Efficacy of SNR loss as a clinical tool for hearing aid evaluation

Priyanka Jaisinghani

Reg. No.: 13AUD020

A Masters Dissertation Submitted in part fulfillment of final year

Masters of Science (Audiology)

University of Mysore,

Mysore

All India Institute of Speech and Hearing,

Manasagangothri, Mysore - 570 006

May, 2015

Matra-Pitra-Kritabhyaso Gunitam_eti Balakah

Na Garbha Chyuti Matrena Putro Bhavati Panditah

The child taught by mother and father becomes qualified.

The child does not become learned just by being born.

Dedicated to

My lovely **"Mumma and Papa"**

My elder sister and a forever friend **"Limsy Di"**

And

The one who completes me **"Jithin Ji"**

None of my success would have been possible without you all……..

CERTIFICATE

This is to certify that this masters dissertation entitled '**Efficacy of SNR loss as a clinical tool for hearing aid evaluation'** is a bonafide work submitted in part of fulfillment for the degree of Master of Science (Audiology) of the student **Registration No: 13AUD020**. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore

May, 2015

Dr. S. R. Savithri

DIRECTOR

All India Institute of Speech and Hearing,

Manasagangothri, Mysore- 570 006

CERTIFICATE

This is to certify that this masters dissertation entitled **'Efficacy of SNR loss as a clinical tool for hearing aid evaluation'** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore,

May, 2015

Dr. P. Manjula

Guide

Professor in Audiology

Department of Audiology

All India Institute of Speech and Hearing

Manasagangothri, Mysore – 570 006

DECLARATION

This is to certify that this masters dissertation entitled **'Efficacy of SNR loss as a clinical tool for hearing aid evaluation'** is the result of my own study under the guidance of Dr. P. Manjula, Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore, **Registration No: 13AUD020**

May, 2015

Acknowledgments

Lord Krishna, thank you for blessing me much more than I deserve.

Firstly, I would like to thank my guide ***Prof. P. Manjula*** for her constant support and guidance through this journey. You have been my inspiration and you brought about the best from me. Thank you Ma'am this work was nothing without your teachings and directions. You have enlightened me with knowledge.

Thank you Ma'am ☺

I would like to thank our beloved Director, AIISH ***Prof. S. R. Savithri*** for permitting me to carry out this study. Thank you Madam

I would give heartfelt thanks to H.O.D of Department of Audiology, ***Dr. Ajith Kumar*** for permitting me to utilize instruments for my study. Sir, you have been a wonderful teacher. Thank you Sir.

I would like to thank all the wonderful teachers ***Prof. Asha Yathiraj, Prof. K. Rajalakshmi, Dr. Prawin Kumar, Mr. Niraj Kumar, Dr. Sandeep, Dr. Sujeet Kumar Sinha, Ms. Mamatha, Dr. Vijay Kumar Narne.***

I would like to thank ***Mr. Santosha C. D. Sir and Dr. Vasanthalakshmi Ma'am*** for their constant help in making me understand the complex statistical analysis.

I would like to ***thank the staffs in library*** especially, ***Dr. Shijith Kumar*** for their advice and all time help.

Thanks to all the ***staffs in Registration section*** for helping me in finding subjects for my study. Thank you all.

Participants of my study… I owe a big thanks to you…thank you all for finding time from your schedule and being co-operative with me. I hope this piece of work will be helpful for you all in future.

Darshini, you have been there in all my good and bad times…A friend like you is hard to find and lucky to have. I always felt a shelter to speak to you… You have been like a sister. Thank you ☺ Love YOU

Supreeth Bro, you and your pranks I'll never forget in my life… You made the classes absolutely fun. You have knowingly or unknowingly always supported me. Thank you ☺

Sneha, machi it was fun with you…you will be always remembered. We have spent a joyful time together in AIISH. No matter whether it was classes or clinics we have always comforted each other in bad times and laughed together in bad times. I wish the best in life for you.

Rohan, you are an awesome posting partner. I am sure we broke the records of having longest break time in clinical postings. It was fun with you in all cool and messy days.

Akhil, Amritha, Sowmya, Swathi, Aisha, Zeena, Thareeque, Suman, Rakesh P.G., Vaishnavi, Preeta, Kiran and all my classmates and friends. I would like to thank you all with whom this journey of six years became memorable and cherish able. Wish you all a very pleasant and successful life ahead… Will miss you all ☺

Priyanjali Di, Prabhash Sir, Usha di and Neha Di thank you all for all the timely help and all the support you gave me uptil now.

Love you all my juniors**…especially Deeksha, Setu, Pratyasha, Vaishali** for adding fun always in tensed days.

Thanking my **family**…where life begins and love never ends….

Mumma and Papa words are not enough to thank you for everything you both have done for me. You have planted the seeds of knowledge in me. I have seen my God in you both. You both have consumed yourselves like a candle in brightening me. Thank you for imparting me such good education. I love u both ☺

Limsy Di, you are an amazing sister. You have been like a parent for me and sacrificed a lot just for my happiness. You have been my teacher too and yes you are my forever friend. You have laughed with me and wiped my tears when I cried. I wish and pray the best in life for you. I love you. ☺

Jithin Ji, you were there through thick and thin. Thank you for believing in me, for never putting me down, for forever trying to lift my spirits and for being my living hero. You have always been a helping hand…Thank you...Waiting to start a lovely life with you ☺

Thank you ***Neetu***, you are my cousin….nope my best friend …Love you dear for always being with me no matter how far or how long.

Thanks to all the ***elders in my family*** for showering blessings on me always. Really it worked miracle.

Thanks to all the ***younger ones in the family*** who added joy and laughter to my life. Love you all

Childhood friends still bonded in good or bad times….**Ankita Patni, Apeksha Garg, Aditi Jain and Deepika Meena** you all have supported in each phase of life thank you.

Thank you is the least I can say to you to show my appreciation for everything you all have done

Thank you.

Thank you.

Sorry, if I forgot to mention your name dear reader….. ☺ ☺

Have a happy reading ☺

Abstract

Individuals with sensorineural hearing loss (SNHL) report their maximal difficulty in comprehending speech in the presence of noise. The routine clinical hearing aid evaluation is carried out in quiet situation and hence this problem is not addressed generally. Even hearing aid users report greater dissatisfaction with their hearing aid in noisy situations. Involving a speech in noise paradigm for hearing aid evaluation may help in prescribing the hearing aid yielding better signal-to-noise (SNR). In the present study, efficacy of one such measure called SNR loss was investigated in clinical hearing aid evaluation. For this purpose, ability of measure SNR loss in demarcating the need for amplification device was studied. Apart from this, outcome by two kinds of hearing aid evaluations was compared, one being traditional approach of testing aided speech in quiet and other being alternate approach of measuring aided SNR loss. The cut-off point for SNR loss with maximum sensitivity and specificity based on the ROC curve was established and was 5.5 dB. It is recommended that individuals having SNR loss equal to or above this are rightfully eligible for hearing aids whereas, those having SNR loss below this are discarded from the hearing aid candidacy. The traditional approach failed at differentiating the two trial hearing aids whereas, alternate approach of using SNR loss helped in differentiating the two trial hearing aids well. Further, knowledge of aided SNR loss by the trial hearing aids will assist the audiologist in prescribing the hearing aid giving minimal SNR loss. This in turn will improve listening performance in natural situations and enhance the satisfaction of hearing aid user with the amplification device. Hence, SNR loss measure has a potential utility in hearing aid evaluation.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

Listeners with sensorineural hearing loss (SNHL) have a pervasive complaint in appreciating speech, in quiet as well as in the presence of background noise or babble. The evidence, that individuals with even mild SNHL may have greater difficulty when listening in noisy situations than do listeners with normal hearing, is strong (Plomp, 1978; Cohen & Keith, 1976; Plomp & Mimpen, 1979; Plomp & Duquesnoy, 1982; Smoorenburg, de Laat, & Plomp, 1982). Managing these individuals with amplification device may also not always be beneficial.

Several studies have revealed that individuals having SNHL using hearing aids report their maximal dissatisfaction in difficult-to-hear conditions such as reverberation, background noise and in multi-talker babble (Kochkin, 2002; Kochkin, 2010). This difficulty of understanding speech in noise is also because of the loss of frequency selectivity (Evans, 1975; Pickles, 1986). It is necessary to imply this finding also into the assessment procedure. There are several ways mentioned in literature to measure the speech intelligibility. As reported by Plomp (1986) measuring speech intelligibility only at a few intensity levels may not be beneficial as it is not feasible to compare the results from one experiment to another. On the other hand, Plomp and Mimpen (1979) suggested that speech-reception-threshold (SRT) which refers to minimum sound pressure level (SPL) required for 50% of speech intelligibility helps in achieving this purpose. Hence, SRT is a better clinical tool to assess speech perception than the speech identification scores (SIS).

Dirks, Morgan, and Dubno (1982) further proposed a procedure to quantify the effect of background noise on speech recognition. They suggested that the results needs to be reported in terms of signal-to-noise ratio (SNR) in dB, needed for 50% correct word recognition. This measure is referred to as SNR-50. This SNR-50 permits to quantify the improvement with the management option and also to measure the extent of SNR impairment.

Killion (1997a) classified difficulties of individuals with cochlear hearing loss into two domains. 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. This latter measure is called SNR loss or clarity 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 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.

The procedure to measure SNR loss is reported extensively in literature. The SNR loss is the increase in decibels (dB) required by an individual with hearing loss to perform equally well as an individual with normal hearing on the task of speech recognition in noise (Killion, 1997b). For example, if a subject with normal hearing has an SNR-50 of 2 dB, i.e., he requires an SNR of 2 dB for 50% correct word recognition (SNR-50); and a subject with hearing loss has an SNR-50 of 12 dB, then the SNR loss for the subject with hearing loss will be 10 dB, i.e., SNR loss is obtained by subtracting the SNR-50 of an individual with normal hearing from the SNR-50 of an individual with hearing loss.

Dirks et al. (1982) described that the sensitivity loss and SNR loss are independent parameters. In their opinion, it is not necessary that the individuals having same degree of hearing loss will also have the same extent of SNR loss. Therefore, even though two individuals have similar audiograms, they have different SNR loss and should be managed differently when prescribing amplification device. The extent of SNR loss will help in deciding the type of technological modification such as noise reduction algorithm, directional microphone, remote microphone or speech enhancer required in hearing aids (Beattie, Barr, & Roup, 1997).

Hearing aids work extremely well at improving audibility of the speech cues. However as indicated by Plomp (1978), amplification causes deterioration of the speech signal as compared to unaided condition. This deterioration is caused due to factors such as upward spread of masking and distortion. Hence, hearing aids essentially have limited applicability. This assumption is true for hearing aids of 1970s which resulted in low SNR in aided condition than the unaided. With the advent of modern hearing aids it is possible to bring a reduction in SNR loss from 20 dB or 30 dB in the unaided to 5 dB in the aided condition (Killion, 1997c). Based on the extent of SNR loss as mentioned before, the extent of assistance required to reduce the SNR loss can be decided and appropriate hearing aid feature can be provided. Such hearing aid fitting will provide greater satisfaction to the client (Killion & Niquette, 2000; Fabry, 2005).

1.1. Need for the Study

Evidence in literature reveals that individuals with hearing impairment demonstrate marked reduction in speech recognition scores in the presence of noise compared to individuals having normal hearing (Cohen & Keith, 1976; Leshowitz, 1977). In routine hearing aid evaluation, an audiologist often relies on information obtained in a quiet situation to determine how an individual with hearing loss will perform in a natural situation. In other words, clinical hearing aid evaluations are often done in quiet situation. Though the results obtained in quiet sound treated or acoustically treated booth are valuable, they may not simulate the real-life situations. Such testing may actually overestimate the performance in other situations. Such kind of testing gives false expectations to the client regarding hearing device. Ultimately, the client ends up feeling dissatisfied with the hearing aid in real-life. Hence, there is a need for more scientific research to measure and quantify the speech recognition ability in the presence of noise for individuals having hearing loss.

The SNR loss as mentioned before 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 acknowledged earlier, even individuals having the same degree of hearing loss perform differently in presence of noise and rate their degree of hearing handicap differently. There are many other measures other than hearing thresholds that can be utilized to decide upon the need to pursue amplification.

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). 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-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 need for amplification device.

Apart from this objective, the present study compared the traditional method of hearing aid evaluation carried out in quiet with an alternate method of assessing aided performance in the presence of noise. This might help an audiologist to provide realistic expectations to the client. One such method 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 yielded the minimum SNR loss. The hearing aid evaluation utilizing SNR loss as a clinical tool, being an alternate method, requires a scientific evidence or research to substantiate its efficacy and to compare it with the traditional hearing aid testing in quiet condition. It would 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 therefore was taken up to assess the appropriateness of using the SNR loss measure in clinical hearing aid evaluation as compared to traditional hearing aid evaluation of assessing speech in quiet.

1.2. Aim of the study

The aim of the present study was to evaluate the efficacy of SNR loss as a clinical tool for hearing aid evaluation. Additionally, to provide important insight regarding what useful or additional information is provided by measure SNR loss that goes undetected by routine assessment made in quiet. The present study thereby explains the need to include SNR loss measure into routine clinical evaluation.

1.3. Objectives

In order to meet the above aim, the following objectives were framed –

1. To compare the SNR-50 and SNR loss across participants with normal hearing, minimal SNHL and mild SNHL.
2. To compare the rating score on hearing handicap questionnaire across minimal and mild degrees of hearing loss.
3. To check the relationship between SNR loss, SIS and questionnaire rating scores for speech comprehension in quiet and noise.
4. To estimate a cut-off criterion for SNR loss to demarcate the need for amplification device.
5. To compare the traditional hearing aid evaluation approach based on testing speech in quiet and the alternate approach of hearing aid evaluation based on SNR loss.
6. To check the relationship between subjective quality ratings obtained after traditional and alternate approach of hearing aid evaluation with aided SIS and aided SNR loss.

1.4. Hypotheses

The following hypotheses were framed for the present study-

1. There is no significant difference in SNR-50 and SNR loss across test ears with normal hearing, test ears with minimal and mild SNHL.
2. There is no significant difference in questionnaire rating score for hearing handicap questionnaire across minimal and mild SNHL.

3. There is no relationship between SNR loss with rating scores on hearing handicap questionnaire for speech comprehension in quiet and noise.
4. The SNR loss cannot be utilized to demarcate those who require hearing aid from those who do not.
5. There is no difference across traditional approach (comparing aided SIS measured in quiet) and alternate approach (comparing aided SNR loss) of hearing aid evaluation.
6. There is no relationship between aided SIS and aided SNR loss with the subjective quality ratings obtained after traditional and alternate approach of hearing aid evaluations.

Chapter 2

Literature Review

The most common management option for sensorineural hearing loss is fitting of amplification device. Generally, the hearing aid selection is carried out in quiet situation. Such quiet or sound treated conditions are not representative of real-world situations. There is a narrow scope of such hearing aid prescription, for the reason that individuals wearing hearing aids report their biggest problem as difficulty in understanding speech in the presence of noise.

As reported by Kochkin (2002), only 30% of individuals wearing hearing aids were satisfied with the performance of their device in noisy situation. Plomp (1978) has opined that individuals using hearing aids are maximally satisfied with their aid when they are listening to one person in quiet; whereas, minimally satisfied while listening in a group conversation. The reason behind this is that hearing aid amplifies both the wanted speech signal and the interfering sounds, keeping the signal-to-noise ratio (SNR) almost constant. Hence, a successful hearing aid fitting should maximize hearing aid benefit even in complex listening environments such as simulated background noise, competing speech, and reverberation. In the present study, investigation of SNR loss as a clinical tool for hearing aid trial was envisaged. The literature relevant to the present study has been given under the following headings.

2.1. Effect of sensorineural hearing loss on understanding speech in noise

2.2. Measures of performance in noise

2.2.1. SNR-50 in individuals with normal hearing

2.1. Effect of sensorineural hearing loss on understanding speech in noise

It is widely accepted that 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). It is important to realize that even typically developing elementary school children with no history of speech, language and hearing problems require higher signal-to-noise ratios (SNRs) as the reverberation increases in the classroom since, speech recognition performance degrades with the hostile combination of noise and reverberation (Neuman, Wroblewski, Hajicek & Rubinstein, 2010). Younger children (6 year old) had higher SNR-50 than the older children (12 year old) at all reverberation times. Hence, if general classroom acoustics affects speech understanding in children having normal hearing then it will have even greater impact on speech recognition abilities of children with hearing impairment. Furthermore, Crandell and Smaldino (2000) reported that SNR of a classroom varies from +5 to -7 dB and SNR requirement for above 50% correct speech recognition by children having normal hearing is +6 dB. On the other hand, children having SNHL require SNR of +15 dB or more for correct speech recognition. Such findings are alarming towards the perception difficulty faced by individuals having SNHL and direct us towards techniques to enhance the SNR.

