Effectiveness of SNR-50 and SNR loss in hearing aid evaluation

(SH/CDN/ARF-35/2015-16 dated 02.11.2015)

Principal Investigator:

Dr. P. Manjula
Professor of Audiology, AIISH, Mysore

Co-investigator:

Ms. Megha
Clinical Assistant, Dept. of Audiology, AIISH, Mysore

Research Officer:

Ms. B N Navya

Duration of the project: One year

Date of commencement: 04.11.2015

Abstract

Objective: To study the effectiveness of signal-to-noise ratio-50 (SNR-50) and signal-to-noise ratio (SNR) loss in hearing aid evaluation. *Design:* A total of 210 participants in the age range from 13 to 60 years participated in the study. The participants were divided into two groups. Group I comprised of participants having normal hearing, minimal sensorineural hearing loss (SNHL), mild SNHL, and moderate SNHL. Group II comprised of separate set of participants with mild SNHL, moderate SNHL, and moderately-severe SNHL. The data from Group I were considered for setting the criterion based on SNR-50 for differentiating the participants who require a hearing aid from those who do not. The data from Group II were considered for evaluating the effectiveness of SNR-50 and SNR loss in selection of hearing aids. *Results:* Area under the Receiver Operating Curve (ROC) curve propounded that SNR-50 or SNR loss measure had good accuracy in discriminating those who require hearing aid from those who do not. Using the ROC, it was found that those individuals who have got SNR-50 or SNR loss more than 3 dB are the candidates who require hearing aid. Performance in terms of speech identification scores did not differ significantly between the two different hearing aids using both the traditional and alternative approach. There was a significant negative correlation between the speech identification scores and questionnaire scores in quiet and a significant positive correlation between the SNR-50 and questionnaire scores in noise. *Conclusions:* The SNR-50 could be effectively used for setting the criterion for differentiating the participants who require a hearing aid from those who do not. An SNR-50 of 3 dB or more would warrant use of a hearing aid. Since the SNR-50, SNR loss, and the SIS are comparable in terms of differentiating the hearing aids, it seems to be justified in inferring that the alternate approach using SNR-50 or SNR loss is equivalent to the traditional approach of SIS measure in selection of hearing aids.

Key words: SIS, SNR-50 SNR loss, Hearing aids

Chapter 1

INTRODUCTION

Individuals with sensorineural hearing loss (SNHL) generally report of difficulty in understanding speech in quiet as well as in the presence of noise. In routine speech audiometry, the speech reception threshold (SRT), speech identification scores (SIS), and the uncomfortable loudness levels (UCL) are established in quiet. However, these measures do not reflect the entire gamut of the problems faced by individuals with hearing impairment. This is because an individual with hearing impairment will have to understand speech not only in a quiet situation but also in the presence of background noise.

It has been documented in literature that the ability to understand speech in the presence of noise cannot be predicted by the pure-tone thresholds (Plomp & Mimpen, 1979; Smoorenburg, 1992). Further, speech recognition has been noted to vary depending on the type of hearing loss, degree of hearing loss, and on the configuration of the audiogram (Bilger & Wang, 1976). There have been reports in literature that listeners with even a mild degree of hearing loss show greater difficulty in the presence of noise when compared to those with normal hearing (Plomp, 1978; Plomp & Mimpen, 1979).

Testing speech recognition in quiet, without and with the hearing aid, is one of the routine measures used in hearing aid evaluation. Relatively good speech recognition in quiet does not ensure good speech recognition in noise as well. In real life, the clients report of more problem while listening to speech in noise. The clients continue to be dissatisfied in the noisy situations, as a result they stop using the device. It is the responsibility of the audiologists to acknowledge such problems and think of ways to evaluate appropriately. Thus, it would be required to measure speech recognition in quiet as well as in noise separately (Taylor, 2011). Thus, testing speech recognition in the presence of noise during hearing aid evaluation is warranted.

Before using the measures of speech in noise for hearing aid fitting clinically, there is a need to accumulate evidence to verify the utility of such measures. It needs to be evaluated if such measures are useful in hearing aid evaluation, both for deciding if a person requires a hearing aid and also in deciding which among the trial hearing aids suits the client.

There are several ways to measure the speech intelligibility. The most common measure being Speech Identification Scores (SIS), measured in percentage, during speech audiometry. Measurement of speech intelligibility at only a few intensity levels may not be beneficial as it may not simulate all the listening situations that an individual faces (Plomp, 1986). It has become increasingly popular to report the speech test findings in terms of signal to noise ratio (SNR) after Dirks, Morgan, and Dubno (1982). They suggested that the speech test finding needs to be reported in terms of SNR, in dB, required for 50% correct recognition of words. This measure is referred to as SNR-50. This is a measure proposed by Dirks, Morgan, and Dubno (1982) in which the effect of background noise on speech recognition can be quantified. The term 'SNR loss' refers to the increased signal-to-noise ratio required by listeners with hearing impairment to understand speech in noise, relative to that required by listeners with normal hearing (Yoon & Allen, 2006). The SNR-50 or SNR loss permits not only the measurement of the extent of SNR impairment but also quantifies the extent of improvement with any of the management options.

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 relationship between the audiogram and SNR loss.

Individuals having sensorineural hearing loss (SNHL) and using hearing aids generally report their maximal dissatisfaction in difficult-to-hear conditions such as in the presence of background noise, multi-talker babble, and reverberation (Kochkin, 2002; Kochkin, 2010). The difficulty of understanding speech in noise is because of the loss of frequency selectivity (Evans, 1975; Pickles, 1986) and reduced temporal resolution (Larsby & Arlinger, 1999), in addition to reduced audibility.

Hearing aids are a common form of management option for individuals with permanent hearing impairment. According to Plomp (1978), a hearing aid amplifies speech and also introduces degradation of the speech signal to some extent. In modern hearing aids, it is possible to bring down the SNR loss from 20 dB in the unaided condition to 5 dB in the aided condition (Killion, 1997). Thus, finding out the extent of SNR-50 or SNR loss in individuals and using this information during hearing aid fitting will increase the amount of benefit obtained from hearing aids. This in turn will help in achieving better satisfaction with hearing aid usage.

Hearing aids are expected to improve audibility of sounds for people with hearing loss. However, the ability to make use of the amplified signal, especially in the presence of competing noise, can vary across people. The person may perform well in a quiet situation but not so in a noisy situation. This warrants use of appropriate measures during selection of hearing aids.

Need for the study

In routine audiological and hearing aid evaluation, the speech stimulus is presented in quiet. The performance in the absence of any form of background competitor (such as noise) is a poor predictor of the speech recognition ability in noise (Carhart & Tillman, 1970). Thus, it is important to assess speech recognition in noise as it gives more information about the realistic environmental situation that an individual with hearing impairment faces. Cohen and Keith (1976) and Leshowitz (1977) have demonstrated marked reduction in speech recognition scores in the presence of noise in individuals with hearing impairment compared to those with normal hearing. Hence, there is a need to quantify the speech recognition in presence of noise in different degrees of hearing impairment. In the present study, speech recognition in the presence of noise is measured in individuals with different degrees of sensorineural hearing loss under the aided condition. Generally, hearing aids are recommended based on the hearing aid evaluation in a quiet situation in clinics. But this does not fully reflect the disability that an individual has in reality. Testing in a quiet situation may actually overestimate the performance in other situations. Such kind of a testing gives false expectations to the client regarding the hearing device. Ultimately, the client ends up feeling dissatisfied with the hearing aid in real life. Hence, there is a need for a more comprehensive approach to measure the speech recognition ability in the presence of noise for individuals having hearing loss. Thus, quantification of speech recognition ability in the presence of noise can help the clinician to objectively prove and counsel about the realistic expectations from a hearing aid.

The outcome from a hearing aid can be known from administering questionnaires. One of the subjective means for measuring the extent of problem faced by an individual with hearing loss is using ratings on self perceived hearing handicap scale (Palmer, Solodar, Hurley, Byrne, & Williams, 2009). If such scales are administered without and with a hearing aid, then the extent to which a hearing aid improves the hearing ability could be measured.

In order to know that evaluation of speech perception in the presence of noise is better than the routinely used procedure, there is a need to compare the traditional method of hearing aid evaluation, i.e., testing speech identification in quiet with an alternate method of assessing the aided performance, i.e., testing speech identification in the presence of noise. One of the methods of testing speech identification in the presence of noise for clinical hearing aid evaluation is by computing the measure called SNR loss and prescribing the hearing aid that yields the minimum SNR loss. This would in turn provide a scientific evidence to substantiate its efficacy and to compare it with the traditional hearing aid testing in a quiet condition. It would also be interesting to note if the same hearing aid would be prescribed when tested in quiet and/or in noise. One of the objectives of the present study was therefore to assess the appropriateness of using the SNR loss as a measure in clinical hearing aid evaluation as compared to the traditional hearing aid evaluation of assessing speech in quiet.

Aim of the study:

To study the effectiveness of SNR-50 and SNR loss in hearing aid evaluation.

