

2. SNR loss in individuals with normal hearing and those with hearing loss in whom the unaided SNR-50 was measurable

To estimate the SNR loss, mean and standard deviation of SNR-50 values were calculated. The SNR-50 values in different participant groups are provided in Table 5. This was utilized to calculate the SNR loss.

Table 5: *Mean, standard deviation and range values of the SNR-50 at 45 dBHL*

Groups		*SNR-50*	
		Mean	*Standard deviation*
Normal hearing		-7.23	3.65
Sensorineural hearing loss	Mild	-3.56	2.34
	Moderate	10.82	6.62
	Sloping	3.75	4.49
Conductive hearing loss	Mild	-4.00	4.80
	Moderate	-2.00	1.63

From Table 5, it can be seen that for both the sensorineural and conductive hearing loss groups, the SNR-50 is increasing as the degree of hearing loss is increased. To assess whether this difference is significant, Mann Whitney U test was conducted. For the group of individuals with sensorineural hearing loss there was a significant difference between the mild and moderate degrees of hearing loss ($Z = -4.24$, $p < 0.05$). However, there was no significant difference between the two degrees ($Z = -0.70$, $p > 0.05$) for the individuals with conductive hearing loss. Thus, for individuals with sensorineural hearing loss, with the increase in degree of hearing loss, the speech recognition in noise becomes significantly poorer. This could be due to the lack of audibility, poor temporal resolution (Zwicker & Schorn, 1982; Festen & Plomp, 1990), reduction of redundancy for speech (Hall, Buss, & Grose, 2008) and inability to utilize temporal fine structure cues (Moore & Moore, 2003; Buss, Hall, & Grose, 2004).

Following this, to obtain the SNR loss the mean value of the SNR-50 of each group was subtracted from the mean value of SNR-50 for the individuals with normal hearing. For example, for the individuals with normal hearing the SNR loss was calculated by subtracting -7.23 from itself thereby achieving a value of 0 dB [-7.23 - (-7.23) = 0]. That is, the SNR-50 of individuals with normal hearing was considered as reference for SNR loss. The SNR loss of each of the groups can be observed in Table 6.

Table 6: *Mean SNR loss in different groups of participants*

Groups		*Mean SNR loss*
Normal hearing		0 dB
Sensorineural hearing loss	Mild	3.67
	Moderate	18.05
	Sloping	10.98
Conductive hearing loss	Mild	3.23
	Moderate	5.23

It can be observed from Table 6 that the SNR loss increased as the degree of hearing loss increased. The SNR loss was lesser for the individuals with conductive hearing loss than for the individuals with sensorineural hearing loss. Further, it can be noted that among those with sensorineural hearing loss, the SNR loss was greatest for the individuals with moderate hearing loss followed by sloping and mild hearing loss. The SNR loss that was obtained in the present study is not very similar to that obtained previously by Fabry (2005) as observed in Table 1. This could be due to the procedural variations in the two studies. The present study used sound field speakers instead of headphones; and speech noise instead of multi-talker babble. In sound field, the binaural hearing facilitates listening to speech in the presence of noise, especially for the group with normal hearing. It can also be observed that individuals with different SNR losses benefit from different hearing aid technologies Fabry (2005). Therefore, an audiologist can assess the extent of benefit an individual with greater SNR loss can expect from hearing aids.

3. SNR-50 in the aided and unaided conditions for the individuals with hearing loss

The mean, standard deviation and median values of SNR-50 obtained in the unaided, aided - without noise reduction and with noise reduction, for the group with hearing impairment are summarized in Table 7.