Plomp and Mimpen (1979) assessed speech recognition in noise as a function of age and reported a rapid decrease in performance above 50 years of age. Generally, this handicap is not reduced with the use of amplification device alone. The deficit in speech recognition in noise in elderly individuals can also be attributed to two underlying factors, i.e., central auditory processing disorder and deficit in cognitive function (Crandell, 1991).

As per the 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. Therefore, this distortion component is primarily responsible for speech recognition in noise. Dirks, Morgan, and Dubno (1982), evaluated speech recognition in noise performance of 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 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. Hence, increasing intensity of the speech will address 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. They utilized a simple up-down adaptive procedure to measure speech recognition in noise as a tool to differentiate listeners having normal hearing and those with mild hearing loss but 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 was seen at speech levels ranging from soft (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 notion that individuals having as small as mild SNHL have deviated speech recognition in noise in comparison to performers with normal listening. Also the researchers suggested that use of such adaptive strategy is necessary to identify subtle communication difficulties which go unseen 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.

Many researchers have even suggested that ability of understanding speech in noise varies across individuals with same degree and configuration of SNHL (Crandell, 1991; Plomp, 1986). Such variability may explain the differences across how these individuals benefit from rehabilitation strategies. For example, 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 be a boon to 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 (i.e., the difference in speech recognition in quiet and noise) indicated a variability from 23% to 67% at an SNR of -5 dB. Several 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.

Crandell (1991) reported data of his two subjects having same degree of hearing loss (mild-moderate high frequency hearing loss) and equal speech recognition in quiet but varying performance on speech recognition in presence of noise. To assess speech recognition ability he employed speech reception threshold (SRT) procedure with revised Speech Intelligibility in Noise (SPIN) sentences. The performance on speech recognition in noise varied across the two subjects when the competing multi-talker babble was presented at two levels of 75 and 85 dB SPL. Such that, there was a difference of 3.6 dB at 75 dB SPL babble level and of 7.1 dB at 85 dB SPL babble level. Thus, there are several findings supporting differences in speech recognition in noise abilities of listeners having same degree of hearing loss.

Kochkin (2010) reported outcome of the Marke Trak VIII survey carried out for evaluating customer satisfaction with hearing aids from 1989-2008. Ratings on a seven-point Likert scale (“Very dissatisfied”, “Dissatisfied”, “Somewhat dissatisfied”, “Neutral”, “Somewhat satisfied”, “Satisfied”, “Very satisfied”) were obtained from the consumers. Under consumer satisfaction with signal processing and sound quality, the area with highest negative ranking was the use in ‘noisy’ situations. Consumer satisfaction was further assessed in 19 listening situations, the results of which are shown in Table 2.1. The listening situations which were rated with minimal satisfaction were in 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. 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).

Table 2.1: Customer satisfaction across various listening conditions based on Marke Trak VIII Survey (Kochkin, 2010)

S.No.	*Listening Situation*	*Satisfaction*
1.	One-to-one communication	91%
2.	Small group conversation	85%
3.	Watching television	80%
4.	Outdoors	78%
5.	Leisure activities	78%
6.	While listening to music	78%
7.	Shopping	77%
8.	While riding in car	77%
9.	In place of worship	75%
10.	Restaurant	75%
11.	Telephone	73%
12.	In Concerts/ Movies	72%
13.	On cell phone	69%
14.	During recreation and exercise	68%
15.	In large group conversation	68%
16.	Sporting Events	66%
17.	Workplace	65%
18.	School / Classroom	59%
19.	In Bed	53%

Lavie, Banai, Attias, and Karni (2014) studied the speech perception of elderly individuals with hearing impairment in presence of multi-talker noise. The finding of their study was that speech identification in multi-talker noise of older group was significantly poorer by SNR loss of 10 dB than the younger group. Hence, they suggested that even with hearing aid it is unreasonable to expect the elderly individuals who have hearing impairment to fully comprehend speech in multi-talker environments.

The findings reported in literature highlight the prevailing problem of understanding speech in adverse listening conditions confronted by individuals with SNHL. In routine clinical practice, this ability of listeners is not assessed while prescribing amplification devices. A prototype speech in noise paradigm can be utilized to assess word recognition abilities of listeners in presence of multi-talker babble. Employing such protocol will help in estimating the clarity loss or SNR loss in terms of decibels SNR (Wilson, Abrams, & Pillion, 2003). Hence, there is a need to administer speech in noise paradigm in clinical practice while performing hearing aid trial to assure benefit or to counsel on realistic expectations with the amplification device in maximum listening conditions. The present research focuses on this aspect and examines the utility of measurement of SNR-50 or SNR loss for hearing aid fitment in clinical practice.

2.2. Measures of performance in noise

Earlier percent correct scores in form of ‘PB-Max’ were the most reported measure from speech tests thereby involving quiet environment to maximize the potential for good speech recognition score. As already mentioned in Section 2.1., individuals with SNHL have difficulty in comprehending speech in noise. Therefore, assessing performance in the absence of competing stimulus is often a poor indicator of recognition ability of an individual in everyday life. Following the study by Dirks et al. (1982), commonly the results are reported in terms of signal-to-noise ratio (SNR) in dB required for 50% correct recognition of words. Killion (1997) suggested that reporting speech tests results in terms of SNR permits direct comparison between proposed management option like amplification device or FM device and the severity of SNR impairment.

Killion (1997) explained that there are two kinds of problems experienced by individuals with hearing loss: 1) sensitivity loss which is loss of ability to hear sounds in quiet, and 2) loss in clarity, which leads to loss of understanding speech, especially in noise. Killion and Niquette (2000) reported that this sensitivity loss is caused due to loss of outer hair cells; and on the other hand, loss of clarity is caused by loss of inner hair cells. Findings of several psycho acoustical and physiological studies (Evans, 1975; Pickles, 1986; Patterson & Moore, 1986) have demonstrated reduced frequency selectivity in individuals with SNHL. This impaired frequency selectivity due to widened auditory filters leads to greater masking by interfering sounds like noise. As a consequence, their speech recognition ability in presence of noise is degraded.

In order to acknowledge this problem of loss of clarity of speech in noise, presently several speech in noise tests are present which can accurately assess performance in the real world and can be used clinically. As reported by Taylor (2003) many sentence type speech-in-noise tests are available which are quick to administer as well as easy to score. These tests overpower the usual speech tests of presenting word lists in quiet conditions in the sound field due to their limited utility in hearing aid dispensing practice.

The speech-in-noise sentence tests are performed using two methods, either by fixed or adaptive procedure. Under fixed SNR tests, SNR conditions are pre-determined by the clinician and percent correct is measured at these SNRs. Usually the fixed SNR test is performed at three SNR levels: (1) challenging listening condition (-1 dB SNR), (2) moderate difficult condition (+3 dB SNR), and (3) relatively easy listening condition (+6 dB SNR). They are presented in sound field with speech and noise both being through the same loudspeaker of the audiometer. In addition, it can be done for unaided as well as aided conditions to estimate the benefit with the hearing aid.

Two most popular fixed SNR tests include Connected Speech Test (CST) (Cox, Alexander, & Gilmore, 1987) and the Speech Perception in Noise test (SPIN) (Bilger, Neurzel, Rabinowicz, & Rzeczkowski, 1984). The CST uses speech passage of nine to ten sentences in length presented along with multi-talker babble. Percent correct of 25 key words is computed as the score. The SPIN test uses five- to eight- words long sentences presented along with multi talker babble. Scoring is done for the last word of each sentence. Test items are equally divided as having high and low predictability. The test is separately scored for high predictable (maximal contextual cues) and low predictable (minimal contextual cues) speech and noise presented through the same loudspeaker. The fixed SNR tests are more prone to ceiling and floor effects and hence less preferred.

Under adaptive SNR tests, intensity level of speech or noise is varied in order to measure the speech-to-noise ratio. These adaptive tests can be carried out under the headphones or in sound field condition. Two adaptive SNR tests explicitly used are Hearing in Noise Test (HINT) (Nilson & Sullivan, 1994) and Quick Speech in Noise Test (SIN) (Etymotic Research, 2001). Both the tests have very short span of administration such that it takes 5 to 10 minutes for HINT; whereas, it takes 2 or 3 minutes for Quick

SIN. The HINT test comprises of modified Bamford-Kowal-Bench sentences (BKB) (Bench, Kowal & Bamford, 1979) which are delivered in a group of ten. Speech shaped noise is utilized as the competing background noise. The task for the subject is to repeat the key words of sentences to be considered as correct response. In HINT test, the level of noise is kept fixed at 65 dB SPL, while the presentation level for sentences is varied in 2 dB steps. The reception threshold for sentences (RTS) is obtained which is the SNR at which 50% of the sentences are repeated correctly. Another adaptive test is Quick SIN test which is faster and more accurate version of the original SIN test developed by Killion, Niquette, Gudmundsen, Revit, and Banerjee (2004). This test comprises of IEEE sentences which are presented in presence of four-talker babble. The presentation level of the sentences remains fixed at a loud MCL (either 75 or 80 dB HL) while the level of noise varies. The CD automatically changes the SNR in 5 dB steps starting at +25 dB SNR. Five key words are present in each sentence and score of one point is rewarded for each correctly repeated word. A sentence is presented at six SNRs starting from +25 dB to 0 dB, in 5 dB steps such that there are 30 key words per list. In order to compute SNR loss, the number of correct key words has to be subtracted from the reference 25.5 dB. The obtained numerical difference is referred to as SNR loss. The SNR loss for both ears can be determined in both ears in a short span of two minutes.

2.2.1. SNR-50 –In individuals with normal hearing

The SNR-50 measure is the signal to noise ratio (SNR) required for 50 % correct repetition of words. Manjula and Megha (2012) calculated the mean SNR-50 of 44 normal hearing Kannada speaking adults within the age of 15 - 65 years. The method used by them was by presenting speech at 45 dB HL and speech noise with initial level kept at 30 dB HL through the same loudspeaker kept at one meter distance at 0^0 Azimuth. The SNR required for 50% correct repetition of words was calculated which was considered as SNR-50. The approximated mean SNR-50 for individuals having hearing sensitivity within normal limits in their study was -7.23 with the standard deviation of 3.65. The median of the SNR-50 for normal hearing individuals was -7.00. The SNR loss for listeners with normal hearing was also estimated by Manjula and Megha (2012) by subtracting the SNR-50 of the group with mean SNR-50 of normal hearing ears which resulted in value of zero (0 dB).

Wilson et al. (2003) also 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 S/B ratios. 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 using simple metric of Spearman-Karber equation, they estimated SBR at which 50% correct responses were obtained which was 4.1 dB. Further, at 6 dB SBR, 90^{th} percentile was achieved for listeners with normal hearing.

2.2.2. SNR-50 and SNR loss- In individuals with hearing impairment

Taylor (2003) reported that an individual with normal hearing sensitivity requires a 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 individual with hearing impairment to comprehend speech in noise at equal power to those with normal hearing. Many researchers have considered SNR loss as an ideal counseling 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 0-2 dB is normal, an SNR loss of 2-7 dB is mild SNR loss, an SNR loss of 7-15 dB is moderate SNR loss and 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 useful information can be obtained only by administering the SNR test.

Killion (1997) described that as greater hearing losses are encountered, more SNRs are required on an average. He also reported that large individual variability exists such that some individuals having 40-50 dB loss have greater SNR-50 than some of the individuals having moderate loss of 50-60 dB. This discrepancy could be attributed to more of inner hair cell loss in the former case while more of outer hair cells damage in latter one. Unpublished data of Bentler (2012) also showed a similar trend of variability in SNR-50 across individuals with same degree of hearing loss. Hence, there exists a difference in abilities to manage in competing backgrounds across individuals.

In a study by Souza and Tremblay (2006), individuals with a PTA of 40 dB HL had an SNR-50 ranging from -3 dB to + 4 dB. They suggested probable biological reason for this variability to be neural codes in cortex which are interrupted due to the presence of noise. Accordingly, a few listeners have neural responses which are highly sensitive to noisy inputs thereby causing poor speech perception.

Further, Killion (1997) in an attempt to estimate average SNR loss as a function of hearing loss obtained a smoothed averaged data of SNR loss versus hearing loss. As depicted in Figure 2.1, at 70 dB HL presentation levels individuals having mild to moderate loss required 4-6 dB greater SNR; listeners with moderate-to-severe loss required 7-9 dB greater SNR and those listeners having severe to profound hearing loss required 12-18 dB greater SNR. Killion (1997) has also put forward that the above illustrated deficits persist even after making hearing aid circuitry defect free and set to settings for maximal intelligibility in noise.

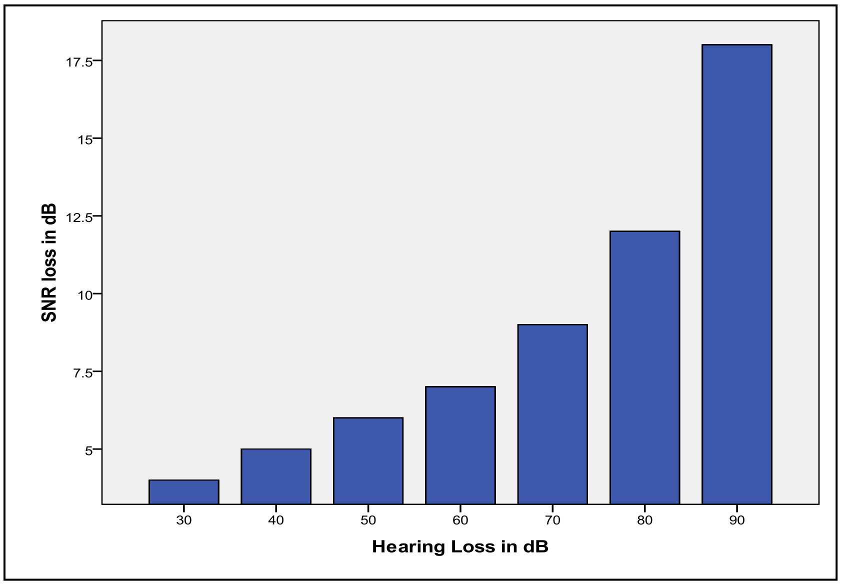

Figure 2.1: Smoothed average data of SNR loss versus hearing loss (Killion, 1997)

Killion and Niquette (2000) also suggested categories for SNR loss as Mild category with 0 to 4 dB SNR loss, moderate category with 5 to 10 dB SNR loss, severe category with 11 to 19 dB SNR loss, 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 SNR loss which is derived from SNR-50 as a tool most appropriate to estimate listening performance of speech in noise of an individual.

Manjula and Megha (2012) estimated SNR-50 of individuals with different types, degrees and configurations of hearing loss. The participants included in their study were native speakers of Kannada language and between 15 to 65 years of age. The SNR-50 was estimated for all the participants by presenting speech (at a constant level of 45 dB HL) and varying the level of speech noise (initial level kept at 30 dB HL) through the same audiometric loudspeaker of the audiometer. The difference in intensity (in dB) between speech and speech noise at which 50% of the words were repeated correctly was considered as the signal to noise ratio for 50% recognition or was referred to as SNR-50. The SNR-50 measure was calculated for individuals with mild and moderate hearing losses wherever possible. The group mean of the unaided SNR-50 for individual with hearing loss was 1.22. The SNR-50 was significantly higher for individuals with hearing loss than those with normal hearing (mean SNR-50 for normal hearing was -7.23). This reflected better performance in individuals with normal hearing. Poorer scores in speech recognition in noise of individuals with sensorineural hearing loss can be attributed to affected temporal resolution skills and inability to utilize the good signal to noise ratios (Zwicker & Schorn, 1982; Festen & Plomp, 1990). In addition to this, they lack the ability to utilize temporal fine structure cues which is reflected with their poor performance in presence of noise (Moore, 2003; Hall, Buss, & Grose, 2004).

Further, in their study across different types of hearing losses, the mean SNR-50 of individuals with conductive hearing loss was -3.12 which was lesser than the mean SNR-50 of individuals with sensorineural hearing loss which was 2.30. However, this difference was not significant. It has been reported by Hsieh, Lin, Hu, and Liu (2009) that individuals with conductive hearing loss had significantly poor SNR-50 than individuals with normal hearing. There is evidence present in literature regarding long standing conductive hearing loss affecting central auditory processing which in turn influences the ability to perform in the presence of noise. Within conductive hearing loss, the mean SNR-50 varied across degrees, such that the mean SNR-50 for mild conductive was -4; whereas, the SNR-50 was -2 for moderate conductive hearing loss. But this difference in

SNR-50 with increase in degree of conductive loss was not significant. Within sensorineural hearing loss too, with increase in degree the mean SNR-50 increased such that it was -3.56 for mild degree and 10.82 for moderate degree. This difference was found to be statistically significant. The mean SNR-50 estimated in the above study was 3.75 for sloping sensorineural hearing loss.