Objectives: The specific objectives were:

1.1. To derive a cut-off criterion based on SNR-50 to decide if a person is a candidate for hearing aid.

- 1.1.1. To compare the SNR-50 across participants with normal hearing, minimal SNHL, mild SNHL, and moderate SNHL.
- 1.1.2. Comparison of the rating score on hearing handicap questionnaire across mild, moderate, and moderately severe hearing loss.
- 1.1.3. Derivation of a cut-off criterion based on SNR-50.

1.2. To select a hearing aid based on the identification of speech in quiet (traditional approach) and identification of speech in noise (alternate approach).

- 1.2.1. To compare SRS, SNR-50, and SNR loss with two hearing aids

1.2.2. To compare the rating score on hearing handicap questionnaire with two hearing aids.

1.2.3. To select a hearing aid based on speech in quiet (traditional approach) and identification of speech in noise (alternate approach)

Chapter 2

REVIEW OF LITERATURE

The hearing aid selection is carried out generally by evaluating the aided performance in quiet situation. Such quiet or sound treated conditions are not representative of real world situations. Hearing aid wearers report that the biggest problem with their hearing aids is that of understanding speech in the presence of background noise.

Pearsons, Bennet, and Fidell (1977) determined that in a typical face-to-face communication, the signal to noise ratio reduces as the background noise increases. Individuals with cochlear hearing impairment often complain that it is difficult to understand speech, especially in background noise. In individuals with sensorineural hearing loss, the frequency selectivity and temporal resolution is usually reduced.

There are several measures that evaluate an individual's ability to understand speech in the presence of noise. There are tests that assess speech identification in noise and thus they are directly related to the communication difficulties that an individual actually faces in the real life. Such measures would be useful to make a decision about a hearing aid and also to select a particular hearing aid from a group of pre-selected hearing aids. These measures are useful in counselling since they reveal the extent of problem that an individual has and to what extent a hearing aid will help in those situations.

There are several studies conducted on speech recognition at different SNRs in individuals with cochlear hearing loss. Individuals with cochlear loss required higher SNR level to achieve the same performance as that of individuals with normal hearing (Festen, 1987; Glasberget 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).

Killion (1997) reported that when fitting and counselling patients, it is important to know that sensitivity loss and signal-to-noise ratio (SNR) loss can be relatively independent qualities. For example, one person may report incredible results after being fit with hearing instruments, while another person may be disappointed. As reported by Kochkin (2002), only 30% of individuals wearing hearing aids were satisfied with the performance of their device in noisy situation. Individuals with sensorineural hearing loss (SNHL) have more difficulty in understanding speech in the presence of background noise or babble than those with normal hearing (Dubno, Dirks, & Morgan, 1984; Plomp, 1978; Plomp & Duquesnoy, 1982). Individuals who require more favourable SNRs to understand speech are less likely to be successful with hearing aids than those who can understand speech at lesser SNRs (Walden & Walden, 2004).

Beattie, Barr, and Roup (1996) assessed word recognition scores in individuals with normal hearing and those with hearing impairment. In this study, 51 subjects were tested at 50 dB HL using SNRs of 5, 10, and 15 dB. Thirty subjects with mild to moderate sensorineural hearing losses were tested, in quiet and in noise, at SNR of 10 dB and 15 dB. The results suggest that subjects with mild to moderate sensorineural hearing loss require more favourable SNR than those with normal listeners to achieve comparable word recognition scores.

Wilson et al. (2003) measured the word recognition abilities of 24 listeners with normal hearing; wherein ten monosyllabic words were presented at seven different Signal to Babble Ratios (SBRs), i.e., at 24 dB, 20 dB, 16 dB, 12 dB, 8 dB, 4 dB, and 0 dB SBRs. They employed a quasi-randomized method by presenting babble at fixed level and speech signal level at varying levels. In their study, listeners with normal hearing performed greater than 90% accurately at SBRs of greater than 8 dB. The participants achieved 50% correct score at 4 dB SBR. In the same study, for listeners with normal hearing, they estimated SBR at which 50% correct responses were obtained which was 4.1 dB.

According to quantitative model given by Plomp and Duquesnoy (1982), hearing loss for speech is due to two different classes of impairments. They include Class A loss which is the attenuation of all the sounds entering the ear leading to sound energy to fall below the threshold and hence not being detected at all; and Class D loss which refers to the distortion of sounds which are otherwise within the audible region of the individual. They explained that, Class A loss is effective for only quiet situation and where noise levels are so low that it does not affect the speech recognition threshold; whereas Class D loss leads to increase in thresholds in both quiet as well as in noise. This distortion component is primarily responsible for speech recognition in noise.

Individuals with pure tone average (PTA) of 40 dB HL had an SNR-50 ranging from -3dB to +4 dB. Souza and Tremblay (2006) suggested probable biological reason for this variability to be neural codes in the cortex which are interrupted due to the presence of noise. Dirks, Morgan, and Dubno (1982) evaluated the performance in terms of speech recognition in noise in individuals with mild sensorineural hearing loss using an adaptive psychophysical procedure. They measured the signal to babble ratio (SBR) required to obtain a pre-determined score at various speech presentation levels. They reported that larger SBRs, than that required by listeners with the normal hearing, were required not only at low sensation levels which may be attributed to both attenuation as well as distortion factor; but also at high supra threshold levels (i.e., 96 dB SPL) having contribution solely from distortion factor. Thus, it can be inferred that increasing the intensity of speech will address only the attenuation issue and not the distortion factor.

Dubno, Dirks, and Morgan (1984) measured speech recognition performance in quiet as well as in noise for subjects divided into four groups based on age and their hearing status. The four groups comprised of young individuals having hearing sensitivity within normal limits, older adults with normal hearing sensitivity, young and older participants having equivalent levels of mild SNHL. Such classification of subjects was done to study the independent effect of age and hearing status on speech recognition in noise as a tool to differentiate listeners having normal hearing and those with mild hearing loss but with excellent speech recognition in quiet. The findings of their study revealed the fact that understanding of speech in adverse listening situations is determined not only by audiometric thresholds but also by the age factor. Such that, differences in performance on speech recognition task in noise, as a function of age, were seen at speech levels ranging from moderate to (56 dB SPL) to loud (88 dB SPL). In addition, these age effects were independent of hearing loss, i.e., differences in performance in noise between younger and older subjects were seen for both normal hearing as well as those with mild hearing loss. The finding of this study also supports the fact that individuals having mild sensorineural hearing loss (SNHL) have reduced speech recognition in noise compared to those with normal hearing. In addition, the researchers opined that the use of such adaptive strategy is necessary to identify subtle communication difficulties which go unnoticed by the standard audiometric evaluation. This can further enable the clinician to provide effective counselling regarding realistic expectations from the hearing aid and performance with hearing aid in difficult communication settings.

According to Crandell (1991) and Plomp (1986), the ability to understand speech in noise varies across individuals with same degree and configuration of SNHL. This variability explains the differences in terms of individual benefit from rehabilitation strategies, i.e., individuals having high susceptibility to noise may derive limited benefit from conventional amplification devices; whereas, signal processing strategies, such as noise reduction, speech enhancement and compression, may benefit them.

Nabelek and Pickett (1974) investigated speech recognition performance in noise for five listeners with moderate degree of high frequency SNHL using modified rhyme test (MRT) at an SNR ranging from +10 to -10 dB. The individual data of speech recognition susceptibility scores indicated variability from 23% to 67% at an SNR of -5 dB. Many research findings involving speech recognition data are usually reported as mean values for heterogeneous group of individuals with hearing impairment. Though, the group data are useful in establishing a trend between individuals with normal hearing and individuals with hearing impairment, it is of limited utility in assessment and management of a single individual with hearing impairment.

Killion (1997) classified difficulties of individuals with cochlear hearing loss into two aspects. First being the difficulty hearing in quiet situations or the sensitivity loss; and second being difficulty in understanding speech predominantly in the presence of noise or clarity loss. This latter measure is also called SNR loss. The sensitivity loss or audibility loss is measured using pure tone thresholds and is plotted on the audiogram to represent the dB increase in threshold across frequencies. On the contrary, the SNR loss is the lack of ability to understand speech at an SNR commonly used by individuals with normal hearing and this cannot be predicted by the audiogram (Plomp & Mimpen, 1979; Smoorenburg, 1992). This measure remains undetected in clinical hearing aid evaluation which is routinely performed in a quiet background. Hence, assessing the performance of an individual in the absence of competing noise will be a poor predictor of the difficulty a listener would actually face in real life. This supports the fact that the SNR loss cannot be predicted from the pure tone audiogram. In this context, Killion and Niquette (2000) discussed and weighed the usefulness of two methods of assessment, i.e., audiogram versus SNR loss. They reported that with information on audiogram alone without SNR loss, it becomes difficult to provide realistic expectation to the client regarding performance with the hearing aid in noise. So far, classification of hearing loss is based on the results of the pure tone audiometry. As recognized earlier, even individuals having the same degree of hearing loss perform differently in the presence of noise and rate their degree of hearing handicap differently.