Table 7: *Mean, standard deviation and median values of SNR-50 at 45 dBHL in the unaided, aided (without and with noise reduction) conditions for Group 2*

Group 2	*SNR-50*								
	Unaided			*Aided without noise reduction*			*Aided with noise reduction*		
	Mean	*SD*	*Median*	*Mean*	*SD*	*Median*	*Mean*	*SD*	*Median*
Sloping	3.75	4.94	4	0.90	3.77	0.00	-0.10	4.24	0.00
Mild sensorineural	-3.56	2.34	-5.00	-4.19	5.56	-4.00	-6.81	5.87	-6.50
Moderate sensorineural	10.82	6.62	12.00	3.63	6.64	2.00	1.74	6.50	-1.00
Moderately severe sensorineural	-	-	-	9.94	6.21	10.00	3.94	4.21	5.00
Mild conductive	-4.00	4.80	-5.00	-3.70	6.57	-5.50	-8.40	3.95	-8.50
Moderate conductive	-2.00	1.63	-2.00	-0.80	2.82	0.00	-5.10	3.67	-5.00
Moderately severe conductive	-	-	-	3.80	5.65	2.50	0.10	6.420	0.00

From the Table 7, it can be noted that there is a decrease in the SNR-50 in both the aided conditions in comparison to the unaided conditions, implying better performance in the aided condition. To assess whether these differences were significant, the Wilcoxon Signed Ranks test was conducted. The results of the test are summarized in Table 8 for all the groups.

Table 8: *Results of the Wilcoxon Signed Ranks test to compare unaided and aided SNR-50*

Test conditions	*Sensorineural*						*Conductive*			
	Sloping		*Mild sensorineural*		*Moderate sensorineural*		*Mild conductive*		*Moderate conductive*	
	Z	p	Z	p	Z	P	Z	p	Z	p
Unaided SNR-50 vs. aided SNR-50 without noise reduction	-2.59	0.01*	-0.68	0.49	-2.94	0.00*	0.00	1.00	-0.95	0.34
Unaided SNR-50 vs. aided SNR-50with noise reduction	-2.88	0.00*	-1.98	0.04*	-2.85	0.00*	-2.68	0.00*	-2.30	0.04*

Note: * - p<0.05

The group with moderately severe hearing loss was not included in this calculation since unaided SNR-50 in this group was not measurable since this was done at 45 dB HL. It can be seen from Table 8 that both the aided conditions are significantly different from the unaided condition in most of the groups. In the mild sensorineural, mild and moderate conductive hearing loss groups, there was no significant difference between the unaided condition and the aided without noise reduction conditions. This could be due to the fact that since the users have obtained relatively good scores in the unaided condition itself, there was no room for further improvement. However, even the individuals with good unaided responses seem to benefit from the noise reduction algorithm. The decrease in the SNR-50 with the aided conditions can be explained on the basis of improved audibility and improved redundancy of speech resulting in better performance in the aided condition.

4. Aided SNR-50 with and without noise reduction

From Table 7 it can be noted that there is a general trend in all the groups revealing a decrease in the mean SNR-50 when the noise reduction algorithm was turned 'on'. However, in the moderate sensorineural hearing loss group, there was a slight increase in the SNR-50 with noise reduction. The mean aided SNR-50 with and without noise reduction is depicted graphically in Figure 3. The Wilcoxon Signed Ranks test was used assess if this difference was significant. The results of this test are summarized in Table 9.

Table 9: *Wilcoxon Signed Ranks test to compare the SNR-50 in the aided condition, with and without noise reduction*

Hearing loss groups	*Group*	*Statistic*	*Aided condition: without noise reduction vs. with noise reduction*
Sensorineural	Overall	Z	-.4.44
		p	0.000*
	Flat (overall)	Z	-6.07
		p	0.000*
	Sloping	Z	-1.35
		p	0.176
	Mild	Z	-2.50
		p	0.013*
	Moderate	Z	-1.55
		p	0.120
	Moderately Severe	Z	-3.48
		p	0.000*
Conductive	Overall	Z	-4.26
		p	0.000*
	Mild	Z	-2.84
		p	0.005*
	Moderate	Z	-2.84
		p	0.004*
	Moderately severe	Z	-2.17
		p	0.030*