Wilson et al. (2003) also assessed speech recognition abilities in noise of 24 listeners with mild-to-moderate SNHL. The participants in their study had word recognition scores of ≥76% at 50 dB HL in quiet. In order to obtain 50% correct point in terms of SBR they presented multi-talker babble at a fixed level of 60 dB HL and varied the speech level from 60 dB to 84 dB HL (at seven different SBR- 24 dB, 20 dB, 16 dB, 12 dB, 8 dB, 4 dB and 0 dB). Each participant's verbal responses were recorded on spreadsheet and were later analyzed. Spearman Karber equation was utilized to derive the 50% correct point and was found to be 9.4 dB SBR. More gradual slope of function of 50% correct point (4.5%/ dB) were obtained for the listeners with mild to moderate SNHL than the listeners with normal hearing (6.5%/dB) which suggests the presence of larger inter-subject variability. Also, scores of only two listeners with SNHL were within the 90th percentile of listeners with normal hearing. Further, there was no difference seen in the multi-talker babble data for the two trials which indicates high test-retest reliability of this protocol. They also reported that both age and degree of peripheral hearing loss are expected to be in inverse relationship with the word recognition performance in adverse listening condition such as multi-talker babble.

Manjula and Megha (2012) have also computed the SNR loss for individuals with hearing loss by subtracting their mean SNR-50 from the mean SNR-50 of individuals with normal hearing. Likewise, SNR loss was computed for both types conductive as well as sensorineural hearing loss and for all the degrees. Within sensorineural hearing loss they obtained SNR loss as mentioned here, mild: 3.67 dB of SNR loss, moderate: 18.05 dB and for sloping loss: 10.98 dB of SNR loss. Further, under conductive hearing loss, they obtained 3.23 dB of SNR loss for mild degree and 5.23 dB of SNR loss for moderate degree.

The above literature suggests differences in SNR loss across type, degree and configuration of hearing losses as well as existing individual variability. To conclude, knowledge of SNR loss is necessary in predicting the listening difficulties faced by an individual in different listening environments and to decide about whether management option is required or not; and if required, then to decide the type of option that will facilitate better SNR. Various strategies that can be employed in hearing aid technology to yield better SNR are discussed in the Section 2.4.

2.3. Performance on noise tests vs. Hearing handicap questionnaire rating

It is difficult to predict or quantify the extent of handicap an individual with hearing loss witnesses in day-do-day life. Even individuals with same degree and configuration of hearing loss experience different degrees of handicap. The factor contributing to this could be difference in frequency resolution and temporal resolution (Tyler & Summerfield, 1980) across these individuals. There are several questionnaires proposed in order to measure subjectively the individual’s communication abilities. The correlation between these hearing handicap questionnaire rating and pure tone thresholds or speech identification scores has been studied by several authors. It has been reported in literature that there is a good correlation between pure tone thresholds and hearing handicap questionnaire rating but such agreement is lacking for speech identification and hearing handicap questionnaire rating (Schow & Tannahill, 1977; High, Fairbanks, & Glorig, 1964).

The extent of whether the ability of speech identification in the presence of noise is reflected in these hearing handicap questionnaires is a matter of concern since long. Tyler and Smith (1983) examined the relationship between the sentence identification in noise and rating on handicap questionnaires. They utilized Social Hearing Handicap Index (SHHI) (Ewerstein & Nielsen, 1973) and Hearing Measurement Scale (HMS) (Noble & Atherly, 1973) as the subjective measures for hearing handicap rating. They compared this with performance on sentence identification in noise. To assess sentence identification in noise, they used CID and BKB sentences in presence of continuous speech spectrum shaped noise at signal-to-noise ratio of 0 dB. They reported a high first order negative correlation between questionnaire rating and scores on sentence in noise testing. The participants who performed poorer in sentence identification in noise task rated their handicap more severely on questionnaires.

Smits, Kramer, and Houtgast (2006) studied the relation between minimum signal-to-noise ratio required to obtain 50% correct score and the self-reported hearing disability. They estimated SNR-50 measured over telephone by presenting speech in noise test in diotic mode over telephone and compared with the responses on self-reported hearing handicap questionnaire. The participants, between the age range of 60 and 64 years, had a median SNR loss of 2.2 dB in men and 1.2 dB in women. Whereas, the participants under the age-range of 80-84 years had median SNR loss of 5.0 dB in men and 3.6 dB in women. Further, they found that a single question in the self-reported hearing handicap questionnaire could predict their performance in speech-in-noise test correctly for 62% of the participants. Whereas, when all the five questions of the questionnaire were taken into account 69% of participants were classified correctly according to their performance in speech-in-noise test. The findings of this study suggest that an individual's ability to perform in speech-in-noise task can either be predicted from single question or part of the hearing handicap questionnaire.

In contrast to the findings of the above study, results have been reported on lack of correlation across speech recognition performance in noise and ratings on 'noise' section of self-assessed hearing handicap measures. Rowland, Dirks, Dubno, and Bell (1985) assessed performance in speech recognition task across two conditions of quiet and in presence of babble. The performance in these tests was further compared with ratings on self-assessment scale of communication ability in quiet and noise derived from Hearing Performance Inventory (HPI). Both the ratings over self-assessment scale as well as speech recognition scores accurately differentiated individuals with normal hearing from those with mild-to-moderate sensorineural hearing loss. There was a weak correlation (r = 0.32) between speech recognition performance and the ratings on portions of inventory. Furthermore, a systematic pattern was absent across the speech recognition performance in noise and ratings on 'noise' sub-section of HPI. Such that speech recognition in noise scores was similar to both ‘noise’ and ‘quiet’ sub-sections ratings of HPI. Hence, sub-sections of HPI proved to be a poor predictor of speech understanding in various situations like in quiet and noise.

There could be several factors associated with these equivocal findings such as, number of individuals with SNHL taken as participants, degree of hearing loss considered, questions within questionnaire being related to everyday listening or not and whether the speech recognition task used in the evaluation use relevant listening conditions or not. These divergent reports in literature pave the way for further research into efficacy of various hearing handicap questionnaires in accurately identifying the speech understanding problem and correlating with the scores on speech recognition task. The present study also examines the relationship between SNR loss and ratings on Self Assessment of Hearing Handicap (SAHH) (Vanaja, 2000).

2.4. Rehabilitative strategies based on SNR loss

To predict the benefit provided by the amplification device beforehand is difficult since there are several factors which play and go undetectable. Hearing aids can tackle problems of audibility extremely well but lag behind in improving the residual SNR loss. Miller (2013) reported that the SNR can be studied at different levels, one at input level or environmental level and next after the hearing aid processing i.e., the modified SNR at the output of the hearing aid. With the increase in input SNR, there was tremendous improvement observed in speech perception. Apart from this, the author reported that hearing aid itself modifies the input SNR and hence delivers an altered SNR to the listener's ear. Using Hagerman and Oloffson’s phase-inversion acoustic measure, the

SNR at the output of the hearing aid was determined. In addition, any correlation existing between changes in output SNR by hearing aid processing and speech perception scores in a noisy background was also studied. The findings of the study reported that changes in SNR brought about by hearing aid were small (-0.25 dB) but were found significant. The negative value indicates that the deterioration occurred in the signal after hearing aid processing. These changes in SNR did not cause any change in speech perception. Influence of SNR on subjective hearing aid outcomes like self-reported questionnaire rating is not yet studied and should be considered in future.

As shown in Table 2.2 data reported by Lauren (2009) in her unpublished dissertation, it can be noted that there was no significant difference between unaided SNR-50 (average= 10.43 SNR) and aided SNR-50 (average= 11.07 SNR) using Speech in Noise (SIN) test at presentation level of 70 dB HL. At soft levels like at 40 dB HL, unaided SNR-50 (average= 9.85 SNR) was significantly better than aided (average= 11.54 SNR). These findings are in synchrony with the findings of unpublished dissertation thesis by Miller (2013), suggesting that in noisy situations performance deteriorates with the amplification device. In four out of seven participants it was unable to evaluate SNR-50 at 40 dB HL as it was much above 15 dB SNR. In aided condition, for one participant it was 16.31 and for the remaining three participants it still remained undetectable. Hence, using hearing aid, though improves audibility issues, does not solve problems of understanding speech in the presence of noise.

Table 2.2: Data showing SNR required by an individual to score 50% correct using SIN across different conditions.

Subject	70 dB Unaided	70 dB Aided	40 dB Unaided	40 dB Aided
1	5.42	8.36	7.91	6.03
2	6.36	6.29	11.49	7.5
3	CNE	13.03	CNE	CNE
4	12.59	13.79	CNE	16.31
5	16.06	13.02	CNE	CNE
6	12.67	12.59	CNE	CNE
7	9.46	10.38	10.15	6.22
Mean	**10.43**	**11.07**	**9.85**	**11.54**

Note: From unpublished dissertation (Lauren, 2009). CNE refers to Could not Evaluate, signal-to-noise ratio greater than 15 dB.

Several attempts have been made to tackle this problem of SNR loss by employing different strategies in hearing aids. Killion (1997) stated that no single microphone technology can manage or improve the SNR loss; hence prime focus while improving hearing instruments should be towards reducing noise without compromising the speech cues (Smoorenburg, 1999). De Vries and De Vries (2002) recommend beamformers as the best solution to restore SNR loss. Several techniques which were suggested by Plomp (1978) such as the use of remote microphone closer to the talker and use of directional microphone can be helpful in reversing back the residual SNR deficit. Best directional microphones in hearing aids can provide approximately 4-5 dB improvement in SNR, array microphones up to 8-10 dB improvement, whereas tiny FM transmitters which are known for one-to-one conversations can provide an improvement of 15- 20 dB (Killion, 1997).

The SNR loss helps in deciding how much SNR assistance is required to be given to an individual or whether or not separate accessories are needed for an individual (Killion, 1997). Fabry (2005) recommended that there are different technological needs for individuals with varying degrees of SNR loss such that for individuals with 0 - 2 dB of SNR loss, omni-directional microphones can be a good option, individuals with 2 - 7 dB of mild SNR loss can do well with fixed or adaptive directional microphones, individuals with 7- 15 dB of moderate SNR loss may require adaptive or fixed directional microphones and those having greater than 15 dB SNR loss or severe-profound SNR loss need FM systems. Further, Killion and Niquette (2003) stated that the knowledge of the amount of SNR loss can be helpful in counseling them better regarding the advantage of hand-held microphones, array microphones and FM devices.

Duquesnoy (1982) reported that even a single dB increase in signal to noise ratio may yield a 15 - 20% increase in speech intelligibility. Hence, knowledge on the SNR loss will help in choosing various measures to diminish the SNR deficit that can be incorporated into hearing aid technology. Manjula and Megha (2012) studied the effect of noise reduction algorithm on SNR-50 for individuals with various degrees of hearing loss. They estimated aided SNR-50 for each participant in two conditions, one with noise reduction algorithm kept ‘on’ and second without noise reduction algorithm. The results of their study were that, with noise reduction ‘on’ there was a significant improvement in performance as compared to without noise reduction. They also reported that this improvement was present in all participants except those with moderate sensorineural and sloping sensorineural hearing loss. Similar findings of significant improvement in speech recognition in noise with noise reduction kept ‘on’ were also reported by Alcantara, Moore, Kuhnel, and Launer (2003), Peeters, Kuk, Lau, and Keenan (2009) and Kuk, Peeters, Lau, and Korhonen (2011). Hence, even noise reduction algorithms work well in improving speech recognition during adverse listening situations.

Furthermore, Walden and Walden (2004) reported that SNR loss measure, a tool to estimate supra-threshold distortion is a powerful predictor of everyday success with hearing aids. They compared results of ten predictive measures (including audibility measures as well as supra-threshold distortion measures) with the findings of two outcome measures. They stated that individuals who require higher SNRs to comprehend speech are those who less likely benefit with amplification device in daily life. Additionally, they compared scores of unaided and aided Quick SIN and stated that the difference between the two was not significant. Hence, in essence the amplification device alone does not improve the ability of an individual to comprehend speech in presence of noise.

Taking into consideration that SNR-50 and SNR loss measures are not used clinically and its utility in deciding need for an amplification device is yet to be ascertained. The present study was taken up with the same rationale. Additionally, the present study also assesses whether the appropriateness and efficiency of SNR loss in clinical hearing aid trial overpowers the routine procedure of hearing aid trial utilizing speech recognition in quiet.

Chapter 3

Method

The study aimed at evaluating the efficacy of signal-to-noise ratio (SNR) loss as a clinical tool for hearing aid evaluation. There were six specific objectives of the study. First four objectives were framed to derive cut-off criterion of SNR loss to demarcate the need for amplification device. Last two objectives were to compare the benefit across two approaches of hearing aid evaluation, one being traditional testing of speech in quiet and alternate approach utilizing SNR loss as a measure for hearing aid evaluation. In order to meet the aim of the present study, the six objectives were attained by following method given below.

3.1. Participants

The participants included were adults in the age range from 18 to 55 years. All the participants were native speakers of Kannada language which is an official Dravidian language spoken by the people of Karnataka state. The total number of ears tested in the study was 52. The test ears were classified under two groups, Group 1 and Group 2. The participants under Group 1 were taken for attainment of first four objectives and of Group 2 for fulfilling last two objectives of the study. The division of test ears into two groups is depicted in Table 3.1, where N refers to number of test ears.

Table 3.1: Details of Test Ears

Group 1 (N=42)			Group 2 (N=10)	
			Individuals with moderate flat SNHL who were naive hearing aid users.	
Sub-Group A (N= 20)	Sub-Group B (N=11)	Sub-Group C (N=11)	Sub-Group A (N= 5)	Sub-Group B (N= 5)
Individuals with normal hearing	Individuals with minimal SNHL	Individuals with mild SNHL	*Condition 1:* Traditional hearing aid trial	*Condition 1:* Hearing aid trial based on SNR loss
			Condition 2: Hearing aid trial based on SNR loss	*Condition 2:* Traditional hearing aid trial

Under Group1, the total number of test ears assessed was 42. The test ears under Group 1 were further divided into subgroups i.e., A, B and C based on their hearing status, such that it comprised of 20 test ears having normal hearing sensitivity, 11 test ears having minimal sensorineural hearing loss and 11 test ears having mild flat sensorineural hearing loss. Under Group 2, a total of 10 test ears having moderate flat sensorineural hearing loss were included. The test ears under Group 2 were also further divided into two Sub-groups A and B, each comprising of five test ears. The test ears under Sub-group A of Group 2 initially underwent hearing aid evaluation using traditional approach of testing in quiet situation; followed by hearing aid evaluation based on SNR loss. On the contrary, test ears under Sub-group B of Group 2 initially underwent hearing aid evaluation based on SNR loss followed by traditional approach of hearing aid evaluation that was done in quiet situation. For all the above testing, the better ear was accounted as the test ear. The non-test ear was occluded with an ear plugs to ensure that the non-test ear was not participating in the testing. Written informed consent was obtained from all the participants prior to the testing. Also the ethical guidelines framed by the AIISH ethical committee were followed.

3.1.1. Inclusion Criteria

The test ears (N=20) of participants having hearing sensitivity within normal limits, i.e., pure tone average (PTA) ranging from 3.75 - 11.25 dB HL, were included under Sub-group A of Group 1. They had no history of speech, language and hearing problems. Their age ranged from 18 - 50 years with a mean age of 31.85 years. The Sub-group B under Group 1 comprised of test ears (N=11) of participants having minimal sensorineural hearing loss with a PTA ranging between 16 to 25 dB HL in the better ear. These test ears had 'A' type tympanogram. Their age ranged from 18 - 55 years, with a mean age of 36.36 years. The Sub-Group C under Group 1 comprised of test ears (N=11) of participants with mild sensorineural hearing loss (i.e., PTA ranging between 26 and 45 dBHL) and 'A' type tympanogram in better ear. Their age ranged between 26 and 55 years with a mean age of 45.81 years. The data obtained from the Group 1 participants were utilized for the attainment of first four objectives of the study.

The Group 2 comprised of test ears with acquired moderate flat sensorineural hearing loss. The flat audiogram was operationally defined as the audiogram having thresholds across frequencies that did not vary by more than 20 dB from each other

(Pittman & Stelmachowicz, 2003). Ten test ears were included in this group having ‘A’ type tympanogram. The participants were naïve hearing aid users and were within age range from 15 to 55 years with a mean age of 49.3 years. Group 2 was further divided into two sub-groups, i.e., A and B, based on the order of hearing aid trials they were subjected to. The sub-group A consisted of participants who experienced traditional hearing aid evaluation initially and hearing aid evaluation based on SNR loss later. The sub-group B consisted of participants who experienced hearing aid evaluation based on SNR loss first and then based on traditional technique of speech testing in quiet. The data collected from test ears under Group 2 were utilized to accomplish the last two objectives of the study.