Kochkin (2010) reported the outcome of MarkeTrak VIII survey carried out for evaluating customer satisfaction with hearing aids from 1989 to 2008. Ratings on a seven- point Likert scale (‘very dissatisfied’, ‘dissatisfied’, ‘somewhat dissatisfied’, ‘neutral’, ‘somewhat satisfied’, ‘satisfied’, ‘very satisfied’) were obtained from the consumers. On consumer satisfaction with signal processing and sound quality, the area with highest negative ranking was the use in ‘noisy’ situations. The consumer satisfaction was further assessed in 19 listening situations, the results of which were rated with minimal satisfaction included school/classroom, in large group conversation, sporting events, and at workplace which could be because of noisy background in these situations. In addition to the above findings, Kochkin (2007) also reported that only 29% of the hearing aid users indicated satisfaction with their hearing aid in noisy situations. Hence, it has a modest utility to people with hearing loss, especially in noisy situations and public places. He also described that satisfaction with hearing aid is correlated with ‘multiple environmental listening utility’ or MELU. The consumers report high overall satisfaction with their amplification device when they are able to perform well in many listening situations. It is also estimated that in order to reach a respectable overall 80% level of satisfaction by the consumer, the consumers should at least be ‘somewhat satisfied’ with their amplification devices in 70% of the important listening situations (Kochkin, 2007). Killion and Niquette (2010) also suggested categories for SNR loss. This included mild category with an SNR loss of 0 to 4 dB and profound category with an SNR loss of ≥20 dB. They also explained that SNR loss of 20 dB withdraws an individual from normal conversation at parties; hence it is referred to as profound loss.

Fabry (2005) proposed that SNR loss which is derived from SNR-50 as a tool most appropriate to estimate listening performance of speech in noise of an individual. Taylor (2003) reported that an individual with normal hearing sensitivity requires an SNR between 0 and +2 dB in order to understand 50% of the words in a sentence. Whereas, a person with SNR loss of 10 dB will require the speech to be 10 dB above the noise level in order to comprehend 50% of the sentence. That is, SNR loss is the increase in dB required by an individual with hearing impairment to comprehend speech in noise at a level equivalent to those with normal hearing. Many researchers have considered SNR loss as an ideal counselling tool as it is a true reflection of performance of an individual in real world listening situations. Several researchers have classified the problem in hearing in terms of degree of SNR loss. It has been reported that an SNR loss of 0 to 2 dB is normal, an SNR loss of 2 to 7 dB is mild SNR loss, an SNR loss of 7 to 15 dB is moderate SNR loss, and an SNR loss exceeding 15 dB is considered as severe to profound SNR loss (Fabry, 2005; Taylor, 2003). This information of SNR loss measure is not reflected by the pure tone audiogram. Hence, this valuable information can be obtained only through measurement of the SNR loss.

Wilson, Abrams, and Pillion (2003) reported that word recognition task in the multi-talker babble paradigm can efficiently quantify the ability of individual listeners with either normal hearing or hearing loss to understand speech in background noise. The listeners with normal hearing and peripheral hearing loss had similar word recognition abilities in quiet at 60 dB and 80 dB HL. For equal recognition performance in multi-talker babble, however, listeners with mild-to-moderate hearing loss required on an average of 5.5 dB more favourable SBR than those with normal hearing.

Clinically, two kinds of speech in noise tests can be used. One of them is fixed signal to noise ratio (SNR) tests that measure a percent correct at a fixed SNR. The SNR conditions are established by the clinician prior to the test, and remain unchanged throughout. The main advantage of this is they provide a straightforward percent correct score for hearing aid benefit that is easy to explain to patients. But the disadvantage is that it is difficult to know where to fix the SNR. For example, if the test is given at very challenging SNR (-6 dB SNR), the results may under estimate the amount of benefit the hearing aids are providing the patient. On the other hand, the aided benefit may be over estimated if the selected SNR is too high during hearing aid testing.

An alternate method done using the SNR-50 measure will be useful. The SNR-50 is the signal to noise ratio (SNR) required for correct repetition 50% of the words. The SNR-50 was investigated in a study done by Manjula and Megha (2012) among 44 adults with normal hearing in the age range from 15 to 65 years. The procedure used by them was by presenting speech at a constant level of 45 dB HL and speech noise through the same loudspeaker of the audiometer. The initial level of speech noise was kept at 30 dB HL and varied in order to measure the level that was required for 50% correct repetition of words being presented. The SNR required for 50% correct repetition of words was calculated and was considered as SNR-50. The approximated mean SNR-50 for individuals having hearing sensitivity in their study was -7.23 with a standard deviation of 3.65. The median of the SNR-50 for individuals with normal hearing was -7.00. The SNR loss for listeners with normal hearing was estimated by Manjula and Megha (2012) by subtracting the SNR-50 of the group with mean SNR-50 of ears with normal hearing, which resulted in a value of zero decibel (0 dB).

According to study done by Jaisinghani and Manjula (2015), the SNR loss measure has been used for hearing aid evaluation to identify candidates who require hearing aid and also to select the suitable hearing aid from trial hearing aids. In this study, it was reported that there was a significant difference in SNR loss across the two groups of participants divided based on the decision of hearing aid candidacy. This was such that the participants presumed to be candidates for amplification device based on questionnaire rating score had a significantly higher SNR loss than those who were not considered as candidates. The cut-off SNR loss criterion established using this data was 5.5dB, using the area under the receiver operating curve (ROC). Further, they reported that the aided SIS measure failed in differentiating the two trial hearing aids accurately compared to the aided SNR loss which statistically differentiated the two trial hearing aids. From this finding, it is proposed that the two trial hearing aids employed in the study imparted similar benefit in quiet situation but had statistically significant difference on performance in noise. This would help in recommendation of a hearing aid that would be more useful in noise.

In the same study by Jaisighani and Manjula (2015), it was found that there was no statistically significant correlation between quality ratings across five parameters (loudness, fullness, naturalness, clearness, and overall impression) with the measures of aided SIS, aided SNR loss for both the trial hearing aids. This could be because of variability in expectation and yardstick of rating employed by each participant. Apart from this, lack of acclimatization with hearing aid might have yielded quality rating with less reliability.

One of the subjective methods for measuring the extent of problem faced by an individual with hearing loss is using ratings on self-perceived hearing handicap scale (Palmer, Solodar, Hurley, Byrne & Williams, 2009). Palmer et al. (2009) evaluated the usefulness of a single question in determining the readiness of an individual for amplification. The question considered in their study was “On a scale from one to ten, one being the worst and ten being the best, how would you rate your overall hearing ability?” The test-retest reliability of this question was assessed and also its predictive value was evaluated based on the final purchase of the hearing aid. Ratings from one to five was associated with more likelihood to purchase hearing aid, whereas from eight to ten was associated with less likelihood to purchase amplification device. On a similar note, in order to apply SNR loss as an objective measure clinically, it should be able to distinguish individuals who are candidates for amplification device from those who are not. Hence, there arises a need to fix a cut-off criterion of SNR loss reflecting the need for amplification. In the present study therefore, one of the objectives undertaken was to set the cut-off criterion of SNR loss for demarcating the need for amplification device.

Given the relevant literature on the use of testing the performance on speech perception in noise, the aim and objectives were formulated. The aim of the study was to evaluate the effectiveness of SNR-50 and SNR loss in hearing aid evaluation. There were four objectives of the study. First objective was to set a cut-off criterion and other three objectives were to compare the benefit across two approaches of hearing aid evaluation, i.e., traditional approach of testing in quiet and alternate approach of testing in noise.

Chapter 3

METHODS

To derive a cut-off criterion based on SNR-50, a standard-group comparison type of research design was used. In order to evaluate the two hearing aid selection approaches (i.e., speech recognition in quiet, i.e., SIS, and speech recognition in noise, i.e., SNR-50 & SNR loss), a quasi-experimental research design was utilized.

Participants

A total of 210 participants in the age range from 13 to 60 years who were native speakers of Kannada language, which is an official Dravidian language spoken by the people of Karnataka state, were recruited for the study. All of them had adequate speech and language.

Inclusion criteria.

The participants were divided into two groups. Group I comprised of participants having normal hearing (NH group, n=30), minimal SNHL (Minimal SNHL group, n=30), mild SNHL (Mild SNHL group, n=30), and moderate SNHL (Moderate SNHL group, n=30). Group II comprised of separate set of participants with mild SNHL (Mild SNHL group, n=30), moderate SNHL (Moderate SNHL group, n=30), and moderately-severe SNHL (Mod-severe SNHL group B, n=30). The data from Group I were considered for setting the criterion based on SNR-50 for differentiating the participants who require a hearing aid from those who do not. The data from Group II were considered for evaluating the effectiveness of SNR-50 and SNR loss in selection of hearing aids.

For the above testing, either right or left ear was the test ear in case of participants in whom the hearing loss was symmetrical; and the better ear was considered as the test ear in case the hearing loss was asymmetrical. Prior to the testing, written informed consent was obtained from all the participants. Further, the ethical guidelines framed by the AIISH ethical committee were followed. In addition, ethical clearance was obtained from the AIISH ethical committee.

Exclusion criteria.

Individuals with middle ear infections, retro-cochlear pathology, auditory neuropathy spectrum disorders, and cognitive / psychological complaints were excluded from the study.