Note: * - p<0.05

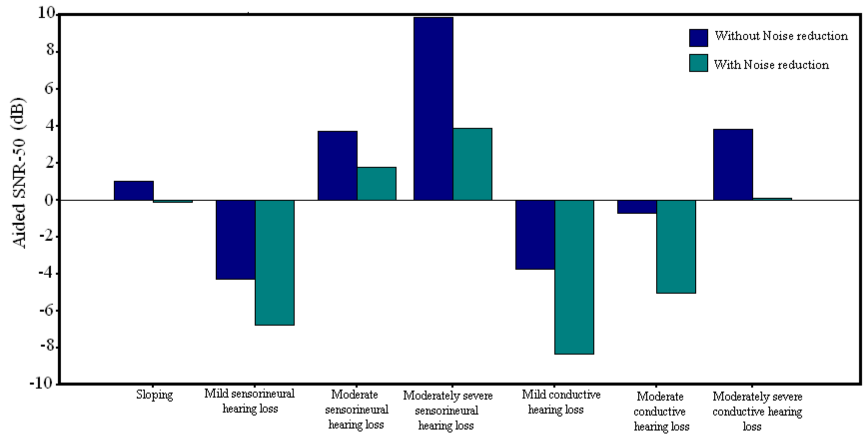

Fig 3: Mean aided SNR-50 at 45 dBHL with and without noise reduction

From Figure 3 it can be observed that overall there was a significant difference in performance when the noise reduction algorithm was switched 'on' in most groups, except the sloping and moderate sensorineural groups. Results from the past have shown contradicting results. Boymans and Dreschler (2000), Ricketts and Hornsby (2005) and Quintino et al., (2010) have reported that there is an improvement in the speech recognition in the presence of noise due to the use of noise reduction algorithms. However, they have reported that this difference was not significant. The present study obtained such results in the sloping and moderate sensorineural hearing loss groups. The present study is in concurrence with findings reported by Alcantra et al. (2003), Peeters et al. (2009) and Kuk et al. (2011) who have reported a significant improvement in the speech in noise performance with the use of noise reduction algorithms. Thus, noise reduction algorithm is effective in improving the performance in noise.

5. **Comparison of the unaided SNR-50 and the ratings on the self-assessment of hearing handicap questionnaire**

The chi square test was used to estimate the association of the questions with respect to configuration of the audiogram, type and degree of hearing loss. The association with degree was estimated separately for sensorineural and conductive hearing loss groups.

a) *Effect of type of hearing loss on listening in noise:* The results of the chi square test to assess the association between the responses to the questions and the type of hearing loss can be observed in Table 10.

Table 10: *Results of chi square test for the association between the responses to the questions and type of hearing loss*

Pearson Chi square for following questions		*Value*	*df*	*p*
1i	While watching a TV program, if the TV is turned on at a normal volume, at a distance of 6-8 feet and there is other noise in the room (eg. others talking)	9.10	2	0.011*
1j	While conversing with a bus conductor in a crowded bus	4.24	2	0.120
1k	While conversing with a friend standing beside you on a crowded railway platform	6.92	2	0.031*
1l	While conversing with a salesman in a busy shop	6.56	2	0.038*
1m	While listening to a speech at a public gathering when you are at a distance of 6-8 feet from the loudspeaker	6.56	2	0.038*
1n	While carrying out conversation with a friend sitting opposite you at a restaurant	5.31	2	0.070
1o	While conversing with a familiar person seated next to you at a wedding hall, if you cannot see his/her face	6.92	2	0.031*
1p	While conversing with a familiar	6.56	2	0.038*

	person who is beside you when you are walking in a busy street			
1q	While conversing with another person seated next to you, if there is a TV/radio playing at normal volume in the same room	6.92	2	0.031*
1u	While conversing with a small group of people at home	3.13	2	0.209
2	Do you turn down the volume of TV/radio before you try to carry on a conversation?	1.26	2	0.533
3	Do you find it hard to understand when several people are talking at the same time?	2.53	2	0.282
4	Can you carry out a conversation when several people are talking in a large room?	4.65	2	0.098
22	Can you hear somebody calling you from behind (from a distance of 6-8 feet), if the TV is turned on at a normal volume?	1.06	2	0.589