3.1.2. Exclusion Criteria

Individuals having middle ear infections were not taken as participants. Individuals with cognitive or psychological deficits were excluded. Individuals with auditory neuropathy spectrum disorder were also discarded from being participants in the study.

3.2. Test Environment

Air-conditioned, sound treated single- or double- room test suite was used to carry out all the audiological tests. The noise levels were within the permissible limits.

3.3. Equipment and Material

- A calibrated two-channel 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 sound field testing.

- A calibrated middle ear analyzer was used to obtain tympanogram and acoustic reflex thresholds in order to rule out any middle ear pathology.
- NOAH and hearing aid programming software installed in the personal computer, that was connected to NOAH link was used to program the digital behind the ear (BTE) hearing aids.
- Digital programmable BTE hearing aids, two in number, were utilized for hearing aid trials. The hearing aids had four-channels, three programs, and two microphone modes (omni-directional & directional). Both were powerful BTE hearing aids using a battery of size 13. Both had fitting range from mild to severe degrees of hearing loss.
- A Dell Vostro 2520 laptop with intel core 2 duo processor was connected to the auxiliary input of audiometer using maxcord audio/video cable for presenting multi-talker babble, Kannada speech test material and Kannada passage through the audiometer.
- Recorded phonemically balanced (PB) speech test material in Kannada, developed by Manjula, Geetha, Kumar, and Antony (2014) as part of AIISH research fund (ARF) project was utilized. The test material consisted of 21 lists of bi-syllabic words that were used to obtain the speech identification in quiet as well as in noise (SNR-50).

- Kannada four-speaker multi talker babble developed by Kumar, Ameenudin, and Sangamanatha (2012) was used to obtain SNR-50.
- The questionnaire titled Self Assessment of Hearing Handicap (SAHH) (Vanaja, 2000) was used for rating on a seven-point response scale by the participants. In all there were 23 questions in the questionnaire. The response for only eight questions with its sub-parts that were relevant for the purpose of the study was considered for analysis. These included 14 questions assessing speech comprehension in quiet (1a to 1h, 1s, 1t, 1v, 5, 6, and 7) and 15 questions assessing speech comprehension in noise (1i to 1r, 1u, 2, 3, 4 and 22). The seven-point (Always, Almost always, Generally, Half-the-time, Occasionally, Seldom and Never) response scale was derived from the Abbreviated Profile of Hearing Aid Benefit (APHAB) (Cox & Alexander, 1995). At the end of questionnaire, an open ended question was included for the participant to mention any other situation in which he / she faced difficulty in hearing. The original questionnaire, its Kannada translated version and rating scale utilized in the study are attached in Appendices A, B and C respectively. This questionnaire rating was used to set a cut-off criterion for SNR loss in order to determine the requirement for a hearing aid.
- Recorded Kannada passage (Sairam, 2002) was utilized for rating the quality of speech through the two test hearing aids.
- Quality rating scale given by Eisenberg, Dirks, and Bell (1995) was utilized to verbally rate the quality of aided speech with each trial hearing aid. Rating scale

comprised of five dimensions (loudness, fullness, clearness, naturalness and overall impression) which were rated on a ten-point continuous scale. In which the two extremes 0 referred to very poor and 10 referred to excellent. The mid points 2, 4, 6 and 8 referred to poor, fair, good and very good.

3.4. Procedure

In order to confirm the inclusion criteria for each group/sub-group, air-conduction hearing thresholds were established at octave frequencies from 250 Hz to 8000 Hz and bone-conduction thresholds from 250 Hz to 4000 Hz for all test ears using modified Hughson-Westlake procedure (Carhart & Jerger, 1959). Immittance evaluation was carried out to rule out any middle ear pathology in the test ears of the participants. Speech reception thresholds (SRT) were obtained using the method given by Tillman and Olsen (1973). The speech identification scores (SIS) were 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 and the number of words repeated correctly was noted. The uncomfortable level for speech in the test ear of the individual was also noted. For the purpose of the study, the data were collected in two phases, Phase 1 and Phase 2. The Phase 1 of the study was carried out to achieve first four objectives of the study whereas Phase 2 to achieve the last two objectives.

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

In this phase, a cut-off criterion was established to facilitate the use of SNR loss as a criterion for hearing aid prescription. Prior to this, the signal to noise ratio for 50 % correct scores (SNR-50) was measured for each test ear of all the participants in Group 1.

This was followed by estimating the SNR loss for the participants under sub-groups B and C of Group 1. Their SNR loss was compared with their ratings on hearing handicap questionnaire in order to derive the cut-off criterion for deciding the need for a hearing aid using the SNR loss measure.

3.4.1.1. Procedure for obtaining SNR-50 and SNR loss measures:

Unaided SNR-50 was computed for all the participants under Group 1. Each participant was made to sit comfortably in the test room. Dell Vostro 2520 laptop containing recorded speech material (PB words) and Kannada four-speaker multi-talker babble was connected to auxiliary input of audiometer using maxcord audio/video cable. The PB word list was presented at a constant level of 45 dBHL through the audiometric loud speaker kept in front of the participant at 0^o Azimuth and one meter distance, in the presence of speech babble. The initial level of Kannada four-speaker multi talker babble through the same loud speaker was kept 15 dB HL below that of the speech (i.e., 30 dB HL). An adaptive method was utilized in which the level of speech babble was varied systematically in order to establish the SNR-50.

The participant was instructed that he/she will be hearing words in Kannada along with the noise/babble. The participant was informed to listen to the words and repeat them while ignoring the noise/babble. Gradually, level of noise was increased and they were instructed to try and repeat back the words. The level of the babble was increased in 5 dB steps, till the participants repeated two out of four words (i.e., 50 %) being presented. At this point, the babble was varied in 1 dB steps in order to obtain a more precise level of multi talker babble level at which 50 % of the words were correctly repeated. At this instance, the difference in level of the speech and multi talker babble was noted as the SNR-50 measure. This procedure of obtaining SNR-50 was repeated for all the participants.

The mean SNR-50 of individuals with normal hearing was computed. The SNR loss for each participant with minimal and mild hearing loss was computed using the method suggested by Killion and Niquette (2000). According to which SNR loss is obtained by subtracting the mean SNR-50 of individuals with normal hearing from the SNR-50 of the participant. This was done for each test ear of participants in sub-groups B and C of Group 1.

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

The participants with minimal and mild sensorineural hearing loss were administered a Kannada translated version of SAHH questionnaire. The participants were 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 8 questions with its sub-parts were considered. This comprised of 14 questions including sub-parts assessing speech comprehension in quiet (1a to 1h, 1s, 1t, 1v, 5. 6, and 7) and 15 questions including sub-parts assessing speech comprehension in noise (1i to 1r, 1u, 2, 3, 4 and 22). At the end, an open ended question was included to collect information on any other condition in which he/she feels difficulty in hearing. The original SAHH questionnaire from which questions were derived for the present study is attached in

Appendix A. In addition, the Kannada version of the questionnaire and rating scale utilized in the study are given in Appendices B and C.

To assure test-retest reliability on the questionnaire response, the participants were sent back along with the copy of questionnaire and the rating scale, after the testing. With a minimum span of two days, 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 one, seldom (12%) was scored as two, occasionally (25%) as three, half-the-time (50%) as four, generally (75%) as five, almost always (87%) as six and always (99%) was scored maximum as seven. Independent scores of questions in quiet (15 questions) and noise (14 questions) were computed for each participant in addition to the overall score for all the 29 questions. Thus, a total score for each participant ranged from a minimum score of 29 to maximum score of 203.

3.4.1.3. Setting the cut-off criterion for SNR loss

The data on SNR loss of participants with minimal and mild hearing loss were tabulated and analyzed to investigate if a relationship existed between SNR loss, SIS and the questionnaire rating. Taking the findings of the study by Palmer, Solodar, Hurley, Byrne, and Williams (2009) as the basis, 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 relates 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 amplification device. The participants were divided into two groups based on whether they require hearing aid (total score ≥ 80) or not (total score < 80).

The data from Phase I of the study comprised of unaided SIS in quiet and unaided SNR-50 for Group 1 A participants. Whereas, for participants under Group 1 B and 1 C, the data comprised of unaided SIS in quiet, unaided SNR-50, and the hearing handicap questionnaire scores. The questionnaire scores comprised of scores for speech comprehension in quiet, scores for speech comprehension in noise and the overall score. The data for each test ear from groups 1 B and 1 C were tabulated and subjected to statistical analysis using Statistical Package for Social Science (SPSS version 17.0).

The minimum amount of SNR loss affecting the ability of a participant to listen in various situations and the amount of SNR loss that would demarcate participants who require a hearing aid and those who do not was computed statistically. In addition, SIS in quiet was also established to know its relationship with SNR loss. The obtained SIS in quiet and SNR loss were compared with the scores on the questionnaire rating for two situations i.e., speech comprehension in quiet and in noise. The SNR loss criterion thus established is expected to be useful clinically to determine the need for audiological rehabilitation during hearing aid evaluation.

3.4.2. 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/routine 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 tried on Group 2 participants. This phase was carried out to achieve the last two objectives of the study.

3.4.2.1. 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. The NOAH and hearing aid fitting softwares were loaded into this computer. 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. Aforementioned two hearing aids were tested for two conditions that is, trials for identification of speech in quiet as well as trials involving estimation of SNR loss. Each participant under Group 2 was tested with both the evaluation, i.e., evaluation in quiet and evaluation in noise, which were counterbalanced in order across sub-groups A and B in Group 2.

3.4.2.2. Aided speech identification in Quiet

Under traditional hearing aid evaluation, 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^{o} 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 maximum speech identification score of 25. The hearing aid yielding better speech identification scores was fitted to the participant for a duration of ten minutes. In the course of this duration, the participant was made to converse with family member/s or informant, in a non-acoustically treated room. Additionally, the participant was made to hear to a recorded Kannada passage presented through loudspeaker of an audiometer at 45 dB HL.

3.4.2.3. Aided speech identification in Noise

Under hearing aid evaluation using SNR loss, initially SNR loss for all participants under Group 2 was estimated. For this purpose, the SNR-50 measure was obtained first for the unaided condition, with the speech kept constant at 70 dB HL and multi talker babble was varied from a starting level of 50 dB HL (i.e., 20 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 participant by comparing the obtained SNR-50 to the mean SNR-50 of the individuals with normal hearing (Group 1A). The aided SNR loss was also estimated for both the trial hearing aids by keeping level of speech constant at 45 dB HL; while the level of babble was kept at 30 dB HL initially. The procedure described earlier in Section 3.4.1. to obtain SNR loss was followed. The hearing aid yielding minimal SNR loss 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 non-acoustically treated room. Additionally, the participant was made to hear to a recorded Kannada passage presented through the loudspeaker of an audiometer in quiet at 45 dB HL.

At the end of testing with each trial hearing aid, the participants were given a quality rating scale to evaluate the quality of speech through the hearing aids for the recorded passage. The quality rating scale used consisted of five parameters - loudness, clearness, fullness, naturalness, and overall impression. All the parameters had to be rated on a scale from 0 to 10, where 0 was very poor, 2 was poor, 4 was fair, 6 was good, 8 was very good, and 10 was excellent.

3.4.2.4. Comparison across two approaches of hearing aid evaluations

The data obtained from the Phase 2 comprised of unaided SNR-50, unaided SIS, aided SIS with first hearing aid, aided SIS with second hearing aid, aided SNR-50 with first hearing aid and aided SNR-50 with second hearing aid for all ten participants in Group 2. Apart from this, quality ratings on five parameters (loudness, fullness, clearness, naturalness and overall impression) for the two trial hearing aids were also noted. The data from the second phase of the study were compiled, tabulated and were subjected to statistical analyses using Statistical Package for Social Science (SPSS for

Windows version 17.0). Appropriate statistical tests were carried out to compare which approach among the traditional (aided SIS in quiet) and alternate (aided SNR loss) is a better tool to prescribe hearing aids in a clinical set-up. Further, the quality judgment ratings for each hearing aid were assessed for any existing correlation with aided SIS or SNR loss.

Chapter 4

Results

The aim of the present study was to evaluate the efficacy of signal-to-noise ratio and (SNR) loss as clinical tool for hearing aid evaluation. The specific objectives of the study were:

1. To compare the SNR-50 and SNR loss across participants with normal hearing, minimal SNHL and mild SNHL.
2. To compare the rating score on hearing handicap questionnaire across minimal and mild degrees of hearing loss.
3. To check the relationship between SNR loss, SIS and questionnaire rating scores for speech comprehension in quiet and noise.
4. To estimate a cut-off criterion for SNR loss to demarcate the need for amplification device.
5. To compare the traditional hearing aid evaluation approach based on testing speech in quiet and the alternate approach of hearing aid evaluation based on SNR loss.
6. To check the relationship between subjective quality ratings obtained after traditional and alternate approach of hearing aid evaluation with aided SIS and aided SNR loss.

To realize these objectives, data from 52 ears were tabulated for statistical analyses. To evaluate the first four objectives, data from 20 ears of participants with normal hearing, 11 ears of participants with minimal sensorineural hearing loss (SNHL), and 11 ears of participants with mild SNHL were tabulated. The data included the total scores obtained on hearing handicap questionnaire ratings, scores obtained for questions assessing speech comprehension in quiet and noise, unaided speech identification score (SIS), unaided SNR-50 and unaided SNR loss. Further, the participants with minimal and mild SNHL were divided into two groups based on the total scores obtained on the questionnaire. Those participants who had a total score of greater than or equal to 80 were considered to be candidates for amplification device. The remaining participants who had a total score of less than 80 were not considered as candidates for amplification device. The cut-off criterion of SNR loss was derived from this data by evaluating for any significant difference between the two groups of participants who were candidates for amplification device and those who were not.

In order to evaluate the last two objectives of the study, 10 ears of participants with flat moderate hearing loss were subjected to two approaches of hearing aid evaluation. This was done in order to evaluate whether the use of SNR loss in hearing aid evaluation is more advantageous compared to the traditional approach of testing aided speech identification in quiet.

The results of the present study are mentioned under the following headings:

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

4.2. SNR loss in ears with normal hearing, minimal SNHL and mild SNHL

4.3. Comparison of PTA, SIS, SNR-50, SNR loss and scores on questionnaire rating between ears with minimal and mild SNHL

4.4. Relationship between SNR loss and SIS with questionnaire rating in terms of speech comprehension in quiet and in noise

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

4.6. Comparison across traditional and alternate approaches of hearing aid evaluation

4.7. Relationship between aided quality ratings and aided SIS, aided SNR loss measures.

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

The mean, median, range and standard deviation of SNR-50 in ears with normal hearing and those with minimal and mild SNHL are mentioned in Table 4.1. The box plot in Figure 4.1 represents the SNR-50 data in form of mean and 95% confidence interval (CI) across the degree of hearing loss.

Table 4.1:Mean, median, range and standard deviation of SNR-50 in ears with normal hearing, minimal and mild SNHL

Groups	*SNR-50, in dB*			
	Mean	*Median*	*Range*	*Standard Deviation*
Normal hearing (N=20)	0*	0	-2 to 2	1.16
Minimal SNHL (N=11)	3.36	3	0 to 8	2.90
Mild SNHL (N=11)	5.36	5	2 to 9	1.85

Note: * - For ease of calculation taken approximately as 0 instead of the actual value of 0.1.