Test Environment

The testing was carried out in an air-conditioned, sound treated single- or double- room test suite. The noise levels were within the permissible limits [re: ANSI S3.1-1991 (R2013)].

Instruments and tools

The following instruments and speech material were used in the study.

- A calibrated two-channel diagnostic audiometer was used to measure the pure tone air-conduction and bone-conduction thresholds, speech recognition threshold (SRT), speech recognition scores (SRS), uncomfortable level (UCL), and, the unaided and aided sound field testing.
- A calibrated middle ear analyzer was used to measure tympanogram and acoustic reflexes in order to ensure normal functioning of the middle ear.
- Test hearing aids: Two best suitable digital behind the ear (BTE) hearing aids connected to custom ear molds were used. The hearing aids having four channels, three programs, and two microphone modes (omni-directional & directional) with a fitting range from mild to severe degrees of hearing loss were selected.

- Hardware and software for programming the test hearing aids: NOAH and hearing aid programming software installed in the personal computer. NOAH link was used to connect the test hearing aid that was in turn connected to the personal computer.
- A Dell Latitude 3540 laptop with Intel core processor was connected to the auxiliary input of the audiometer using audio/video cable for presentation speech stimuli. Kannada speech material and multi-talker babble were presented from laptop, using Adobe Audition software (version 3.0)
- Recorded phonemically balanced (PB) speech test material in Kannada, developed by Manjula, Geetha, Kumar, and Antony (2014) was utilized. The test material consists of 21 lists of bi-syllabic words. This was used to obtain the unaided and aided speech identification - in quiet (SRS) as well as in noise (SNR-50).
- Four-speaker multi talker babble in Kannada (Kumar, Ameenudin, & Sangamanatha, 2012) was used to obtain the SNR-50.
- The questionnaire titled Self-Assessment of Hearing Handicap (SAHH) (Vanaja, 2000) was used, with modification in rating scale. That is, the rating scale was changed from a three-point to a seven-point (Cox & Alexander, 1995) scale.

Procedure

The following procedure was utilized to select the participants and also to collect the data for the study.

Procedure for selection of participants.

Pure tone thresholds at octave frequencies from 250 Hz to 8000 Hz in air- conduction and 250 Hz to 4000 Hz in bone-conduction were obtained using modified Hughson-Westlake procedure (Carhart & Jerger, 1959). The immittance evaluation was carried out to rule out any middle ear pathology in the test ears of the participants. The speech recognition threshold (SRT) was obtained using the method given by Tillman and Olsen (1973). The speech recognition scores (SRS) was obtained at 40 dB SL (re: SRT) by presenting the recorded PB word list in Kannada (Manjula et al., 2014). The participant was instructed to repeat the words that were presented. The number of words correctly repeated was noted, maximum number of words in the list being 25. The uncomfortable level (UCL) for speech in the test ear of the individual was noted.

For the purpose of the study, the data were collected in two phases, Phase 1 and Phase 2. The Phase 1 was carried out to achieve the first objective of the study; whereas, Phase 2 was carried out to achieve the other three objectives.

Phase 1: Estimation of SNR-50 and SNR loss to set the cut-off criterion

This phase was conducted to derive a cut-off criterion based on the SNR loss in order to decide if a person is a candidate for hearing aid. For this, the signal to noise ratio required for correctly identifying 50% of the words being presented (i.e., SNR-50) was measured for each test ear of all the participants in Group I. This was followed by estimating the SNR loss for the participants under Group I. The SNR loss was computed by subtracting the average SNR-50 of the participants with normal hearing (in Group I) from the SNR-50 of each participant with hearing loss in Group I. The SNR loss was then compared with the ratings on the self-assessment of hearing handicap (SAHH) questionnaire in order to derive the cut-off criterion for deciding the need for a hearing aid.

To ensure test-retest reliability on the questionnaire response, the participant was sent back along with the copy of questionnaire and the rating scale, after the testing. With a minimum span of four weeks of hearing aid usage, the experimenter asked each one of them, telephonically, to judge the performance in aided hearing. Scoring was done based on the rating scale of the questionnaire (Jaisinghani, 2015). The decision on whether a participant required a hearing aid or not was based on the criterion inferred from that given by Palmer et al. (2009). The participants were divided into two groups based on their overall scores on the questionnaire. Palmer et al. (2009) evaluated usefulness of single question in determining need of amplification device. They reported that 40% worse hearing ability rating was related to 58% predicted probability of hearing aid purchase. Therefore taking this as the reference, 40% of the total maximum score (40% of 203 = 81.2 ≈ 80) was considered as the score which demarcates the need for the amplification device. The participants were divided into two groups based on whether they require hearing aid (total score ≥ 80) or not (total score < 80).

Phase 2: Hearing aid evaluations using two approaches and comparison of benefit

The audiological evaluation to confirm the participant criteria was performed. In Phase 2, hearing aid benefit across two hearing aid evaluation approaches, the traditional/routine approach of testing aided speech identification in quiet versus the alternate approach of using aided SNR loss was compared. For the purpose of hearing aid evaluation, two different digital BTE hearing aids were programmed with NAL-NL1 procedure with an acclimatization level of 2. For optimization, audibility for Ling's six sounds was ensured while programming. This was carried out on participants from Group II. In Phase 2, the aided speech identification in quiet and in noise (using SNR-50 & SNR loss) were established in a calibrated sound field. This was performed in aided conditions for the two test hearing aids.

The speech recognition score in quiet was obtained at 45 dB HL using the recorded speech identification test material in Kannada. The number of correctly identified words was noted for each test ear. For SNR-50, the recorded speech material (PB words) and four-speaker multi-talker babble in Kannada was used. The PB word list was presented at a constant level of 45 dB HL through the audiometric loud speaker kept in front of the participant at 0^o Azimuth and one meter distance. The speech babble was also presented through the same audiometric loud speaker. The initial level of speech babble was kept 15 dB HL below that of the speech (i.e., 30 dB HL). An adaptive method was used, in which the level of speech babble is varied systematically in order to establish the SNR-50.

The participant was instructed to listen to the words and repeat them while ignoring the noise/babble. Gradually, the level of noise was varied till the participant repeated two out of four words (i.e., 50 %) being presented. At this instance, the difference in level of speech and multi-talker babble was noted as the SNR-50 measure. All these measurement was done for each test ear of participants.

The mean SNR-50 of individuals with normal hearing was computed. The SNR loss for each participant with minimal, mild, and moderate hearing loss was computed using the method suggested by Killion and Niquette (2000). According to which the SNR loss was obtained by subtracting the mean SNR-50 of individuals with normal hearing from the SNR-50 of the participants with different degrees of hearing loss.

Analyses:

The data from the first and second phases of the study were compiled, tabulated, and subjected to statistical analyses using Statistical Package for Social Science (SPSS for Windows, version 17.0). The mean, median, range, and standard deviation of SIS in quiet, SNR-50, and SNR loss were obtained for the basic description of the data. Receiver operating curve (ROC) was performed to develop a cut-off criterion to differentiate clients who require hearing aid from those who do not. Analyses were also done to know the approach, among the traditional (i.e., aided SRS in quiet) and alternate i.e., (aided SNR loss), that was better to prescribe hearing aids in a clinical set-up. Further, the benefit scale and quality judgment ratings for each hearing aid was assessed to know if any correlation existed between them and the aided SIS and SNR loss.

Administration of self-assessment of hearing handicap (SAHH) questionnaire

The participants with minimal, mild, moderate, and moderately-severe sensorineural hearing loss were administered the Kannada translated version of SAHH questionnaire. The participant was instructed to rate their difficulty in listening across varied situations on a seven-point (always-99%, almost always-87%, generally-75%, half-the-time-50%, occasionally-25%, seldom-12%, and never-1%) rating scale. For the purpose of scoring, only eight questions with its sub-parts were considered. This comprised of a total of 14 questions, including sub-parts assessing speech comprehension in quiet (1a to 1h, 1s, 1t, 1v, 5, 6, & 7) and 15 questions including sub-parts assessing speech comprehension in noise (1i to 1r, 1u, 2, 3, 4, & 22). At the end, an open-ended question was included to collect information on any other condition in which he/she felt difficulty in hearing.

To ensure test-retest reliability on the questionnaire response, the participants was sent back along with the copy of questionnaire and the rating scale, after the testing. With a span of four weeks, the experimenter again asked them, telephonically, to judge the difficulty in hearing. The scoring of responses over the rating scale was done such that, most frequent occurrence of difficulty over rating scale for a listening situation was given the highest score. Hence, rating for never (1%) was given a score of 1, seldom (12%) was scored as 2, occasionally (25%) as 3, half-the-time (50%) as 4, generally (75%) as 5, almost always (87%) as 6, and always (99%) was scored maximum as 7. Independent scores of questions in quiet (15 questions) and noise (14 questions) were computed for each participant, in addition to the overall score considering all the 29 questions. Thus, a total score for each participant ranged from a minimum score of 29 (i.e., score of 1 * 29 questions) to a maximum score of 203 (i.e., score of 7 * 29 questions).