Note: * - $p<0.05$

From the Table 10, it can be observed that there is a significant association in the type of hearing loss and the responses to the questions 1i, 1k, 1l, 1m, 1o, 1p and 1q. The other questions did not have any significant association. For the questions that had significant association, it was observed that the responses for individuals with sensorineural hearing loss were concentrated around ‘most of the time’ followed by ‘sometimes’ and then ‘seldom’. However, for those with conductive hearing loss, the responses were concentrated around ‘most of the time’ followed by ‘seldom’ and then ‘sometimes’.

b)Effect of different degrees of sensorineural hearing loss on listening in noise: The results of the chi square test to assess the association between the responses to the questions and the degree of hearing loss for individuals with sensorineural hearing loss can be observed in Table 11.

Table 11: *Results of Pearson's chi square test for the association between the responses to the questions and degree of hearing loss for individuals with sensorineural hearing loss*

Pearson's Chi square for following questions		*Value*	*df*	*p*
1i	While watching a TV program, if the TV is turned on at a normal volume, at a distance of 6-8 feet and there is other noise in the room (eg. others talking)	13.25	4	0.010*
1j	While conversing with a bus conductor in a crowded bus	10.01	4	0.040*
1k	While conversing with a friend standing beside you on a crowded railway platform	10.49	4	0.033*
1l	While conversing with a salesman in a busy shop	10.01	4	0.040*
1m	While listening to a speech at a public gathering when you are at a distance of 6-8 feet from the loudspeaker	10.01	4	0.040*
1n	While carrying out conversation with a friend sitting opposite you at a restaurant	8.42	4	0.077
1o	While conversing with a familiar person seated next to you at a wedding hall, if you cannot see his/her face	10.49	4	0.033*

1p	While conversing with a familiar person who is beside you when you are walking in a busy street	10.01	4	0.040*
1q	While conversing with another person seated next to you, if there is a TV/radio playing at normal volume in the same room	10.49	4	0.033*
1u	While conversing with a small group of people at home	26.26	4	0.000*
2	Do you turn down the volume of TV/radio before you try to carry on a conversation?	21.73	4	0.000*
3	Do you find it hard to understand when several people are talking at the same time?	18.71	4	0.001*
4	Can you carry out a conversation when several people are talking in a large room?	11.51	4	0.021*
22	Can you hear somebody calling you from behind (from a distance of 6-8 feet), if the TV is turned on at a normal volume?	34.60	4	0.000*

Note: * - p<0.05

It can be observed from Table 11 that the responses of all the questions, except question 1n, have a significant association with the degree of hearing loss for individuals with a sensorineural hearing loss. For individuals with mild sensorineural hearing loss, the responses were concentrated around ‘most of the time’ for the first 8 questions and ‘sometimes’ for the remaining 5 questions. For the individuals with moderate sensorineural hearing loss, responses for almost all the questions were centered around ‘most of the time’ and for those with moderately severe sensorineural hearing loss, the responses of all the questions were centered around ‘most of the time’.

c)Effect of different degrees of conductive hearing loss on listening in noise: The results of the chi square test to assess the association between the responses to the questions and the degree of hearing loss for individuals with conductive hearing loss can be observed in Table 12.