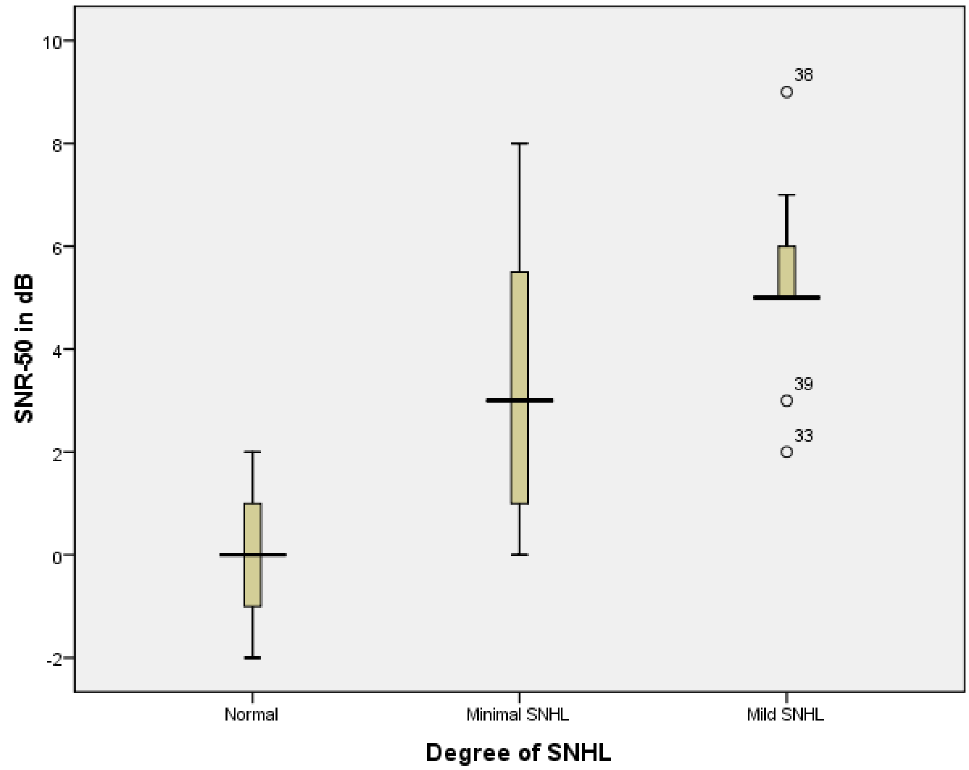

Figure 4.1: Box plot depicting mean and 95% CI of SNR-50 data of ears with normal hearing, minimal and mild SNHL

Levene's test was carried out to check for homogeneity of variance for SNR-50 parameter across all the three groups, i.e., normal hearing, minimal and mild SNHL. Since, homogeneity of variance was not satisfied ($p < 0.05$), Dunnett's T3 post-hoc analysis test was carried out to check for significant difference in SNR-50 across the three groups. The mean, standard error and significance value for SNR-50 across all comparisons are reported in Table 4.2.

Table 4.2: Comparison of mean SNR-50 across ears with normal hearing, minimal and mild SNHL using Dunnett's T3 multiple comparison procedure

SNR-50, in dB	*Mean difference*	*Standard error*	*Significance*
Normal hearing vs. minimal SNHL	-3.26	0.91	0.01*
Normal hearing vs. mild SNHL	-5.26	0.61	0.00*
Minimal SNHL vs. mild SNHL	-2.00	1.04	0.19

Note: *- mean difference significant at $p < 0.05$

The SNR-50 of the ears with minimal and mild SNHL was significantly higher than the ears with normal hearing. However, there was no significant difference between the mean SNR-50 of ears with minimal and mild SNHL. Hence, the data of minimal and mild SNHL were clubbed together to obtain cut-off criterion for SNR-50 in order to decide on the need for amplification.

4.2. SNR loss in ears with normal hearing, minimal and mild SNHL

The mean SNR-50 for ears with normal hearing as represented in Table 4.1 was 0 dB. Thus, the SNR loss for ears with normal hearing was 0 dB and for ears with minimal and mild SNHL, SNR loss was equal to their respective SNR-50 value which is computed by subtracting the mean SNR-50 of normal hearing from the mean SNR-50 for minimal/mild SNHL (i.e., mean SNR-50 for minimal/mild SNHL - 0 dB). Therefore, in the present study, values of SNR-50 and SNR loss measures remain the same. Interpolating from the findings of SNR-50, the value of SNR loss for mild and minimal SNHL group was significantly higher than that for the group with normal hearing. However, there was no significant difference in SNR loss across minimal and mild SNHL group. In the Figure 4.2 box plot depicts SNR loss data for the two groups of ears, minimal and mild SNHL.

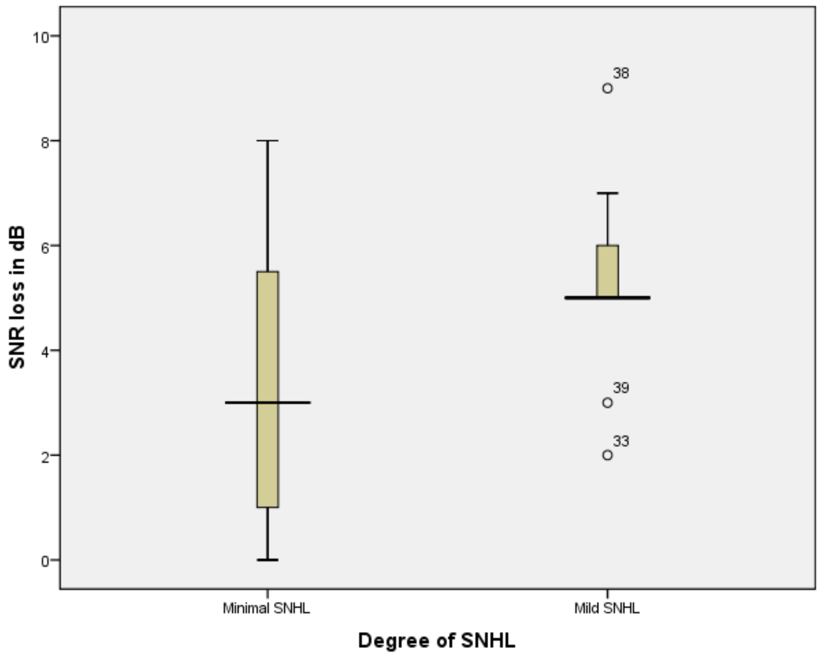

Figure 4.2: Box plot depicting mean and 95% CI of SNR loss for the groups minimal and mild SNHL

4.3. Comparison of PTA, SIS, SNR-50, SNR loss and scores for questionnaire rating between ears with minimal and mild SNHL

The data of the ears with minimal and mild SNHL comprising of pure tone average (PTA), speech identification score (SIS), SNR-50, SNR loss, questionnaire rating score for speech comprehension in quiet and in noise as well as total score were tabulated and subjected for statistical analysis using SPSS version 17. The result of the descriptive statistics is shown in the Table 4.3.

Table 4.3 Mean and standard deviation of PTA, SIS, SNR-50, SNR loss and questionnaire ratings across minimal and mild SNHL

Parameters		*Degree of hearing loss*	*Mean*	*Standard deviation*
PTA (in dB HL)		Minimal	20.47	3.07
		Mild	32.12	4.65
SIS (Max = 25)		Minimal	24.36	3.24
		Mild	22.36	5.44
SNR-50 (in dB HL)		Minimal	3.36	2.90
		Mild	5.36	1.86
SNR loss (in dB HL)		Minimal	3.36	2.90
		Mild	5.36	1.86
Hearing Handicap Questionnaire	Speech comprehension in quiet (Out of 98)	Minimal	22	8.210
		Mild	35.09	13.12
	Speech comprehension in noise (Out of 105)	Minimal	28	11.54
		Mild	45	17.75
	Total score of quiet and noise (Out of 203)	Minimal	50	19.63
		Mild	80.09	29.87

Shapiro-Wilk test of normality was carried out to check for normality across all the parameters (PTA, SIS, SNR-50, SNR loss, speech comprehension in quiet, speech comprehension in noise and total score for quiet and noise). Except SIS all the parameters followed normal distribution (i.e., $p > 0.05$) in the two groups of ears with minimal and mild SNHL. All the parameters except SIS were compared across the two groups (Minimal and Mild SNHL) using independent 2 samples t-test. Followed by this, Levene's test of equality of variance was carried out to check whether two groups, Minimal SNHL and Mild SNHL, have homogenous variance. It was noted that there was equal variance present across the two groups ($p > 0.05$) for all the parameters SNR-50, SNR loss, speech comprehension in quiet, speech comprehension in noise and total score, except for parameter PTA ($p < 0.05$). The result of independent 2 samples t-test is reported in the Table 4.4.

Table 4.4 Significant difference between minimal and mild SNHL on different audiological measures, based on independent 2 samples t-test

Measures	*t*	*df*	*P*
PTA	-6.93	17.33	0.00*
SNR-50	-1.92	20	0.07
SNR loss	-1.92	20	0.07
Questionnaire rating:			
- Speech comprehension in quiet	-2.80	20	0.01*
- Speech comprehension in noise	-2.66	20	0.02*
- Total score of quiet and noise	-2.79	20	0.01*

Note: * - significant at $p < 0.05$

Findings on independent 2 samples t-test revealed that the PTA and ratings on questionnaire (i.e., speech comprehension in quiet score, speech comprehension in noise score and also in total score) were significantly higher in mild group compared to the minimal group. But there was no significant difference seen across the two groups for SNR-50 and SNR loss parameters. A similar finding was revealed when Dunnett's T3 test was administered in Section 4.1. The SNR-50 data for the two groups minimal and mild SNHL is also represented in Figure 4.3.

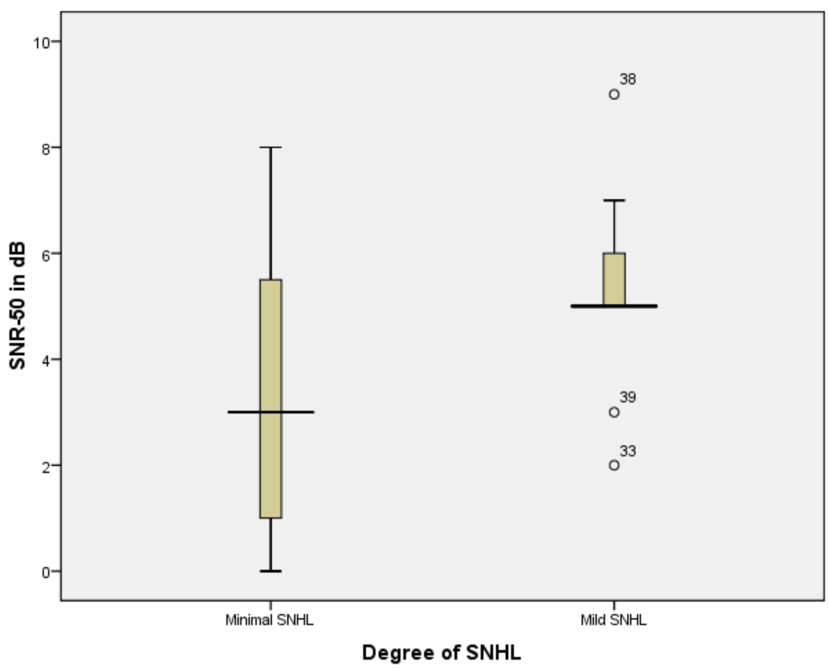

Figure 4.3: Box plot depicting mean and 95% CI of SNR-50 for ears with minimal and mild SNHL.

To compare mean SIS of two groups minimal and mild SNHL, non-parametric Mann-Whitney U test was employed, as the data were not normally distributed. There was a significant difference in mean SIS across the two groups. The test statistic and the significance value are mentioned in Table 4.5. The box plot in the Figure 4.4 depicts the SIS data across minimal and mild SNHL groups, as mean and 95% confidence interval.

Table 4.5 Significant difference in SIS across minimal and mild SNHL using non-parametric Mann-Whitney U test

SIS	Mean difference	Z	P
Minimal SNHL group vs. Mild SNHL group	2.00	-3.479	0.001*

Note: *- significant at p < 0.05

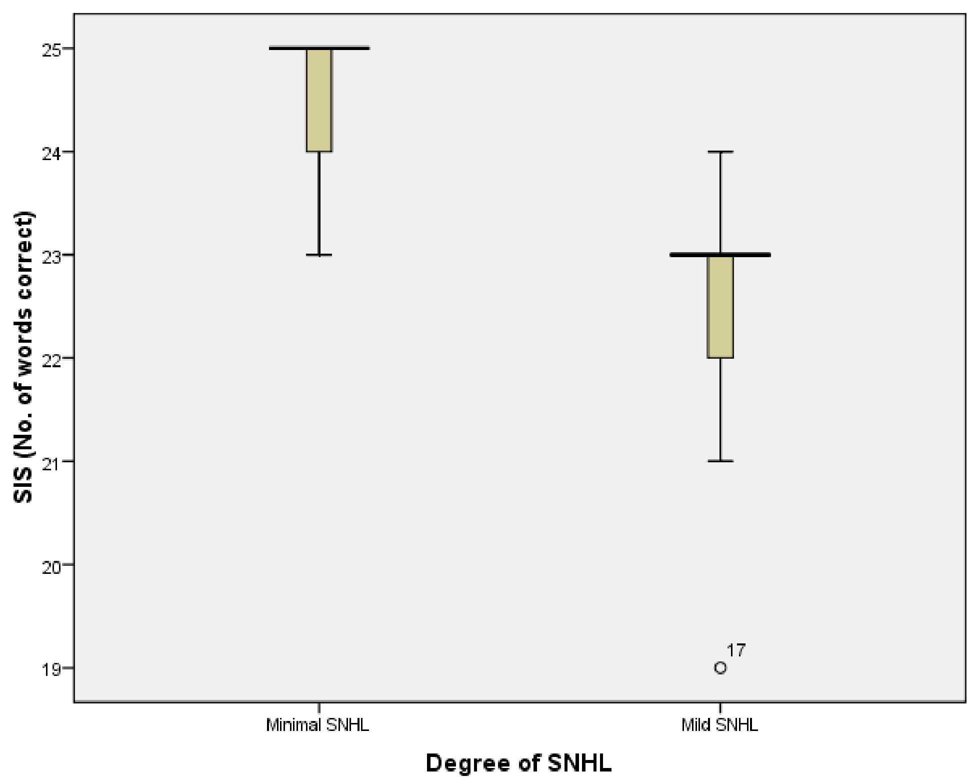

Figure 4.4: Box plot depicting SIS raw scores of the individuals with minimal and mild SNHL.

4.4. Relationship between measures SNR loss, SIS with questionnaire rating in terms of speech comprehension in quiet and in noise

Spearman's rank correlation was employed to check for any existing correlation between SNR loss and hearing handicap questionnaire rating for quiet and noise. On a similar note, correlation between SIS and hearing handicap questionnaire rating for quiet and noise was also studied. The correlation coefficient (r) with the significance level across all the conditions is mentioned below in Table 4.6.

Table 4.6 Relationship between SNR loss, SIS with rating on hearing handicap questionnaire using Spearman's rho correlation

Parameters	Correlation coefficient (r)	Significance level
SIS and Speech comprehension in quiet	-0.71	0.00*
SIS and Speech comprehension in noise	-0.69	0.00*
SNR loss and Speech comprehension in quiet	0.69	0.00*
SNR loss and Speech comprehension in noise	0.70	0.00*

Note: * - significant at $p < 0.05$

There was a moderate to strong statistically significant positive correlation between SNR loss and rating scores on hearing handicap questionnaire for speech comprehension in quiet and noise. The participants with more SNR loss rated significantly more difficulty on hearing handicap questionnaire and correlation was more with ratings for speech comprehension in noise than for quiet. There was a moderate to strong negative correlation between SIS and rating on hearing handicap questionnaire for speech comprehension in quiet and noise. The participants who had higher SIS rated significantly lesser difficulty on the hearing handicap questionnaire and correlation was more with hearing handicap ratings for quiet than in noise condition.

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

The data of participants with minimal and mild SNHL comprising of SNR loss, SIS, rating scores over hearing handicap questionnaire for quiet, noise and total were tabulated. The mean and standard deviation of SNR loss of the two groups of participants divided based on the decision of hearing aid candidacy using questionnaire rating scores is represented in Table 4.7.

Table 4.7 Mean and standard deviation for SNR loss of participants across the two groups divided based on hearing aid candidacy

Hearing aid required	SNR loss	
	Mean	Standard deviation
Yes (score ≥ 80)	7.00	1.581
No (score < 80)	3.59	2.320

The mean SNR loss across the two groups was compared using independent 2 samples t-test. There was a significant difference in SNR loss between the two groups [t (20) = 3.059, p = 0.006]. The group of participants who were predicted to require a hearing aid, based on questionnaire rating score, had significantly higher SNR loss than the group of participants who did not require. The SNR loss data across two groups of participants divided based on decision of hearing aid candidacy is depicted in the form of box plot in the Figure 4.5.