Setting the cut-off criterion for SNR loss

The data on SNR loss of participants with minimal, mild, moderate, and moderately-severe hearing loss were analyzed to investigate if a relationship existed between SNR loss, SIS, and the questionnaire rating.

Phase 2: Hearing aid evaluations using two approaches and comparison of benefit

In this phase, hearing aid benefit across two hearing aid evaluation approaches, the traditional approach of testing aided speech identification in quiet versus the alternate approach of using aided SNR loss were compared. For the purpose of hearing aid evaluation, two different digital BTE hearing aids were tested on participants from Group 2. This phase was carried out to achieve the last three objectives of the study.

Hearing aids programming and optimization.

To accomplish Phase 2, two four-channel digital BTE hearing aids were programmed for the test ear. The hearing aids were connected to the NOAH link which in turn was connected to the personal computer into which the NOAH and hearing aid fitting softwares were loaded. The hearing aids were programmed to 'first-fit' setting using the NAL-NL1 fitting formula, keeping the acclimatization level at 2. The gain for each of the hearing aid was optimized until the individual was able to repeat the Ling's six sounds. These two hearing aids were tested in two conditions that is, trials for identification of words in quiet (SRS) as well as trials involving estimation of SNR-50 and SNR loss. Each participant under Group 2 was tested with evaluation of speech recognition in quiet and in noise.

Aided speech identification in quiet.

Each participant was made to sit comfortably at one meter distance away from loud speaker of the audiometer in a sound treated test room. The performance of each test ear was evaluated with both the hearing aids. This was done by presenting the recorded PB word list (Manjula et al., 2014) in the sound field through loud speaker kept at 0° Azimuth and at a distance of one meter. Each PB word list contained 25 words. The participant was instructed to repeat the words. The scoring was based on number of words identified correctly. Each correctly identified word was given a score of one, thereby yielding the SRS. The maximum speech recognition score was 25. The hearing aid yielding better speech recognition scores was fitted to the participant for duration of ten minutes. In the course of this duration, the participant was made to converse with family member/s or informant, in a regular room. Additionally, the participant was made to hear to a recorded Kannada passage presented through the loudspeaker of an audiometer at 45 dB HL.

Aided speech identification in noise.

Initially, the SNR loss for all participants under Group 2 was estimated. For this, the SNR-50 measure was obtained first in the unaided condition, with the speech presented at 20 dB SL(ref: SRT) and multi talker babble was varied from a starting level of 15 dB HL below the level of speech. The level of the babble was increased in 5 dB steps and later in 1 dB steps to accurately obtain the SNR-50. The SNR loss was computed for each test ear of the participant by subtracting the mean SNR-50 of the individuals with normal hearing from the SNR-50 of the participant with hearing loss.

The aided SNR loss was also estimated for both the trial hearing aids by keeping speech at a constant level of 45 dB HL, while the babble was kept at 30 dB HL initially. Then the same procedure was followed to obtain the SNR loss as described earlier. At the end of the testing with each trial hearing aid, the participant was administered the SAHH questionnaire.

Comparison across two approaches of hearing aid evaluations.

The data obtained from the Phase 2 comprised of unaided SNR-50 and SIS. Also aided SIS with first and second hearing aid and aided SNR-50 with first and second hearing aid were obtained for all the participants in Group 2.

The data were tabulated and SPSS was used for statistical analysis. Tests of normality, descriptive statistics and inferential statistics were carried out.

Chapter 4

RESULTS

The aim of the present study was to evaluate the effectiveness of SNR-50 and SNR loss in hearing aid fitting. To satisfy the specific objectives, a total of 220 participants were included in the study. The data were collected on Speech identification scores (SIS) for words in quiet, Signal-to-noise ratio- 50 (SNR-50), and SNR loss. The data were also tabulated on subjective rating on a questionnaire regarding speech perception in quiet and noise for participants with normal hearing and with different degrees of hearing impairment. The tabulated data were subjected to statistical analyses using the Statistical Package of Social Sciences (SPSS version 17). Initially the mean, median, range, and standard deviation (SD) of these measures were computed. Shapiro-Wilk test of normality was performed and the results revealed that the data were not normally distributed. Hence, non-parametric tests were employed in the study. The results are provided under the following headings:

4.1. Cut-off criterion, based on SNR-50, to decide if a person is a candidate for hearing aid.

- 4.1.1. Comparison of the SNR-50 across participants with normal hearing, minimal SNHL, mild SNHL, and moderate SNHL.
- 4.1.2. Derivation of a cut-off criterion based on SNR-50.

4.2. Hearing aid selection based on the identification of speech in quiet (traditional approach) and identification of speech in noise (alternate approach).

- 4.2.1. Comparison of SRS, SNR-50, and SNR loss with two hearing aids.
- 4.2.2. Comparison of the rating score on hearing handicap questionnaire with SNR-50.

PTA, SIS, SNR-50, and SNR loss in ears with normal hearing, minimal, mild, and moderate sensorineural hearing loss

The mean and standard deviation (SD)of pure tone average (PTA), speech identification scores (SIS), SNR-50, SNR loss, and rating on handicap questionnaire (speech comprehension in quiet, speech comprehension in noise and total speech comprehension - in quiet & noise) are provided in Table 1. This is given separately for groups with normal hearing, minimal, mild, and moderate SNHL.

Earlier, the SNR loss was computed by subtracting the mean SNR-50 of the group with normal hearing from the mean SNR-50 of the group with hearing loss. The SNR-50 for the group with normal hearing was zero. Hence while computing the SNR loss, the SNR-50 was equal to the SNR loss. That is, the SNR-50 and the SNR loss will be the same for the group with hearing loss.

Table 1.

Mean and standard deviation (SD) of PTA, SIS, SNR-50, SNR loss, and questionnaire rating score for minimal, mild, moderate, and moderately severe SNHL.

Parameters	**Degree of hearing loss**	**Mean**	**SD**
Audiological measures			
PTA in dB HL	Minimal	18.57	1.81
	Mild	33.19	4.34
	Moderate	49.50	4.25
	Moderately severe	64.82	3.76
SIS	Minimal	24.77	0.43
(Max. SIS=25)	Mild	19.60	1.32
	Moderate	13.47	2.09

	Moderately severe	8.27	1.50
SNR-50 in dB	Minimal Mild Moderate	1.47 4.63 6.97	1.57 1.92 0.89
SNR loss	Minimal Mild Moderate	1.47 4.63 6.97	1.57 1.92 0.89
Hearing handicap questionnaire measures			
Speech comprehension in quiet (Max. score = 98)	Mild Moderate Moderately severe	35.60 55.87 56.63	2.55 7.42 6.09
Speech comprehension in noise (Max. score = 105)	Mild Moderate Moderately severe	34.53 69.00 74.10	2.63 12.08 9.84
Total speech in quiet & noise (Max. score = 203)	Mild Moderate Moderately severe	70.13 124.87 130.73	3.45 17.64 14.22

From Table 1, it can be noted that as the degree of hearing loss increased, the SIS decreased; whereas the SNR-50, SNR loss, and the handicap rating score increased. From the data obtained from different groups of participants, a cut-off criterion for hearing aid candidacy and efficacy of SNR-50 for hearing aid fitting were evaluated.

4.1.Cut-off criterion based on SNR-50 to decide hearing aid candidacy

A comparison of SNR-50 across participants with normal hearing, minimal SNHL, mild SNHL, and moderate SNHL was done. Further, a cut-off criterion was derived based on SNR-50 in order to decide the candidacy for hearing aid. This criterion would be useful to decide if an individual with hearing impairment is a candidate for hearing aid.

4.1.1. Comparison of the SNR-50 and SNR loss in participants with normal hearing, minimal SNHL, mild SNHL, and moderate SNHL.

The mean, median, range, and standard deviation (SD) of SNR-50 and SNR loss of participants with ears having normal hearing, minimal, mild, and moderate sensorineural hearing loss (SNHL) were computed as in Table 4.2.

Table 4.2

Mean, median, range, and SD of SNR-50 (in dB) and SNR loss (in dB) in ears with normal hearing, minimal, mild, and moderate SNHL.

Groups	Measure (in dB)	Mean	Median	Range	SD
Normal hearing (n=30)	**SNR-50**	0.433	0	-1 to 2	0.817
	SNR loss	-	-	-	-
Minimal SNHL (n=30)	**SNR-50**	1.47	2	-2 to 4	1.570
	SNR loss	1.12	1.57	-1.57to3.57	1.38
Mild SNHL (n=30)	**SNR-50**	4.63	4.5	2 to 9	1.921
	SNR loss	4.20	4.07	1.57 to 8.57	1.92
Moderate SNHL (n=30)	**SNR-50**	6.97	7	5 to 9	0.890
	SNR loss	6.54	6.57	4.57 to 8.57	0.89

From Table 4.2, it can be noted that the SNR-50 and the SNR loss increased with increase in degree of hearing impairment. That is, the signal to noise ratio required for speech recognition increased as the hearing loss increased.

To check for normality of distribution of data, Shapiro-Wilk test was carried out. The results indicated that the data were not normally distributed ($p<0.05$). Hence, Kruskal Wallis test and Mann-Whitney U tests were employed when indicated.