Table 12: *Results of chi square test for the association between the responses to the questions and degree of hearing loss for individuals with conductive hearing loss*

Pearson Chi square for following questions		*Value*	*df*	*p*
1i	While watching a TV program, if the TV is turned on at a normal volume, at a distance of 6-8 feet and there is other noise in the room (eg others talking)	9.64	4	0.047*
1j	While conversing with a bus conductor in a crowded bus	12.77	4	0.012*
1k	While conversing with a friend standing beside you on a crowded railway platform	12.90	4	0.012*
1l	While conversing with a salesman in a busy shop	12.90	4	0.012*
1m	While listening to a speech at a public gathering when you are at a distance of 6-8 feet from the loudspeaker	12.90	4	0.012*
1n	While carrying out conversation with a friend sitting opposite you at a restaurant	12.90	4	0.012*
1o	While conversing with a familiar person seated next to you at a wedding hall, if you cannot see his/her face	12.90	4	0.012*
1p	While conversing with a familiar person	12.90	4	0.012*

	who is beside you when you are walking in a busy street			
1q	While conversing with another person seated next to you, if there is a TV/radio playing at normal volume in the same room	12.90	4	0.012*
1u	While conversing with a small group of people at home	16.15	4	0.003*
2	Do you turn down the volume of TV/radio before you try to carry on a conversation?	13.90	4	0.008*
3	Do you find it hard to understand when several people are talking at the same time?	15.61	4	0.004*
4	Can you carry out a conversation when several people are talking in a large room?	13.70	4	0.008*
22	Can you hear somebody calling you from behind (from a distance of 6-8 feet), if the TV is turned on at a normal volume?	3.25	4	0.517

Note: * - p<0.05

It can be observed from Table 12 that the responses to all the questions except question 22 have a significant association with the degree of hearing loss for the individuals with conductive hearing loss. For the individuals with mild conductive hearing loss, the responses were concentrated around ‘seldom’ for all the questions. For the individuals with moderate and moderately severe conductive hearing loss, the responses to all the questions were centered on ‘most of the time’.

d) *Effect of configuration of audiogram on listening in noise:*

The results of the chi square test to assess the association between the responses to the questions and the configuration of the audiogram can be observed in Table 13.

Table 13: *Results of chi square test for the association between the responses to the questions and configuration of audiogram*

Pearson Chi square for following questions		*Value*	*df*	*p*
1i	While watching a TV program, if the TV is turned on at a normal volume, at a distance of 6-8 feet and there is other noise in the room (eg others talking)	5.96	2	0.051
1j	While conversing with a bus conductor in a crowded bus	3.47	2	0.176
1k	While conversing with a friend standing beside you on a crowded railway platform	3.63	2	0.163
1l	While conversing with a salesman in a busy shop	4.05	2	0.132
1m	While listening to a speech at a public gathering when you are at a distance of 6-8 feet from the loudspeaker	4.05	2	0.132
1n	While carrying out conversation with a friend sitting opposite you at a restaurant	2.22	2	0.330
1o	While conversing with a familiar person seated next to you at a wedding hall, if you cannot see his/her face	3.63	2	0.163
1p	While conversing with a familiar person who is beside you when you are walking in a busy street	4.05	2	0.132
1q	While conversing with another person seated next to you, if there is a	3.63	2	0.163

	TV/radio playing at normal volume in the same room			
1u	While conversing with a small group of people at home	11.22	2	0.004*
2	Do you turn down the volume of TV/radio before you try to carry on a conversation?	3.70	2	0.157
3	Do you find it hard to understand when several people are talking at the same time?	2.12	2	0.347
4	Can you carry out a conversation when several people are talking in a large room?	1.34	2	0.511
22	Can you hear somebody calling you from behind (from a distance of 6-8 feet), if the TV is turned on at a normal volume?	3.72	2	0.156

Note: * - $p<0.05$

It can be observed from the Table 13 that there is no significant association between the configuration of the audiogram and the response to most of the questions except 1u. For this question, the responses of individuals with flat configuration were concentrated around 'most of the time'. For individuals with sloping configuration the responses were concentrated equally for 'seldom' and 'most of the time'. Individuals with sloping configuration of audiogram have better thresholds in the low frequencies which could have contributed to this finding.

e) Comparison of the association of the unaided SNR-50 with the responses obtained by the questionnaire

To assess whether the responses of the participants to the questions varied with respect to the severity of the SNR-50, the unaided SNR-50 was classified into gradations. The SNR-50 was said to be excellent if it was between -15 and -5 dB, good if it was between -5 and 5 dB, and poor if it was between 5 and 15 dB. Those individuals in whom the unaided SNR-50 was not measurable due to the severity of hearing loss were categorized into the very poor group.