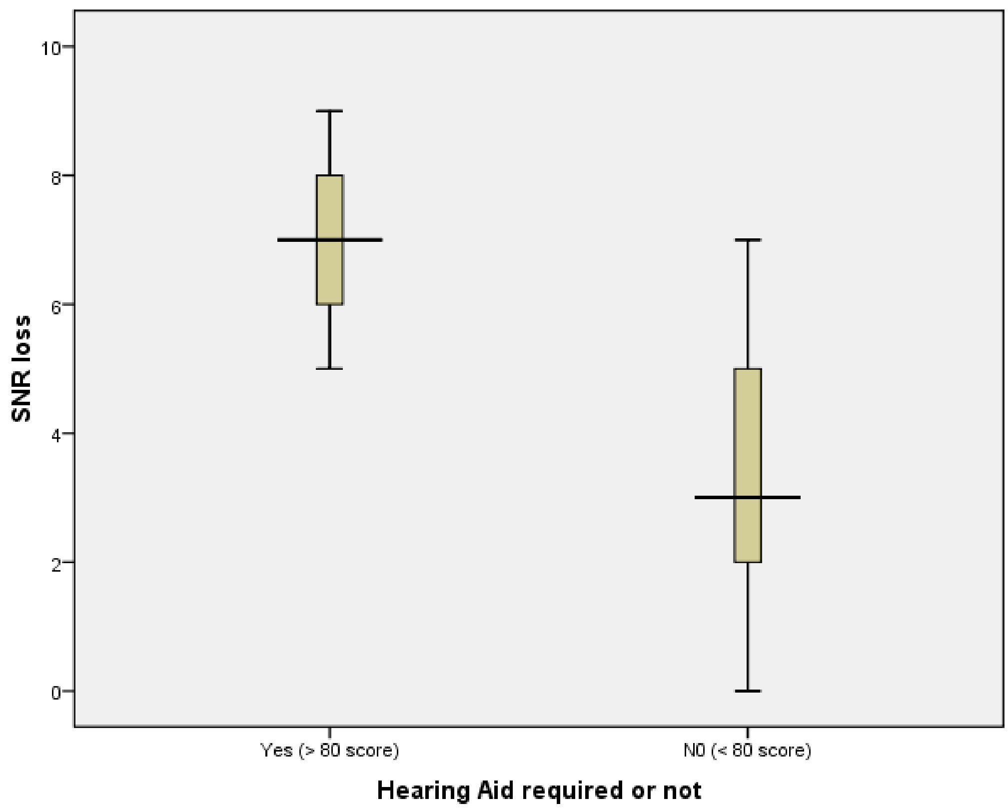

Figure 4.5: Box plot showing SNR loss data for the two groups of participants divided based on hearing aid candidacy

The cut-off criterion was derived by subtracting SD from the mean SNR loss of the group of participants who were predicted to be candidates for hearing aid. Thereby, the SNR loss cut-off criterion obtained was 5.419 dB (i.e., 7 – 1.581). The participants with SNR loss of lesser than this cut-off criterion are not candidates for amplification device whereas those having an SNR loss above this criterion were presumed to be the candidates for amplification device.

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 loss. The ROC curve obtained for the measure SNR loss is represented in Figure 4.6.

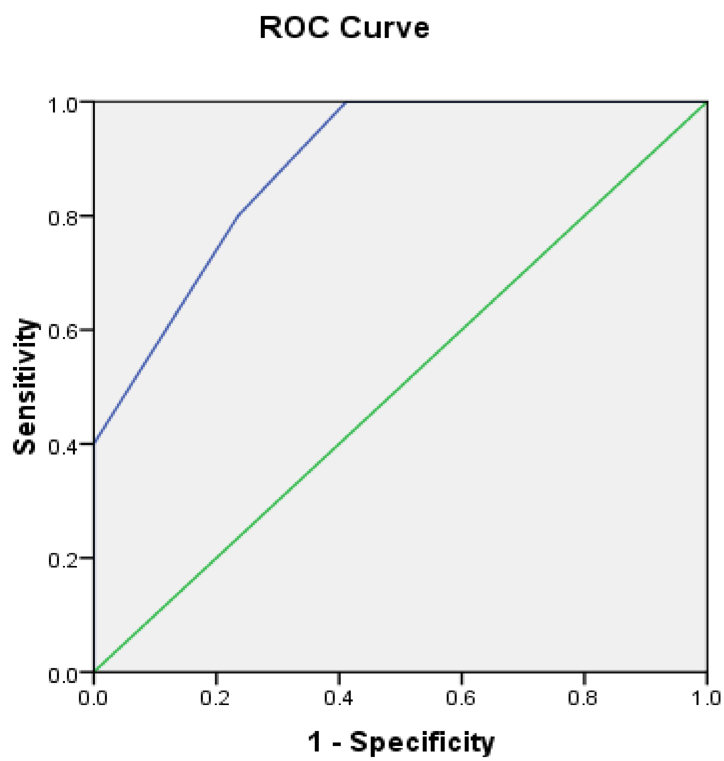

Figure 4.6: **ROC curve for the SNR loss as an approach for deciding hearing aid candidacy criterion.**

The area under the ROC curve was 0.88 (p value= 0.01) propounding that 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 each coordinate or point are mentioned in Table 4.8.

Table 4.8 Trade-off in sensitivity and specificity across all SNR loss coordinates

Positive if greater than or equal to	*Sensitivity*	*1-Specificity*
-1	1	1
1	1	0.8
2.50	1	0.706
3.50	1	0.471
4.50	1	0.412
5.50*	0.800	0.235
6.50	0.600	0.118
7.50	0.400	0.000
8.50	0.200	0.000
10	0.000	0.000

Note: *Cut-off value of SNR loss with maximum specificity and sensitivity

As depicted above in table the coordinate or point with SNR loss of 5.50 yields maximum sensitivity (80%) and specificity (76.5%). Thus, this value can be utilized as the cut-off value of first choice while using SNR loss measure for deciding hearing aid candidacy.

4.6. 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 loss obtained for two trial hearing aids were tabulated. In addition to this quality rating on five parameters viz. loudness, fullness, naturalness, clearness and overall impression were obtained for the two hearing aids and was also tabulated and subjected for statistical analysis. Shapiro-Wilk test was administered to test the normality of the data. The test was found to be non-significant ($p > 0.05$) for all the parameters. Hence, the presumption of normality was met for all the parameters. Following this, paired-sample t-test was administered to know which of the two approaches of hearing aid evaluations i.e., aided SIS in quiet (traditional approach) or aided SNR loss (alternate approach), differentiated the two trial hearing aids well. The results of the paired-sample t- test are shown in Table 4.9.

Table 4.9 Efficacy of both the approaches of hearing aid evaluations in differentiating the two trial hearing aids using paired-samples t-test

Hearing aid evaluation	t	df	p
Aided SIS in quiet (Traditional)	-2.12	9	0.054
Aided SNR loss (Alternate)	2.606	9	0.028*

Note: * - significant at $p < 0.05$

As shown in the Table 4.9, when using the aided SIS in quiet (traditional hearing aid trial), there was no significant difference in performance between the two hearing aids ($p > 0.05$). On the other hand, when the aided SNR loss (alternate approach) was considered, there was a significant difference seen across two tested hearing aids ($p < 0.05$). Hence, the alternate approach was more powerful in differentiating the two trial hearing aids than the traditional approach.

Further, Pearson's correlation coefficient (r) was estimated to check for any relationship between aided SIS and aided SNR-loss obtained in traditional and alternate hearing aid evaluations. The results of the Pearson product moment correlation in terms of correlation coefficient and significance value are reported in Table 4.10.

Table 4.10 Relationship between aided SIS and aided SNR loss for both the trial hearing aids using Pearson's product moment correlation

Correlation between	*Correlation coefficient (r)*	*Significance Value (p)*
Aided SIS and SNR loss for 1st hearing aid	-0.36	0.30
Aided SIS and SNR loss for 2nd hearing aid	-0.18	0.61

As shown in the Table 4.10 there was a negative relationship between aided SIS and aided SNR loss measure. Such that for both trial hearing aids, with increase in SIS there was reduction in SNR loss but this was not statistically significant ($p > 0.05$).

4.7. Relationship between aided quality ratings and aided SIS, aided SNR loss measures

Spearman's rank correlation coefficient was used to study the relationship between aided overall impression on quality ratings with the aided SNR loss and aided SIS. The correlation coefficients along with significance level across all the conditions are mentioned in Table 4.11.

Table 4.11 Relationship between aided overall impression ratings and aided SNR loss, SIS using Spearman's rho correlation

Parameters	Correlation coefficient (r)	Significance Level (p)
Overall impression and aided SNR loss with Hearing aid 1	0.39	0.27
Overall impression and aided SNR loss with Hearing aid 2	0.37	0.29
Overall impression and aided SIS with Hearing aid 1	-0.44	0.20
Overall impression and aided SIS with Hearing aid 2	-0.37	0.30

There was no statistically significant correlation between the overall impression on quality ratings for hearing aids and the measures of aided SNR loss and aided SIS. Similarly, each parameter of quality rating (loudness, naturalness, fullness and clearness) independently had no significant correlation with aided SIS and aided SNR loss for both the trial hearing aids. Additionally, there was a difference in the direction of correlation than the expected for quality measures and aided SIS, aided SNR loss.

Chapter 5

Discussion

The aim of the present study was to assess efficacy of SNR loss measure as a clinical tool for hearing aid evaluation. In order to achieve this aim six objectives were framed. The objectives of the study were attained by collecting the data in two phases of research**.** The results of the present study are discussed in depth 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 across ears with minimal and mild SNHL in terms of PTA, SIS, SNR-50, SNR loss and questionnaire rating for noise, quiet and total.

5.3. Relationship between SNR loss, SIS and questionnaire rating for speech comprehension in quiet and noise

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

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

5.6. Relationship between subjective quality ratings with aided SIS and aided SNR loss, in traditional and alternate method 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 -2 dB to +2 dB with the mean SNR-50 and SNR loss of $0.1 \approx 0$

dB (Table 4.1). 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. The use of four-speaker multi-talker babble in the present study is presumed to have led to a more complex task.

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. Subtracting the number of correct repeated key words from the reference 25.5 yielded the SNR loss. Though, there was a difference in method employed for computation of SNR-50 in the present study, the results remained comparable.

The SNR-50 and SNR loss for the individuals with minimal SNHL varied from 0 dB to 8 dB; with a mean SNR-50 and SNR loss being 3.36 dB (Table 4.1). 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 has exclusively analyzed SNR-50 or SNR loss for participants having minimal or slight SNHL. Likewise, 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 5.36 dB and 5 dB respectively (Table 4.1). These results are in harmony with the smoothed averaged data provided by Killion (1997) who reported that those participants having mild-moderate SNHL required 4 to 6 dB SNR greater 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 for 50% correct scores.

There were three participants with mild SNHL who were outliers with extreme values of SNR-50 and SNR loss (Figure 4:1). Those three participants had 2 dB, 3 dB and 9 dB as their SNR-50 or SNR loss. This could be attributed to existing individual variability in speech recognition in noise performance even within same degree of hearing loss. The reason for this variability in performance in noise could be attributed to factors including audibility, distortion, and difference in frequency selectivity. The inter-subject variability for SNR-50 or SNR loss was also studied by Wilson et al. (2003) by using 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 of them having same extent of hearing problem. Killion (1997) also outlined this individual variability in his data wherein, individuals with pure tone hearing loss of 40-50 dB HL had greater SNR loss than a few individuals with pure tone hearing loss of 50-60 dB HL. For which, he suggested presence of more inner hair cells loss in former case attributing to the greater SNR loss. The presence of individual variability in SNR loss for individuals with same degree of hearing loss was also witnessed in data by Bentler (2012).

The findings of the inferential statistics revealed that individuals with normal hearing had SNR-50 and SNR loss that was significantly better than the individuals with minimal and mild loss SNHL. Also with increase in degree of hearing loss from minimal to mild SNHL, the mean SNR-50 or SNR loss became poorer (Table 4.1). However, this difference was not statistically significant. Regardless of a statistically significant difference seen in speech identification scores (SIS) across minimal and mild SNHL over non-parametric Mann-Whitney U test, such an effect was not seen for SNR-50 or SNR loss. Lack of such significant difference could be attributed to variability seen for SNR-50 or SNR loss within the same degree of hearing loss. These findings are in agreement with Wilson et al. (2003) study, in which participants having mild to moderate SNHL were subjected to Northwestern University Auditory Test No. 6 (NU 6) monosyllabic test in quiet as well as in noise. Their performance was greater than 90% for quiet condition whereas, SNR-50 points were widely spread suggesting of greater inter-subject variability. The obtained result is also supported by Crandell (1991) who reported that individuals even with the same degree and configuration of hearing loss have varying abilities to perform in the presence of noise**.** By drawing inference from findings of Crandell (1987), the speech recognition in noise ability is highly correlated with frequency selectivity. Therefore, listeners having a similar configuration and degree of hearing loss but performing differently in presence of noise might have varied frequency selectivity. Hence in the present study, variability in SNR-50 or SNR loss across the same degree of hearing loss is suggested to be due to inter-subject differences in frequency selectivity. Killion (1997) also opined that as the degrees of hearing losses becomes greater, greater is the SNR that is required on an average; though large individual variability exists.

5.2. Comparison across ears with minimal and mild SNHL for PTA, SIS, SNR-50, SNR loss and questionnaire rating for noise, quiet and total.

With increase in degree of loss from minimal to mild SNHL, there was a significant increase in PTA as expected and significantly poorer speech identification scores. Ratings over hearing handicap questionnaire were significantly more severe for mild SNHL group than the minimal SNHL group. This was applicable for ratings over speech comprehension in quiet, noise and also for overall rating. These high scores obtained over questionnaire rating reflect the perceptual increase in sensitivity loss due to lack of audibility as well as clarity loss due to SNR loss being increasing with the degree of loss. But there have been discrepancy between the obtained results for the measure and subjective attitude of the client towards it.

In the present study, with increase in degree of loss from minimal to mild SNHL, there was a significant reduction in SIS as well as significantly poorer rating for questions assessing speech comprehension in quiet. Hence, the results of the SIS measure reflected well in the subjective perception for speech comprehension in quiet. Whereas, though the subjective perception of handicap for speech comprehension in noise significantly increased with degree of loss, it was not well reflected in results of SNR-50 or SNR loss. This finding suggests that even a non-significant reduction in SNR 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 of 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, Killion (1997), Plomp (1978), Smoorenburg (1999), Killion and Niquette (2003), Fabry (2005) recommended directional microphones, array microphones and companion or wireless microphones to solve the problem of hearing in noise across mild to profound hearing loss. These technological modifications when implicated in hearing aids help in reducing the SNR loss.

5.3 Relationship between SNR loss, SIS and questionnaire rating for speech comprehension in quiet and noise

The results of the Spearman's rank correlation revealed a significant moderate to strong positive correlation between SNR loss and ratings for speech comprehension in noise. It was noted that as SNR loss increased, the participants rated their speech comprehension abilities in noisy situations to be much poorer (i.e., higher total scores) than those with lesser SNR loss. Similar findings were reported by Walden and Walden (2004) where the distortion measures Unaided-QSIN and Aided-QSIN significantly correlated (weak to moderate) with ratings on International Outcome Inventory for Hearing Aids (IOI-HA) and Hearing Aid Usefulness Scale (HAUS). The direction of correlation in their study was negative as the lesser the SNR loss an individual had, the higher the rating on the outcome measures was obtained. It may be noted here that higher rating on both IOI-HA and HAUS outcome measures referred to better outcomes. On the other hand, in the present study positive correlation was seen since, the questionnaire rating of higher number referred to greater problems.

In the present study, the SNR loss scores correlated with the questionnaire ratings for speech comprehension both in quiet as well as in noise. There was a slightly higher correlation of SNR loss with ratings for speech comprehension in noise than quiet. This is an expected finding since SNR loss reflects the speech performance in noisy listening condition than the quiet. Similar findings have been reported by several authors (Tyler & Smith, 1983; Smits, Kramer, & Houtgast, 2006). It is expected to have substantially greater correlation of SNR loss with questionnaire ratings over speech comprehension in noise than that in quiet. Lack of such pattern was also noticed in present study as the SNR loss correlation was almost same for questionnaire ratings for speech comprehension in noise as well as quiet. Rowland et al. (1985) also reported lack of systematic pattern of correlation across speech recognition in noise performance and ratings over 'quiet' and 'noise' sub-sections of Hearing Performance Inventory (HPI). They proposed that poor predictability of 'quiet' and 'noise' sections in HPI could be a possible cause for this finding.

In the present study, the correlation between SIS and ratings on hearing handicap questionnaire for speech comprehension in quiet and noise were studied using Spearman's rank correlation. The results reported a moderate to strong negative significant correlation; i.e., as SIS increased, lesser ratings on hearing handicap questionnaire were obtained for difficulties in speech comprehension in noise and quiet. Correlation was slightly more for ratings of difficulties in speech comprehension in quiet than that of noise as expected. In contrast Walden and Walden (2004) reported no significant correlation between speech identification scores in quiet obtained using NU-6 and two of the outcome measures IOI-HA and HAUS. The difference in the findings of the two studies could be attributed to the difference in the outcome measures used. IOI-HA and HAUS were used by Walden and Walden (2004) whereas, self assessment of hearing handicap (SAHH) questionnaire utilized in the present study. The IOI-HA and HAUS are the hearing aid outcome measures whereas SAHH is a hearing handicap questionnaire. Additionally, the material utilized to obtain SIS might have also led to this difference in findings.