The mean SNR-50 values were compared between the groups using the Mann-Whitney U test, as given in Table 4.3. The results showed that there was a significant difference in SNR-50 between all the groups in the study i.e., normal hearing and minimal SNHL; normal hearing and mild SNHL; normal hearing and moderate SNHL; minimal SNHL and mild SNHL; minimal SNHL and moderate SNHL; and, mild SNHL and moderate SNHL.

Table 4.3

Comparison of mean SNR-50 across ears with normal hearing, minimal, mild, and moderate SNHL, on Mann-Whitney U test.

Comparison of SNR-50 between groups	**U**	***p***
Normal hearing Vs. minimal SNHL	-3.43	0.01*
Normal hearing Vs. mild SNHL	-6.63	0.00**
Normal hearing Vs. moderate SNHL	-6.76	0.00**
Minimal Vs. mild SNHL	-5.49	0.00**
Minimal Vs. moderate SNHL	-6.72	0.00**
Mild Vs. moderate SNHL	-4.73	0.00**

Note: *Significant at $p<0.01$, ** Significant at $p<0.001$.

4.1.2. Derivation of a cut-off criterion based on SNR-50

The data from participants with minimal, mild, and moderate SNHL comprising of SNR-50, SNR loss, SIS, rating scores over hearing handicap questionnaire for quiet, noise and total were tabulated. The participants were divided based on the decision of hearing aid candidacy using questionnaire rating scores. The mean and standard deviation of SNR-50 and SNR loss of the three groups of participants (minimal, mild, & moderate SNHL), divided based on the decision on hearing aid requirement, are represented in Table 4.4.

Table 4.4

The mean and standard deviation of SNR-50 and SNR loss of the three groups of participants, divided based on the decision on hearing aid requirement

Hearing aid required	**SNR-50**		**SNR loss**	
	Mean	**SD**	**Mean**	**SD**
Yes (SAHH score > 80)	6.97	0.89	6.54	0.89
No (SAHH score < 80)	2.18	2.34	2.66	2.27

Note: SAHH- Self assessment of hearing handicap

The receiver operating characteristic (ROC) curve for the SNR-50 or SNR loss was used as an approach for deciding hearing aid candidacy criterion. The area under the ROC curve propounded that SNR-50 or SNR loss measure had good accuracy in discriminating those who require hearing aid from those who do not. The obtained coordinates of the curve along with sensitivity and 1-specificity for coordinate or point are mentioned in Table 4.5.The obtained cut-off criterion was verified by plotting the receiver operating characteristic (ROC) curve. The trade-off between sensitivity and specificity at all points was obtained in order to obtain the cut-off criterion for SNR-50 or SNR loss. The ROC curve obtained for the measures SNR-50 or SNR loss is represented in Figure 1.

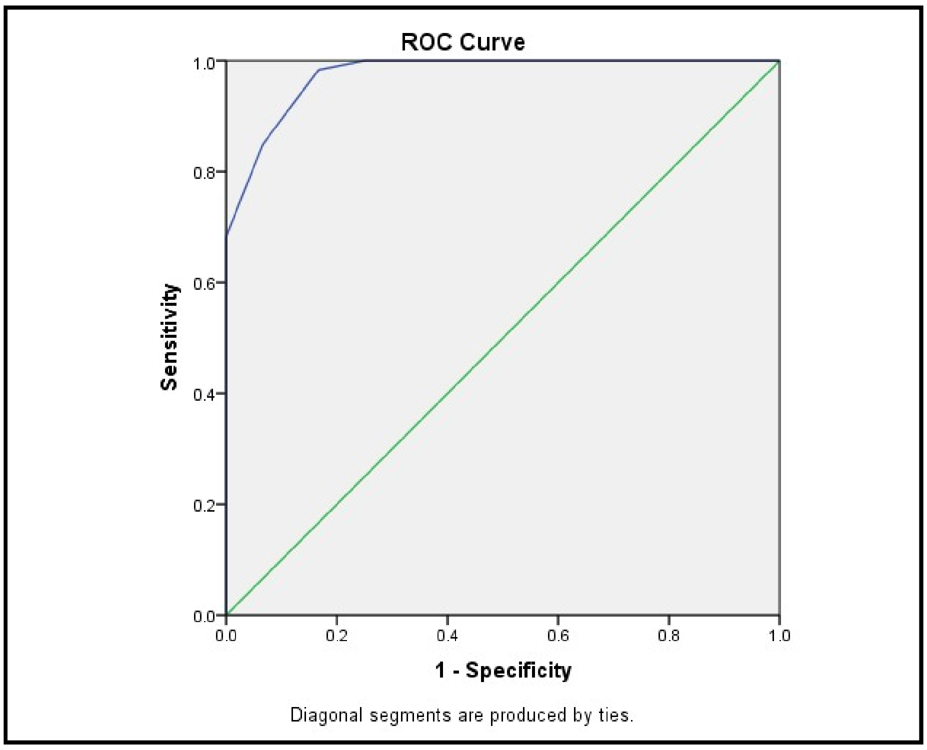

Figure 1. ROC curve for SNR-50.

Table 4.5.

Derivation of cut-off criterion based on the SNR-50 or SNR loss

Positive, if greater than or equal to	Sensitivity	1-Specificity
-1.93	0.050	0.000
-0.93	0.100	0.000
0.07	0.383	0.000
1.07	0.683	0.000
2.07	0.850	0.067
3.07	0.983	0.167
4.07	1.000	0.250
5.07	1.000	0.367
6.07	1.000	0.567
7.07	1.000	0.817
8.07	1.000	0.967
9.57	1.000	1.000

Note: An SNR-50 of 3.07 cut-off value with maximum specificity and sensitivity.

As depicted in Table 4.5, the coordinate or point with SNR loss of 3.07 yields maximum sensitivity (98%) and specificity (83.3%). Thus, this value can be utilized as the cut-off value of first choice while using SNR loss measure for deciding hearing aid candidacy.

4.2 Hearing aid selection based on the speech identification in quiet (traditional approach) and SNR-50 (alternate approach).

The hearing aid selection based on the SNR-50 and SIS within each of the degree of hearing loss is provided below.

4.2.1 Comparison of SNR-50, SIS in two hearing aids within mild, moderate and moderately severe groups.

To compare SNR-50 and SIS between two hearing aids, non-parametric Wilcoxon signed rank test was done. Table 4 illustrates the comparison of SNR-50 and SIS between the two hearing aids for mild SNHL group.

Table 4.6.

Comparison of SNR-50 and SIS between the two hearing aids for mild SNHL group

Comparison pair	**Z**	**Significance**
SIS HA 2 - SIS HA 1	-0.99	0.319
SNR-50 HA2 - SNR-50 HA 1	-1.29	0.197

*significant at 0.001 level (p<0.001); SIS- speech identification scores; SNR - signal to noise ratio; HA- hearing aid

In mild sensorineural hearing loss group, the speech identification scores (SIS) and SNR - 50 scores between hearing aid 1 (HA 1) and hearing 2 (HA 2) did not show any significant difference. Thus, it can be inferred that performance of speech scores did not differ significantly when it was compared between the two different hearing aids using both the traditional and alternative approach. Similar results were also observed for moderate SNHL and moderately-severe SNHL groups. Table 4.7 and Table 4.8 shows the comparison of SNR-50 and SIS between the two hearing aids for moderate and moderately-severe SNHL groups.

Table 4.7

Comparison of SNR-50 and SIS between the two hearing aids for moderate SNHL group

Comparison pair	Z	Significance
SIS HA 2 – SIS HA 1	-1.94	0.05
SNR-50 HA2 – SNR-50 HA 1	-0.27	0.78

Note: * - significant at $p<0.001$; SIS - speech identification scores; SNR - signal to noise ratio; HA- hearing aid

Table 4.8

Comparison of SNR-50 and SIS between the two hearing aids for moderately-severe SNHL group

Comparison pair	Z	Significance
SIS HA 2 – SIS HA 1	-1.17	0.24
SNR-50 HA2 – SNR-50 HA 1	-0.81	0.41

*significant at 0.001 level ($p<0.001$); SIS- speech identification scores; SNR - signal to noise ratio; HA- hearing aid

Comparison across traditional and alternate approaches of hearing aid evaluation: The data from the traditional and alternate hearing aid evaluations which comprised of aided SIS and aided SNR-50were obtained for two trial hearing aids. To compare between the two approaches, spearman's correlation was done.

Table 4.9

Relationship between aided SIS and aided SNR-50 for both the trial hearing aids using Spearman's correlation.

Correlation between aided SIS and SNR-50	**Group**	**Correlation coefficient (*r*)**	**Significance value (*p*)**
HA 1	Mild	-0.295	0.114
	Moderate	-0.406	0.026
	Moderately severe	0.015	0.937
HA 2	Mild	-0.284	0.128
	Moderate	-0.498	0.005
	Moderately severe	0.172	0.364

As shown in the Table 4.9, there was a negative relationship between aided SIS and aided SNR-50 measure in mild hearing loss group. Such that for both trial hearing aids, with increase in SIS there was reduction in SNR-50 scores but this was not statistically significant ($p>0.05$).