The chi- square test was conducted to determine the association between the responses to the questionnaire and the degree of unaided SNR-50. The results of the test are displayed in Table 14.

Table 14: *Chi square test for association between the unaided SNR-50 and response to questionnaire*

Pearson Chi square for following questions		*Value*	*df*	*p*
1i	While watching a TV program, if the TV is turned on at a normal volume, at a distance of 6-8 feet and there is other noise in the room (eg others talking)	22.99	6	0.001*
1j	While conversing with a bus conductor in a crowded bus	14.84	6	0.022*
1k	While conversing with a friend standing beside you on a crowded railway platform	18.76	6	0.005*
1l	While conversing with a salesman in a busy shop	20.72	6	0.002*
1m	While listening to a speech at a public gathering when you are at a distance of 6-8 feet from the loudspeaker	20.72	6	0.002*
1n	While carrying out conversation with a friend sitting opposite you at a restaurant	16.35	6	0.012*
1o	While conversing with a familiar person seated next to you at a	18.76	6	0.005*

	wedding hall, if you cannot see his/her face			
1p	While conversing with a familiar person who is beside you when you are walking in a busy street	20.72	6	0.002*
1q	While conversing with another person seated next to you, if there is a TV/radio playing at normal volume in the same room	18.76	6	0.005*
1u	While conversing with a small group of people at home	32.96	6	0.000*
2	Do you turn down the volume of TV/radio before you try to carry on a conversation?	34.37	6	0.000*
3	Do you find it hard to understand when several people are talking at the same time?	39.22	6	0.000*
4	Can you carry out a conversation when several people are talking in a large room?	27.00	6	0.000*
22	Can you hear somebody calling you from behind (from a distance of 6-8 feet), if the TV is turned on at a normal volume?	23.96	6	0.001*

It can be observed from Table 14 that there is a significant association between the unaided SNR-50 and the responses to the questions relating to noise. Those individuals with very poor and poor SNR-50 mostly responded to the questions with 'most of the time'. These individuals exhibited more difficulty in their daily life in the presence of background noise. This type of pattern was also observed in the individuals with good and poor SNR-50. The individuals with excellent unaided SNR-50 did not exhibit any such pattern in the scores. Their scores varied and were mainly distributed in the ‘seldom’ and ‘sometimes’ categories, with a few participants responding for ‘most of the time’ for some questions. Therefore, the difficulty seen in daily life in understanding speech in the presence of noise can be predicted based on the unaided SNR-50 scores.

Conclusion

From the present study conducted on 147 ears, it can be observed that the SNR-50 was significantly different for the individuals with normal hearing and those with hearing impairment. It was also established that the SNR-50 was lower for individuals with conductive hearing loss than those with sensorineural hearing loss, although this difference was not significantly different. The SNR loss increased as the degree of hearing loss increased, with the moderate sensorineural hearing loss group having the highest SNR loss followed by the sloping sensorineural hearing loss group. The aided SNR-50 was significantly lower for all the groups in comparison to the unaided SNR-50. Also, there was a significant effect of noise reduction observed in all the groups except the moderate sensorineural and sloping hearing loss groups. The association between the responses to the questions from the questionnaire assessing the effect of noise and the type, degree and configuration of the audiogram was assessed. It was found that there was no significant association of the response with the configuration of the audiogram for most of the questions, but there was significant association between the responses to the questions on listening in noise with the type and degree of hearing loss for most of the questions. Further, it was observed that those individuals with very poor and poor unaided SNR-50 exhibited more difficulty understanding speech in the presence of noise in their daily life. Therefore, this difficulty could be predicted from the responses to the questions to a certain extent. Thus, the SNR-50 is a very useful and time saving measure and should be included in the routine clinical evaluation.