In the present study, the participants reported a few situations in which they faced difficulty in listening, as part of the answer for the open ended question asked at the end of questionnaire. They reported difficulty in comprehending speech while riding a bike, while talking over telephone in bus and in presence of wind noise. A few of the participants reported annoyance with tinnitus. The difficulty in these situations was not assessed in the SAHH questionnaire used in the present study. This finding warrants inclusion of such situations into the questionnaire and to incorporate appropriate strategies while fitting amplification device.

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

The two groups of test ears with minimal and mild SNHL divided based on the total score of hearing handicap questionnaire rating were compared on SNR loss. The test ears presumed to require an amplification device had significantly higher SNR loss than the ears not considered eligible for 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 5.419 dB. This was obtained by subtracting SD from mean SNR loss of candidates considered eligible for amplification device (i.e., 7–1.581 dB). 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 a rightful candidate for amplification device. Whereas, if the SNR loss for a test ear is lesser than the cut-off criterion then the individual can be discarded from the hearing aid candidacy. Hence, based on this finding SNR loss can be utilized as an useful clinical tool to decide about the candidacy for amplification device. The present study is a preliminary study to reveal the utility of SNR loss in deciding hearing aid candidacy.

Further, the accuracy of the obtained cut-off criterion for SNR loss was evaluated using Receiver Operating Characteristic (ROC) curve in SPSS. The area under the ROC curve measures the discriminatory power of the concerned measure, 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 0.90-1; good if it is 0.80-0.90 , fair if it is 0.70- 0.80 , poor if it is 0.60-0.70; and failure if it is 0.50- 0.60. The AUC being 0.88 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 point of 5.50 dB that yielded maximum sensitivity (0.80) and minimum 1- specificity (0.23) thereby, was set as the cut-off criterion. Both sensitivity as well as specificity being greater than 75%, it paves the way for SNR loss measure to be used as a clinical use.

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 5.5 dB, then he/she is an eligible candidate for amplification device; whereas, if SNR loss lesser is than this, then a hearing aid is not warranted.

More research is needed in this area over larger population to develop normative for individual clinical set-up and specific to the material and procedure being utilized. Test-retest reliability should also be studied for the measure SNR loss for its easy and reliable use in clinical practice. Wilson, Abrams, and Pillion (2003) conducted an experiment to study test-retest reliability for 50% correct points obtained on speech recognition in babble task across two trials. They employed fixed SNR method to estimate the 50% correct point using seven signal-to-babble ratios. There was no significant difference found across two test trials. Hence, they reported excellent test-retest reliability of the measure. However, until now there is no literature reporting test-retest reliability of measure SNR loss using adaptive procedure.

5.5 Comparison across traditional and alternate procedures of hearing aid evaluation

The efficiency of the two kinds of hearing aid evaluations (traditional and alternate) in differentiating two trial hearing aids was studied using paired-sample t-test.

The results revealed that the aided SIS measure i.e., traditional hearing aid evaluation procedure failed at differentiating the two tested hearing aids. Whereas, the alternate method of hearing aid evaluation i.e., measuring aided SNR loss was an efficient tool in differentiating the two trial hearing aids significantly. Therefore, this finding indicates that though same performance in quiet was achieved with both the trial hearing aids, there was a significant performance difference in simulated noise condition. When prescribing hearing aid based on traditional method an audiologist may end up prescribing any of the two hearing aids since 40% of the participants performed similarly with the two trial hearing aids making the decision difficult.

Duquesnoy (1982) opined that an increase of even 1dB in signal-to-noise ratio will enhance the speech intelligibility by 15-20%. Therefore, when clinically prescribing hearing aid based on an alternate method (aided SNR loss), an audiologist will prescribe the hearing aid yielding minimum SNR loss. Incorporating this finding in hearing aid prescription it can be suggested that hearing aid prescribed by traditional method may not necessarily be same as the hearing aid prescribed by alternate method. Accordingly, it is expected that the hearing aid prescribed using alternate method will provide greater satisfaction to the client. When considering that the prescribed hearing aid yields lesser SNR loss, the listening will be more beneficial in multiple environments.

In the present study for 40% of the participants when the aided SIS failed in differentiating the two trial hearing aids, aided SNR loss outperformed in deciding the better of the two hearing aid. These findings support that reported by Dubno, Dirks, and Morgan (1984) who stated that the SNR loss helps in identifying subtle communication difficulties which otherwise goes undetected during routine evaluation. As per data of Lauren (2009), the aided SNR-50 can either become poorer or better than the unaided SNR-50 and varies from individual to individual. This suggests that amplification device though addresses the audibility issue, fails in eliminating the SNR loss. Further, Miller (2003) discussed about the deterioration in signal caused by the amplification device. Alteration of signal caused by the hearing aid is small (-0.25 dB SNR) but significant as suggested by Miller (2003). Impact of this deterioration in subjective perception judgment is still not known. Hence, it is valuable to decide the hearing aid based on findings of SNR loss measure and to prescribe the one which yields minimum SNR loss.

Further, the correlation between the aided SIS and aided SNR loss measure was studied using Pearson's product moment correlation. It was observed that the two procedures had a weak negative correlation. An increase in aided SIS was associated with a reduction in aided SNR loss but it was non-significant. This suggests that both aided SIS and aided SNR loss measures are not related. The aided SNR loss provides additional information than the aided SIS. Knowledge of SNR loss helps in realistic counseling regarding the amplification device as reported by Killion and Niquette (2000). Better acceptance of amplification device therefore is expected when the client is aware of benefit with device in natural situation. Hence, in essence based on the findings of the study the SNR loss overpowers the SIS in clinical hearing aid evaluation.

5.6 Relationship between subjective quality ratings with aided SIS and aided SNR loss, in traditional and alternate method of hearing aid evaluation.

The results from Spearman's rho correlation coefficient indicated that there was no correlation between aided quality rating for overall impression parameter and aided SIS or aided SNR loss. Moreover, the direction of relation was also reverse of the expected one. Such that, better quality ratings were obtained as SNR loss became more and as SIS became poorer. This unexpected finding might have resulted due to individual variability in expectation with hearing aid. The individuals with greater SIS and lesser SNR loss might have greater expectation in terms of improvement. This might have been the reason to assign lesser rating on quality for the trial hearing aids. Apart from this there could have been different yardstick set by each individual for rating the performance in aided condition. Similar trend of correlation was observed for individual quality parameter (i.e., loudness, fullness, naturalness and clearness). The absence of correlation and change in expected direction of correlation can be also be accounted by lack of acclimatization with hearing aid by naïve hearing aid users taken as participants. Experience with the hearing aid of only a short duration of ten minutes might have resulted variability in the quality rating.

Hence, to summarize the findings of the present study, the SNR loss has a substantial clinical implication. It is effective to decide the need for a hearing aid as it reflects the actual problems faced by the individual in natural situation. While managing the individuals with hearing impairment using amplification device, knowledge of SNR loss by all trial hearing aids is of central importance. Since, the hearing aid itself alters the signal-to-noise ratio of the input signal while processing, the one yielding minimum SNR loss will be more beneficial. Further, several technological modifications can be introduced in hearing aids to solve the problem of SNR loss such as use of directional microphones, array microphones and FM system to reduce the SNR loss. The understanding of the SNR loss also helps in giving a realistic expectation about the hearing aid during counseling.

Chapter 6

Summary and Conclusion

The present study aimed at evaluating the efficacy of SNR loss as a clinical tool for hearing aid evaluation. In order to achieve this aim the following objectives were formulated:

1. To compare the SNR-50 and SNR loss across participants with normal hearing, minimal SNHL and mild SNHL.
2. To compare the rating score on hearing handicap questionnaire across minimal and mild degrees of hearing loss.
3. To check the relationship between SNR loss, SIS and questionnaire rating scores for speech comprehension in quiet and noise.
4. To establish a cut-off criterion of SNR loss to decide the need for amplification device.
5. To compare the traditional hearing aid evaluation approach based on testing speech in quiet and the alternate approach of hearing aid evaluation based on SNR loss.
6. To check the relationship between subjective quality ratings obtained after traditional and alternate approaches of hearing aid evaluation with aided SIS and aided SNR loss.

The procedure incorporated two phases. The Phase I was carried out to achieve first four objectives of the study. Under this phase, data from ears of participants with normal hearing, minimal SNHL and mild SNHL were collected. The data comprising of

PTA, SIS, SNR-50, SNR loss and SAHH questionnaire rating for speech comprehension in quiet, noise and total scores were tabulated. Statistical analysis was done to check for significant difference in these parameters across group of test ears with normal hearing, minimal SNHL and mild SNHL. Based on the questionnaire rating scores, the participants with minimal and mild SNHL were divided into two groups to know whether they require hearing aid or not. The cut-off criterion for SNR loss to demarcate the need for amplification device was derived statistically.

The Phase II was carried out to accomplish the last two goals of the study. Under Phase II, test ears of participants with moderate flat SNHL were subjected to two kinds of hearing aid evaluation. One of it being traditional technique of testing aided speech in quiet and an alternate method of estimating aided SNR loss. Under each kind of hearing evaluation, performance was checked using two trial digital BTE hearing aids. The data in this phase comprising of aided SIS and aided SNR loss obtained with two trial hearing aids was tabulated. Apart from this, subjective quality ratings obtained across five parameters (loudness, fullness, clearness, naturalness and overall impression) for the two trial hearing aids were also compiled and tabulated. A comparison was made across efficacy of the two techniques in hearing aid evaluation. The trial hearing aid yielding better performance in each of the hearing aid evaluations (traditional and alternate) was noted.

The following were the findings of the present study:

1. The SNR-50 and SNR loss for ears with minimal SNHL and mild SNHL was significantly higher (poorer) than for the ears with normal hearing. There was no

statistically significant difference in SNR-50 and SNR loss of individuals with minimal SNHL and mild SNHL.

2. The hearing handicap questionnaire ratings were significantly higher (poorer) for individuals with mild SNHL than those for individuals with minimal SNHL. Similar findings were obtained when only certain set of questions of the handicap questionnaire were considered. Higher ratings for mild SNHL than the minimal SNHL were obtained for questions related speech comprehension in noise as well as in quiet.
3. The SNR loss and SIS measures had moderate to strong correlation with handicap questionnaire ratings for speech comprehension in quiet and noise. There was not much difference in correlation of SNR loss with questionnaire rating for speech comprehension in noise and in quiet.
4. There was a significant difference in SNR loss across the two groups of participants 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 significantly higher SNR loss than those who were not considered as candidates. The cut-off criterion established using this data was 5.419 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 5.5 dB in the ROC curve for SNR loss yielded maximum sensitivity and specificity. The obtained point on ROC curve for SNR loss was synchronous with the cut-off

criterion calculated previously. Hence, a cut-off criterion of 5.5 dB is a reliable cut-off point to demarcate the need for amplification device in a clinical set-up.

5. The aided SIS measure failed in differentiating the two trial hearing aids whereas the measure aided SNR loss statistically differentiated the two trial hearing aids. This finding proposes that the two trial hearing aids employed in the study imparted similar benefit in quiet situation but had statistically significant performance in noise.
6. There was no statistically significant correlation seen in obtained quality ratings across five parameters (loudness, fullness, naturalness, clearness and overall impression) with the measures of aided SIS, aided SNR loss for both 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.

6.1 Clinical Implications

1. Introducing SNR loss measure into routine clinical evaluation to draw inference about actual difficulty faced by individual with hearing impairment in natural situations.
2. Categorizing the degree of impairment based on degree of SNR loss rather than degree of pure tone hearing loss to make the diagnostic procedure more realistic.
3. To decide candidacy for hearing aid based on the cut-off criterion of SNR loss.

4. To manage the loss in clarity by incorporating various technological modifications (directional microphone, remote microphone, array microphone and FM system) in hearing aids depending on the extent of SNR loss.
5. In clinical hearing aid evaluation in prescribing the hearing aid which provides minimal SNR loss. The hearing aid prescribed in this way is expected to yield greater satisfaction by hearing aid users.
6. To give a realistic expectation to the individual with hearing impairment regarding the benefit with amplification device. This in turn will reduce the frequency of hearing aid rejection.
7. The present study utilized rating scales as a fruitful outcome measure which gives a clear picture of performance in real situation. Combining signal enhancement techniques like directional microphones, noise reduction strategies and SNR loss measure assessment along with rating scale in future may assist in more appropriate hearing aid device prescription.

6.2 Future directions for research

1. This study is a preliminary study done to assess the efficacy of measure SNR loss in clinical hearing aid evaluation. More intensive research is needed to establish a clinic specific normative value for SNR loss.
2. In the present study results of obtained quality ratings were studied after hearing aid evaluation and not after hearing aid prescription. Further research is required to assess the difference in quality of perception by hearing aids prescribed by the two methods separately. The difference in quality ratings needs to be assessed

after a period of acclimatization with hearing aids prescribed by both methods of hearing aid evaluation.

3. Further research should be carried out to assess any difference in performance with and without the technological modifications provided in hearing aid based on SNR loss.
4. Future research is needed to design the protocol for SNR loss testing in clinical audiological evaluation.
5. Involving more number of participants to study the trend between extent of SNR loss and questionnaire rating for speech comprehension in noise.

References

Alcantara, J. I., Moore, B. C. J., Kuhnel, V., & Launer, S. (2003). Evaluation of the noise reduction system in a commercial digital hearing aid. *International Journal of Audiology, 42,* 34-42.

Beattie, R., Barr, T., & Roup, C. (1997). Normal and hearing-impaired word recognition scores for monosyllabic words in quiet and noise. *British Journal of Audiology, 31*, 153–164.

Bench, J., Kowal, A., & Bamford, J. (1979). The BKB (Bamford-Kowal-Bench) sentence lists for partially hearing children. *British Journal of Audiology, 13*, 108-112.

Bentler, R. A. (2012). [Personal Communication]. Unpublished raw data.

Bilger, R. C., Nuerzel, J. M, Rabinowicz, W. M., & Rzeczkowski, C. (1984). Standardization of a test of speech perception in noise. *Journal of Speech and Hearing Research, 24*, 32- 48.

Carhart, R.,& Jerger, J. (1959). Preferred method for clinical deterrmination 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.

Cox, R., Alexander, G., & Gilmore, G. (1987). Development of the Connected Speech Test (CST). *Ear and Hearing, 8,* 119S-126S.

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

Crandell, C. C., & Smaldino, J. J. (2000). Classroom Acoustics for Children with Normal Hearing and With Hearing Impairment. *Language, Speech, and Hearing Services in Schools, 31,* 362–371.

De Vries, R., & de Vries, B. (2002). Towards SNR-loss restoration in digital hearing aids. GN Resound- Beltone. Unpublished data. 2-5.

Dirks, D., Morgan, D., & Dubno, J. (1982). A Procedure for Quantifying the Effects of Noise on Speech Recognition. *Journal of Speech and 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.

Duquesnoy, A. J. (1982). Speech intelligibility of the hearing impaired. Doctoral Dissertation, Free University, Amsterdam.

Eisenberg, L. S., Dirks, D. D, & Bell, T. S. (1995). Speech recognition in amplitude-modulated noise of listeners with impaired hearing. *Journal of speech, language, and hearing research, 38* (1), 222-233.

Ethical Guidelines for Bio-Behavioural Research Involving Human Subjects, Publication from All India Institute of Speech and Hearing, Mysore, 2003.

Etymotic Research (2001). Quick SIN: Elk Grove Village, IL: 2001.

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

Ewertsen, H.W., & Nielsen, B. H. (1973). Social hearing handicap index, *Audiology, 12,* 180-187.

Fabry, D. A. (2005). Adaptive directional micrphone 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.

Hall, J.W., Buss, E., & Grose, J. H. (2008). The effect of hearing impairment on the identification of speech that is modulated synchronously or asynchronously, across frequency. *Journal of the Acoustical Society of America, 123* (2), 955-962.

High, W. S., Fairbank, S. G., & Glorig, A. (1964). Scale for self assessment of hearing handicap. *Journal of Speech and Hearing Disorders, 29* (3), 215- 230.

Hsieh, D. L., Lin, K. N., Ho, J.H., & Liu, T.C. (2009). Hearing in noise test in subjects with conductive hearing loss. *Journal of the Formosan Medical Association, 108* (12), 937-942.

Killion, M. C. (1997a). Hearing Aids: Past, present, future: Moving toward normal conversations in noise. *British Journal of Audiology, 31*, 141–148.

Killion, M. C. (1997b). SNR Loss: "I Can Hear What People Say but I Can’t Understand Them. *The Hearing Review, 4*(12), 8–14.

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.

Killion, M. C., Niquette, P. A., Gudmundsen, G. I., Revit, L. J., & Banerjee, S. (2004). Development of a Quick Speech in Noise test for measuring signal-to-noise ratio loss in normal- hearing and hearing-impaired listeners. *Journal of the Acoustical Society of America, 116* (4) , 2395- 2405.