In moderate hearing loss group, negative relationship between aided SIS and aided SNR-50 was noticed. In both trial hearing aids, with increase in SIS there was reduction in SNR-50 scores and it was statistically significant ($p<0.05$).

In moderately severe hearing loss group, there was a positive relationship between aided SIS and aided SNR-50. With increase in SIS there was increase in SNR-50 scores in both trial hearing aids. But this was not statistically significant ($p>0.05$).

Comparison of the rating score on hearing handicap questionnaire with SNR-50.

The questionnaire scores were correlated with the SIS and SNR-50 obtained from the prescribed hearing aid to individuals with SNHL. Table 4.10 provides the comparison between the scores of the questionnaire (in quiet & noise) and SIS and SNR-50 after the hearing aid use with the prescribed hearing aid.

Table 4.10

Relationship between questionnaire scores and aided SIS and SNR-50 for with the prescribed hearing aid

Speech measures	**Questionnaire scores**	
	Quiet	Noise
SIS	-0.621*	
SNR-50		0.629*

Note: **p*< 0.01

The results of Spearman rank correlation revealed a significant negative correlation between the SIS and questionnaire scores in quiet and a significant positive correlation between the SNR-50 and questionnaire scores in noise.

Chapter 5

DISCUSSION

The aim of the present study was to know the effectiveness of SNR loss and SNR-50 in hearing aid evaluation. The objectives of the study were achieved by collecting the data in two phases. The first phase was in order to derive a cut-off criterion based on SNR-50 to decide if a person is a candidate for hearing aid. The second phase was carried out in order to compare the traditional approach (identification of speech in quiet) and alternate approach (identification of speech in noise) for selection of hearing aids. The results of the present study are discussed under the following sub-headings:

5.1. SNR-50 and SNR loss in ears with normal hearing, minimal SNHL and mild SNHL.

5.2. Comparison of PTA, SIS, SNR-50, SNR loss across ears with minimal and mild SNHL and questionnaire

5.3. Cut-off criterion of SNR loss to decide the need for amplification device.

5.4. Comparison across traditional and alternate procedures of hearing aid evaluation.

5.1. SNR-50 and SNR loss in ears with normal hearing, minimal SNHL and mild SNHL

In the present study, the SNR-50 and SNR loss for the individuals with normal hearing ranged between -2dB to +2 dB with the mean SNR-50 and SNR loss of 0.43 ≈ 0 dB. Comparing the findings with existing literature, Manjula and Megha (2012) obtained much lower SNR-50 (mean SNR-50 = -7.23 dB) for individuals with normal hearing. A similar procedure was used in the present study, much poorer SNR-50 for participants with normal hearing in the present study could be accounted by difference in noise used in the two studies. In the present study, a four speaker multi-talker babble was utilized instead of speech shaped noise which was used by Manjula and Megha (2012). In the present study, four-speaker multi-talker babble was used to make the task complex. It has to be noted here that there are no research studies that have exclusively analysed SNR-50 or SNR loss for participants having minimal or slight SNHL.

Killion and Niquette (2000) reported that the SNR-50 for individuals with normal hearing varied from 0 to +2 dB on Quick Speech in noise (SIN). The method involved in their study utilized sentence material presented at five fixed SNRs starting from +25 dB and scoring the correct number of key words repeated. Subtracting the number of correctly repeated key words from the reference 25 yielded the SNR loss. Though, there was a difference in method employed for computation of SNR-50 in the present study, the results remain comparable.

The SNR-50 and SNR loss for individuals with minimal SNHL varied from -2 dB to 4 dB; with a mean SNR-50 and SNR loss being 1.47 dB. In the existing literature, researchers have studied SNR-50 and SNR loss measures in participants with mild-moderate SNHL and more severe degree but none of the research studies have exclusively analyzed SNR-50 or SNR loss for participants having minimal or slight SNHL.

The SNR-50 and SNR loss for individuals with mild SNHL varied between 2 dB to 9 dB. The mean and median SNR loss for the group of participants with mild SNHL was 4.63 dB. The SNR-50 and SNR loss for individuals with moderate SNHL varied between 5 dB and 9 dB. The mean and median SNR loss for the group of participants with moderate SNHL was 6.97. These results are in harmony with the smoothened averaged data provided by Killion (1997) who reported that those participants having mild-moderate SNHL required 4 to 6 dB greater SNR-50 than the participants with normal hearing. Similar findings were reported by Wilson et al. (2003) where subjects with mild-moderate SNHL required 5.3 dB higher signal-to-babble ratios (SBRs) than the subjects with normal hearing. The inter-subject variability for SNR-50 or SNR loss was also studied by Wilson et al. (2003) by using a slope of the psychometric functions at 50%

correct points. More gradual slope was seen for subjects with mild-moderate SNHL (4.5% per dB) as compared to subjects with normal hearing (6.5% per dB) which reflects greater individual variability in them. Hence, it is inappropriate to anticipate closely clustered SNR-50 or SNR loss data for all the individuals despite them having the same extent of hearing problem.

The descriptive statistics revealed that individuals with normal hearing had SNR-50 and SNR loss that was significantly better than the individuals with minimal, mild, and moderate SNHL. Further, with increase in degree of hearing loss from minimal to mild SNHL and mild to moderate, the mean SNR-50 or SNR loss became poorer. There was a significant difference seen in SNR-50 across minimal, mild, moderate SNHL.

5.2. Comparison across ears with normal, minimal, mild, moderate and moderately severe SNHL for PTA, SIS, SNR-50, SNR loss and questionnaire

With increase in degree of loss from minimal to moderately severe SNHL, there was an increase in PTA as expected and poorer speech identification scores. In the present study, with increase in degree of loss from minimal to moderately severe SNHL, there was a significant reduction in SIS. It is well correlated with questionnaire rating of speech perception in quiet as the ratings have increased with the increase in degree of hearing loss. In the subjective perception of handicap, speech comprehension in noise significantly increased with degree of loss. This was well correlated withSNR-50 or SNR loss. This finding suggests that even a non-significant reduction in SNR-50 can lead to a significant impact on speech perception of an individual in the presence of noise. This finding has a wide clinical application while fitting the hearing aids.

The aim of the clinical audiologist while fitting the amplification device to an individual should be to provide maximum comfort of listening in various situations. Thus, directional microphones, array microphones or wireless microphones are recommended to solve the problem of hearing in noise across mild to profound hearing loss (Killion,1997; Plomp, 1978; Smoorenburg, 1999; Killion & Niquette, 2003; Fabry, 2005). These technological modifications along with noise reduction algorithms when implicated in hearing aids help in reducing the SNR loss.

Ratings over hearing handicap questionnaire were significantly increased from mild to moderately severe SNHL group. This was applicable for ratings over speech comprehension in quiet, noise, and also for overall (speech in quiet and noise) rating. These high scores obtained over questionnaire rating reflect the perceptual increase in problem due to increase in loss of audibility as well as clarity.

5.3. Cut-off criterion of SNR loss to decide the need for amplification device

To find out the cut-off criterion, SNR loss was calculated for normal to minimal and mild to moderate groups. The test ears presumed to require an amplification device had significantly higher SNR loss than the ears that did not require an amplification device. Since, a significant difference was present across the two groups, it was possible to obtain a cut-off criterion of SNR loss in order to demarcate those who require a hearing aid from those who do not. The cut-off criterion obtained in the study was 3.07 dB. This was obtained by subtracting one standard deviation from mean SNR loss of candidates considered eligible for amplification device. This cut-off criterion of SNR loss measure can be used clinically to decide candidacy for amplification device. If the SNR loss of the test ear is above this cut-off criterion, then the individual is an eligible candidate for an amplification device. Whereas if the SNR loss for the test ear is lesser than the cut-off criterion, then a hearing aid is not required. Hence, based on this finding, the SNR loss can be utilized as a useful clinical tool to decide about the candidacy for amplification device.

Further, the accuracy of the obtained cut-off criterion for SNR loss was evaluated using Receiver Operating Characteristic (ROC) curve. The area under the ROC curve measures the discriminatory power of the concerned measure, the SNR loss in this case. To measure the accuracy of the diagnostic test traditional academic point system classifies the Area Under the Curve (AUC). According to this, the test or measure is excellent if the AUC varies from 0.90 to 1; good if it is 0.80 to 0.90, fair if it is 0.70 to 0.80, poor if it is 0.60 to 0.70; and failure if it is 0.50 to 0.60. The AUC being 0.88 in the present context and significant (p value = 0.01), it suggests that the SNR loss is a good test measure in deciding the hearing aid candidacy. The trade-off between sensitivity and specificity across all the SNR loss points was used to obtain a cut-off criterion. The SNR loss cut-off point of 3.07 dB that yielded maximum sensitivity (0.98) and minimum 1-specificity (0.83) thereby, was set as the final cut-off criterion. Both sensitivity as well as specificity being greater than 80%, it paves the way for SNR loss measure to be used as a clinical tool.

The cut-off criterion for SNR loss obtained using mean - 1SD was similar to the cut-off point obtained through the ROC curve. Therefore, this cut-off criterion has a potential clinical utility to decide hearing aid candidacy. If an individual has an SNR loss of greater than 3.07 dB, then he/she is an eligible candidate for amplification device; whereas, if the SNR loss is lesser than this, then a hearing aid is not needed. More research is needed in this area over larger population to develop normative for individual clinical set-up and specific to the test material and procedure being utilized.