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Appendix I

SelfAssessment of Hearing Handicap

Vanaja and Nikam (2000)

Rating Scale: Most of the time- 2; Sometimes-1 and Seldom-0

(Please note: Only questions in bold were utilized in the present study)

	Questions
1	Do you have difficulty in understanding speech in the following situations?
a	While conversing with a family member seated next to you, if you cannot see his/her face
b	While conversing with a familiar male from a distance of 6-8 feet, if you cannot see his face
c	While conversing with a familiar female from a distance of 6-8 feet, if you cannot see her face
d	While listening to a family member (without visual cues) who is speaking in a normal tone of voice from a distance of 10-12 feet
e	While conversing with a familiar person over telephone
f	While watching a TV program, if the TV is turned on at a normal volume, at a distance of 6-8 feet, in a quiet room
g	While watching TV news, if the TV is turned on at a normal volume, at a distance of 6-8 feet, in a quiet room
h	While listening to a radio turned on at normal volume, from a distance of three feet in a quiet room
i	**While watching a TV program, if the TV is turned on at a normal volume, at a distance of 6-8 feet and there is other noise in the room (eg others talking)**
j	**While conversing with a bus conductor in a crowded bus**
k	**While conversing with a friend standing beside you on a crowded railway platform**
l	**While conversing with a salesman in a busy shop**
m	**While listening to a speech at a public gathering when you are at a distance of 6-8 feet from the loudspeaker**

n	**While carrying out conversation with a friend sitting opposite you at a restaurant**
o	**While conversing with a familiar person seated next to you at a wedding hall, if you cannot see his/her face**
p	**While conversing with a familiar person who is beside you when you are walking in a busy street**
q	**While conversing with another person seated next to you, if there is a TV/radio playing at normal volume in the same room**
r	While watching a movie in a theatre
s	While listening to somebody whispering at a distance of 6 inches from your ear
t	While carrying out conversation with an unfamiliar person standing beside you, when you are outdoors and it is reasonably quiet
u	**While conversing with a small group of people at home**
v	While conversing with a person seated in front of you at a distance of 3 feet and you are able to watch his face (with adequate light on his face)
2	**Do you turn down the volume of TV/radio before you try to carry on a conversation?**
3	**Do you find it hard to understand when several people are talking at the same time?**
4	**Can you carry out a conversation when several people are talking in a large room?**
5	Do you feel that you understand better when you talk slowly?
6	Do you ask for repetitions when people speak to you?
7	Do you have difficulty in recognizing a familiar voice when your back is turned towards the speaker?
8	Can you identify the direction from which you heard the automobile horn while you are walking on a street?
9	When you are conversing with a group of people, can you identify the location of the speaker?
10	Do you avoid talking to people because you have a hearing problem?
11	Do you hesitate to meet strangers because you have a hearing problem?
12	Does your hearing problem make you to feel left out when you are with a group of people?

13	Do you listen to TV/radio less often because you have a hearing problem?
14	Do you get frustrated when you cannot understand what others say?
15	Do you feel that your family members get annoyed when you do not understand what they say?
16	Do you feel that people leave you out of conversation because you have a hearing problem?
17	Does your family member get annoyed because you raise the volume?
18	Can you hear the following from a distance of 6-8 feet, in a quiet room?
a	A telephone ringing
b	A knock on the door
c	A dog barking
d	Sound of footsteps
e	A tap running
f	Hiss of a pressure cooker
19	Can you hear the following from a distance of 18-20 feet in a quiet room?
a	A bus horn
b	A telephone ringing
c	Hiss of a pressure cooker
20	In a quiet situation, can you hear somebody calling you from a distance of 6-8 feet?
21	In a quiet situation, can you hear somebody calling you from a distance of 18-20 feet?
22	**Can you hear somebody calling you from behind (from a distance of 6-8 feet), if the TV is turned on at a normal volume?**
23	Mention any other situations you have difficulty in hearing (please specify)