5.4. Comparison across traditional and alternate procedures of hearing aid evaluation

The hearing handicap questionnaire ratings were significantly higher (poorer) for individuals with moderately severe SNHL than those for individuals with moderate and mild SNHL. Similar findings were obtained when only certain set of questions of the handicap questionnaire were considered. Higher ratings for moderately SNHL than the moderate and mild SNHL were obtained for questions related speech comprehension in noise as well as in quiet.

There was a significant difference in SNR loss across the groups of participants with different degrees of hearing loss divided based on the decision of hearing aid candidacy. Such that the participants presumed to be candidates for amplification device based on questionnaire rating score had a significantly higher SNR loss than those who were not considered as candidates. The cut-off criterion established using this data was 3.07 dB. The area under the ROC curve obtained for measure SNR loss suggested it as a good test measure. Additionally, the coordinate or point of 3.07 dB in the ROC curve for SNR loss yielded maximum sensitivity and specificity. Hence, a cut-off criterion of 3.07 dB is a reliable cut-off point to demarcate the need for amplification device in a clinical set-up.

The aided SIS measure and the SNR-50 were able to differentiate the two trial hearing aids. However in 26 out of 60 participants in whom the SIS was equal with both the hearing aids, SNR-50 was able to differentiate the two hearing aids in 15 of them (58%). Considering this, it could be inferred that SNR-50 is a better measure than SIS in differentiating the performance with two trial hearing aids. It could further be inferred that testing in noise is better compared to testing in quiet alone during hearing aid selection.

References

ANSI (1991). Maximum permissible ambient noise levels for audiometric test rooms. (ANSI S3.1-1991 R 2013).

Bilger, R. C., & Wang, M. D. (1976). Consonant confusions in patients with sensorineural hearing loss. *Journal of Speech and Hearing Research*, *19*(4), 718-748.

Carhart, R., & Tillman, T. W. (1970). Interaction of competing speech signals with hearing losses. *Archives of Otolaryngology, 91*(3), 273-279.

Carhart, R.,& Jerger, J. (1959). Preferred method for clinical determination of pure-tone thresholds. *Journal of Speech and Hearing Disorders, 24*, 330-345.

Cohen, R. L. & Keith, R.W. (1976). Use of low pass noise in word recognition testing. *Journal of Speech and Hearing Research, 19*, 48- 54.

Cox R. M & Alexander G. C. (1995). The abbreviated profile of hearing aid benefit. *Ear & Hearing, 16* (2), 176-186.

Crandell, C. (1991). Individual diiferences in speech recognition ability: implications for hearing aid selection. *Ear & Hearing, 12*, 100S- 108S.

Dirks, D.D., Morgan, D.E., & Dubno, J.R. (1982). A procedure for quantifying the effects of nosie on speech recognition. *Journal of Speech & Hearing Disorders, 47*, 114-123.

Dubno, J. R., Dirks, D.D., & Morgan, D.E. (1984). Effects of age and mild hearing loss on speech reception in noise. *Journal of the Acoustical Society of America, 76*, 87-96.

Evans.E.F. (1975). The Sharpening of Cochlear Frequency Selectivity in the Normal and Abnormal Cochlea. *Audiology, 14*(5-6), 419–442.

Fabry, D. A. (2005). Adaptive directional microphone technology and hearing aids: theoretical and clinical implications. *Hearing Review*. Retrieved from http://www.hearingreview.com/archives.asp on 18.8.2009

Festen, J.M., & Plomp, R. (1990). Effect of fluctuating noise and interfering speech on the speech reception threshold for impaired and normal hearing. *Journal of the Acoustical Society of America, 88*, 1725-1736.

Jaisinghani, P. (2015). *Efficacy of SNR loss as a clinical tool for hearing aid evaluation*. A Masters Dissertation Submitted in part fulfillment of final year Masters of Science (Audiology) University of Mysore, Mysore

Killion, M. C. (1997c). The SIN report: Circuits haven't solved the hearing- in- noise problem. *The Hearing Journal, 50*(10), 28-32.

Killion, M. C., & Niquette, P. A. (2000). What can the pure- tone audiogram tell us about a patient's SNR loss? *The Hearing Journal, 53*, 46- 53.

Kochkin, S. (2002). "10- Year customer satisfaction trends in the US hearing instrument market". *Hearing Review, 9*(10), 14-46.

Kochkin, S. (2007). Increasing hearing aid adoption through multiple environmental listening utility. *The Hearing Journal, 60*(11), 28–29.

Kochkin, S. (2010). MarkeTrak VIII : Consumer satisfaction. *The Hearing Journal, 63*(1), 19–32.

Kumar, U. A., Ameenudin, S., & Sangamanatha, A. V. (2012). Temporal and speech processing skills in normal hearing individuals exposed to occupational noise. *Noise & Health, 14*(58), 100-105.

Larsby, B., Arlinger, S. (1999). Auditory temporal and spectral resolution in normal and impaired hearing. *Journal of American Academy of Audiology, 10,* 198-210.

Leshowitz, B. (1977*).* Speech intelligibility in noise for listeners with sensorineural hearing damage. *IPO Annual Progress Report, 12*, 11- 23.

Ma, J & Loizou, P.C. (2011). SNR loss: A new objective measure for predicting speech intelligibility of noise-suppressed speech. *Speech Communication, 53*(3): 340-354.

Manjula, P., & Megha. (2012). *Quantification of the Effects of Noise on Speech Recognition.* Unpublished ARF Project, Mysore.

Manjula, P., Antony, J., Kumar, K.S., & Geetha, C. (2015). Development of phonemically balanced word lists for adults in the Kannada language. *Journal of Hearing Science, 5* (1), 22-30.

Nabelek, A. & Pickett, J. (1974). Reception of consonants in a classroom as affected by monoaural and binaural listening, noise, reverberation, and hearing aids. *Journal of Acoustical Society of America, 56*, 628-639.

Palmer, C. V, Solodar, H. S., Hurley, W. R., Byrne, D. C., & Williams, K. O. (2009). Self-Perception of Hearing Ability as a Strong Predictor of Hearing Aid Purchase. *Journal of American Academy of Audiology, 20*, 341–347.

Pearsons, K.S., Bennett, R.L., & Fidell, S. (1977). *Speech Levels in Various Noise Environments.* EPA-600/1-77-025. U.S. Environmental Protection Agency.

Pickles J. (1986). *The neurophysiological basis of frequency selectivity*. In B. Moore (Ed.), Frequency Selectivity in Hearing (pp. 51–122). London: Academic Press.

Plomp, R. (1978). Auditory handicap of hearing impairment and the limited benefit of hearing aids. *Journal of the Acoustical Society of America, 63*, 533- 549.

Plomp, R. (1986). A signal-to-noise ratio model for the speech-reception threshold of the hearing impaired. *Journal of Speech and Hearing Research, 29*, 146–154.

Plomp, R., & Mimpen, A.M. (1979). Speech reception threshold for sentences as a function of age and noise level. *Journal of the Acoustical Society of America, 66*, 1333- 1342.

Plomp, R., & Duquesnoy, A. J. (1982). A model for the speech- reception threshold in noise without and with a hearing aid. *Scandinavian Audiology*, *S15*, 95- 111.

Puttabasappa, M., Rajanna, M., Jaisinghani, P., & Shukla, S. Auditory P300 in Typical Individuals: Age and Gender Effect. *International Journal of Health Sciences and Research, 7*(5), 247- 257.

Smoorenburg, G. F. (1992). Speech reception in quiet and in noisy conditions by individuals with noise induced hearing loss in relation to their tone audiogram. *Journal of Acoustical Society of America, 91*, 421-437.

Souza, E. P., & Tremblay, K.L. (2006). New perspectives on assessing amplification effects. *Trends in Hearing, 10*(3), 119-143

Taylor, B. (2003). Speech-in-noise tests: How and why to include them in your basic test battery. *The Hearing Journal, 56*(1), 40–43.

Taylor, B. (2011). *Using Speech in Noise Tests to Make Better Hearing Aid Selection Decisions.* P1-7; http://www.audiologyonline.com/articles/usingspeechinnoisetests-832 Retrieved on 15.5.17.

Vanaja, C.S. (2000). *Self- Assessment of Hearing Handicap: A few audiological and non-audiological correlates*. Unpublished Doctoral Thesis, AIISH, Mysore.

Walden, T. C., & Walden, B. E. (2004). Predicting Success with Hearing Aids in Everyday Living. *Journal of American Academy of Audiology, 15*, 342–352.

Wilson, R. H., Abrams, H. B., & Pillion, A. L. (2003). A word-recognition task in multi-talker babble using a descending presentation mode from 24 dB to 0 dB signal to babble. *Journal of Rehabilitation Research and Development, 40*(4), 321–327.

Yoon, Y.S. & Allen, J. (2006). *SNR-loss with hearing impaired ears*. Abstracts of Association of Research Otolaryngology.