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.

Kuk, F., Peeters, H., Lau, C., & Korhonen, P. (2011). Effect of maximum power output and noise reduction on speech recognition in noise. *Journal of American Academy of Audiology, 22* (5), 265-273.

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.

Lauren, B. S. (2009). Outcome assessment of audient foundation hearing aids at the James Madison University clinic. Dissertation Abstracts International: Section B: The Sciences and Engineering, 2009, 70/4-B (2163), 4190-4217.

Lavie, L., Banai, K., Attias, J., & Karni, A. (2014). How difficult is difficult? Speech perception in noise in the elderly hearing impaired. *Journal of Basic Clinical Physiology and Pharmocology, 25*(3), 313-316.

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

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

Manjula, P., Geetha, C., Kumar, S., & Antony, J. (2014). *Phonemically balanced (PB) Test Material in Kannada for Adults*. Unpublished ARF Project.

Miller, C.W. (2013). *The role of aided signal-to-noise ratio in aided speech perception in noise*. Unpublished doctoral thesis, University of Washington.

Moore, B. C. J. (2003). Coding of sounds in the auditory system and its relevance to signal processing and coding in cochlear implants. *Otology and Neurotology, 24*, 243-254.

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.

Neuman, A. C., Wroblewski, M., Hajicek, J., & Rubinstein, A. (2010). Combined effects of noise and reverberation on speech recognition performance of normal-hearing children and adults. *Ear and Hearing, 31*(3), 336–344. http://doi.org/10.1097/AUD.0b013e3181d3d514

Nilsson, M., & Sullivan, J. (1994). Development of the Hearing in Noise Test for the measurement of speech reception threshold in quiet and noise. *Journal of Acoustical Society of America, 95*, 1085-1099.

Noble, W. G., & Atherly, G. R. (1970). The hearing measurement scale: A questionnaire for the assessment of auditory disability. *Journal of Audiology Research, 10* (3), 229-250.

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. http://doi.org/10.3766/jaaa.20.6.2

Patterson, R., & Moore. B. (1986). Auditory filters and excitation patterns as representations of frequency resolution. In Moore B, Ed. Frequency Selectivity in Hearing. London: Academic Press, 1986:123-178.

Peeters, H., Kuk, F., Lau, C., & Keenan, D. (2009). Subjective and objective evaluation of noise management algorithms. *Journal of American Academy of Audiology, 20*, 89-98.

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

Pittman, A. L., & Stelmachowicz, P. G. (2003). Hearing Loss in Children and Adults: Audiometric Configuration, Asymmetry, and Progression. *Ear and Hearing, 24* , 198-205.

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 Reserach, 29*, 146–154.

Plomp, R., & Duquesnoy, A. J. (1982). A model for the speech- reception threshold in noise without and with a hearing aid . *Scandinavian Audiology. Supplementum, 15* , 95- 111.

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.

Rowland, J. P., Dirks, D. D., Dubno, J. R., & Bell, T. S. (1985). Comparison of speech recognition-in-noise and subjective communication assessment. *Ear and Hearing, 6*(6), 291–296. http://doi.org/10.1097/00003446-198511000-00003

Sairam, V.V.S. (2002). *Long term average speech spectrum in Kannada.* Unpublished Dissertation, Department of Audiology, AIISH, Mysore.

Schow, R., & Tannahill, C. (1977). Hearing Handicap Scores and categories for subjects with normal and impaired hearing sensitivity. *Journal of the American Auditory Society, 3,* 134-139.

Smits, C., Kramer, S. E., & Houtgast, T. (2006). Speech reception thresholds in noise and self-reported hearing disability in a general adult population. *Ear and Hearing, 27*(5), 538–549. http://doi.org/10.1097/01.aud.0000233917.72551.cf

Smoorenburg, G. (1999). Psychoacoustics of hearing loss. EHIMA. http://www.medical.hear-it.org/multimedia/smoorenburg.pdf

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.

Smoorenburg, G. F., de Laat, J. A. P. M., & Plomp, R. (1982). The effect of noise-induced hearing loss on the intelligibility of speech in noise. *Scandinavian Audiology. Supplement.16* , 123-133.

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.

Tillman, T. W., & Olsen, W. O. (1973). Speech Audiometry. In J. Jerger, Modern developments in audiology (pp. 37- 74). New York: Academic Press.

Tyler, R. S., & Smith, P. A. (1983). Sentence Identification in Noise and Hearing-Handicap Questionnaires. *Scandinavian Audiology, 12*, 285–292.

Tyler, R. S., and Summerfield, Q. (1980). Psychoacoustical and phonetic measures of temporal processing in normal and hearing-impaired listeners, in Psychophysical, Physiological, and Behavioural Studies in Hearing, edited by G. van den Brink and F. A. Bilsen, Delft U.P., Delft

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 multitalker 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. http://doi.org/10.1682/JRRD.2003.07.0321

Yathiraj, A., & Vijayalakshmi, C. S. (2005). *Phonemically Balanced word list in Kannada*. Developed in the department of Audiology, AIISH, Mysore.

Zwicker, E., & Schorn, K. (1982). Temporal resolution in hard of hearing patients. *Audiology, 21*, 474-482.

Appendix A: Self assessment of Hearing Handicap

Vanaja (2000)

(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 members 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 a 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 3 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 (e.g.- 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 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 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 situation you have difficulty in hearing (please specify)

Appendix B: Kannada translated version of Self Assessment of Hearing Handicap

(Please Note: Only Questions from 1-7 & 22 were utilized in the present study)

	ಕೆಲವು ಸಂದರ್ಭಗಳು
1.	ಈ ಕೆಳಗೆ ಕೇಳಿರುವ ಸಂದರ್ಭಗಳಲ್ಲಿ ಮಾತನ್ನು ಅರ್ಥಮಾಡಿಕೊಳ್ಳಲು ನಿಮಗೆ ಎಷ್ಟು ಕಷ್ಟವಾಗುತ್ತದೆ?
a.	ನಿಮ್ಮ ಪಕ್ಕದಲ್ಲಿಯೆ ಕುಳಿತಿರುವ ನಿಮ್ಮ ಮನೆಯ ಸದಸ್ಯರ ಜೊತೆ ಮುಖ ನೋಡಿಕೊಂಡು ಮಾತನಾಡುವಾಗ
b.	6 ರಿಂದ 8 ಅಡಿ ದೂರದಿಂದ ನಿಮಗೆ ಪರಿಚಯವಿರುವ ವ್ಯಕ್ತಿಯ (ಪುರುಷ/ಗಂಡಸು) ಜೊತೆ ಮಾತನಾಡುವಾಗ
c.	6 ರಿಂದ 8 ಅಡಿ ದೂರದಿಂದ ನಿಮಗೆ ಪರಿಚಯವಿರುವ ವ್ಯಕ್ತಿಯ (ಮಹಿಳೆ/ಹೆಂಗಸು) ಜೊತೆ ಮಾತನಾಡುವಾಗ
d.	10 ರಿಂದ 12 ಅಡಿ ದೂರದಿಂದ ಯಾರಾದರು ಒಬ್ಬರು ಮನೆಯ ಸದಸ್ಯರೊಂದಿಗೆ ಮಾತನಾಡುವಾಗ
e.	ನಿಮಗೆ ಪರಿಚಯವಿರುವ ವ್ಯಕ್ತಿಯೊಂದಿಗೆ ಫೋನಿನಲ್ಲಿ ಮಾತನಾಡುವಾಗ
f.	ನಿಶ್ಯಬ್ಧವಾದ ಕೋಣೆ/ರೂಮಿನಲ್ಲಿ ಸುಮಾರು 6 ರಿಂದ 8 ಅಡಿ ದೂರದಿಂದ ಟೀವಿ ನೋಡುವಾಗ (ಚೆನ್ನಾಗಿ ಕೇಳಿಸಿಕೊಳ್ಳುವವರು ಇಟ್ಟಂಥಹ ವಾಲ್ಯೂಂನಲ್ಲಿ)
g.	ನಿಶ್ಯಬ್ಧವಾದ ಕೋಣೆ/ರೂಮಿನಲ್ಲಿ ಸುಮಾರು 6 ರಿಂದ 8 ಅಡಿ ದೂರದಿಂದ ಟೀವಿಯಲ್ಲಿ ನ್ಯೂಸ್ ನೋಡುವಾಗ (ಚೆನ್ನಾಗಿ ಕೇಳಿಸಿಕೊಳ್ಳುವವರು ಇಟ್ಟಂಥಹ ವಾಲ್ಯೂಂನಲ್ಲಿ)
h.	ನಿಶ್ಯಬ್ಧವಾದ ಕೋಣೆ/ರೂಮಿನಲ್ಲಿ ಸುಮಾರು 3 ಅಡಿ ದೂರದಿಂದ ರೇಡಿಯೋ ಕೇಳುತ್ತಿರುವಾಗ (ಚೆನ್ನಾಗಿ ಕೇಳಿಸಿಕೊಳ್ಳುವವರು ಇಟ್ಟಂಥಹ ವಾಲ್ಯೂಂನಲ್ಲಿ)
i.	6 ರಿಂದ 8 ಅಡಿ ದೂರದಿಂದ ಗದ್ದಲವಿರುವ ರೂಮಿನಲ್ಲಿ/ಕೋಣೆಯಲ್ಲಿ ಟೀವಿ ನೋಡುವಾಗ
j.	ಜನರಿಂದ ತುಂಬಿರುವ ಬಸ್ಸಿನಲ್ಲಿ ಕಂಡಕ್ಟರ್‌ನೊಂದಿಗೆ ಮಾತನಾಡುವಾಗ
k.	ತುಂಬಾ ಜನರಿರುವ ರೈಲ್ವೆ ಸ್ಟೇಷನ್ನಿನಲ್ಲಿ ನಿಮ್ಮ ಪಕ್ಕ ನಿಂತಿರುವವರ ಜೊತೆ ಮಾತನಾಡುವಾಗ
l.	ಬಿಡುವಿಲ್ಲದೆ/ತುಂಬಾ ಜನರಿರುವ ಅಂಗಡಿಯಲ್ಲಿ ಮಾಲೀಕನ ಜೊತೆ ಮಾತನಾಡುವಾಗ
m.	ಸಮಾರಂಭಗಳಲ್ಲಿ ಸುಮಾರು 6 ರಿಂದ 8 ಅಡಿ ದೂರದಲ್ಲಿರುವ ಸ್ಪೀಕರ್ ನಿಂದ ಬರುತ್ತಿರುವ ಶಬ್ದ ಕೇಳಿಸಿಕೊಳ್ಳುವಾಗ

n.	ಹೋಟೆಲಿನಲ್ಲಿ ಎದುರಿನಲ್ಲಿ ಕುಳಿತಿರುವ ಪರಿಚಯವಿರುವ ವ್ಯಕ್ತಿಯ ಜೊತೆ ಮಾತನಾಡುವಾಗ
o.	ಮದುವೆ ಮನೆಯಲ್ಲಿ ನಿಮ್ಮ ಪಕ್ಕದಲ್ಲಿ ಕುಳಿತಿರುವ ವ್ಯಕ್ತಿಯ ಜೊತೆ ಮುಖ ನೋಡದೆ ಮಾತನಾಡುವಾಗ
p.	ಗದ್ದಲವುಳ್ಳ ರಸ್ತೆಯಲ್ಲಿ ನಿಮಗೆ ಪರಿಚಯವಿರುವವರ ಜೊತೆ ಮಾತನಾಡಿಕೊಂಡು ಹೋಗುತ್ತಿರುವಾಗ
q.	ಟೀವಿ ಅಥವ ರೇಡಿಯೊ ಹಾಕಿರುವಾಗ ನಿಮ್ಮ ಪಕ್ಕದಲ್ಲಿರುವವರು ನಿಮ್ಮೊಂದಿಗೆ ಮಾತನಾಡಿದರೆ
r.	ಚಿತ್ರಮಂದಿರಲ್ಲಿ/ಥಿಯೇಟರ್‌ನಲ್ಲಿ ನಿಮ್ಮ ಪಕ್ಕ ಕುಳಿತಿರುವ ವ್ಯಕ್ತಿಯೊಂದಿಗೆ ಮುಖ ನೋಡದೆ ಮಾತನಾಡುವಾಗ
s.	ಸುಮಾರು 6 ಇಂಚು ದೂರದಿಂದ ಯಾರಾದರೂ ಪಿಸು ಮಾತಿನಲ್ಲಿ ನಿಮ್ಮೊಂದಿಗೆ ಮಾತನಾಡಿದರೆ
t.	ನಿಶಬ್ಧವಾದ ವಾತಾವರಣದಲ್ಲಿ ನಿಮ್ಮ ಪಕ್ಕದಲ್ಲಿರುವ ಅಪರಿಚಿತ ವ್ಯಕ್ತಿಯೊಂದಿಗೆ ಮಾತನಾಡುವಾಗ
u.	ಮನೆಯಲ್ಲಿ ಒಂದು ಸಣ್ಣ ಗುಂಪಿನಲ್ಲಿ ಮಾತನಾಡುವಾಗ
v.	ನಿಮ್ಮ ಮುಂದೆ 3 ಅಡಿ ದೂರದಲ್ಲಿ ಕುಳಿತಿರುವ ವ್ಯಕ್ತಿಯ ಜೊತೆ ಅವರ ಮುಖ ನೋಡಿಕೊಂಡು ಮಾತನಾಡುವಾಗ (ಕೋಣೆಯಲ್ಲಿ ಚೆನ್ನಾಗಿ ಬೆಳಕಿರುವಾಗ)
2.	ನೀವು ಮಾತನಾಡುವ ಮೊದಲು ಟೀವಿ ಅಥವ ರೇಡಿಯೊ ವಾಲ್ಯೂಮ್/ಶಬ್ದ ಕಡಿಮೆ ಮಾಡುತ್ತೀರ?
3.	ನಿಮ್ಮ ಸುತ್ತಾಮುತ್ತ ಇರುವ ಜನರು ಒಟ್ಟಿಗೆ ಮಾತನಾಡಿದರೆ ನಿಮಗೆ ಅರ್ಥಮಾಡಿಕೊಳ್ಳಲು ಕಷ್ಟವಾಗುತ್ತದೆಯೆ?
4.	ದೊಡ್ಡ ರೂಮಿನಲ್ಲಿ ಹೆಚ್ಚು ಜನರು ಮಾತನಾಡಿದಾಗ ಅರ್ಥಮಾಡಿಕೊಳ್ಳಲು ಕಷ್ಟವಾಗುತ್ತದೆಯೆ?
5.	ನಿಮ್ಮ ಜೊತೆ ನಿಧಾನವಾಗಿ ಮಾತನಾಡಿದಾಗ ಅರ್ಥ ಮಾಡಿಕೊಳ್ಳಲು ಸುಲಭವಾಗುತ್ತದೆಯೇ?
6.	ನಿಮ್ಮ ಜೊತೆ ಮಾತನಾಡುವವರನ್ನು ಪದೇ ಪದೇ ಹೇಳುವಂತೆ ಕೇಳುತ್ತೀರೆ?
7.	ನಿಮ್ಮ ಹಿಂದೆಯಿಂದ ಮಾತನಾಡುತ್ತಿರುವ ಪರಿಚಯವಿರುವ ವ್ಯಕ್ತಿಯ ಧ್ವನಿಯನ್ನು ಗುರುತಿಸಲು ಕಷ್ಟವಾಗುತ್ತದೆಯೆ?
8.	ನೀವು ರಸ್ತೆಯಲ್ಲಿ ಹೋಗುವಾಗ ವಾಹನದ ಹಾರ್ನ್ ಯಾವ ಕಡೆಯಿಂದ ಬರುತ್ತಿದೆಯೆಂದು ಗುರುತಿಸಬಲ್ಲಿರೆ?
9.	ಒಂದು ಗುಂಪಿನಲ್ಲಿ ಮಾತನಾಡುವಾಗ, ಯಾರು ಎಲ್ಲಿಂದ / ಯಾವ ಕಡೆಯಿಂದ ಮಾತನಾಡಿದರು ಎಂದು ತಿಳಿಯುತ್ತದೆಯೆ?
10.	ನಿಮಗೆ ಶ್ರವಣ ತೊಂದರೆ ಇರುವುದರಿಂದ, ಜನರ ಜೊತೆ ಮಾತನಾಡದೆ ದೂರ ಉಳಿಯುತ್ತೀರೆ?
11.	ನಿಮಗೆ ಶ್ರವಣ ತೊಂದರೆ ಇರುವುದರಿಂದ, ಹೊಸಬರ ಜೊತೆ ಮಾತನಾಡಲು ಹಿಂಜರಿಯುತ್ತೀರ?

12.	ನಿಮಗೆ ಶ್ರವಣ ತೊಂದರೆ ಇರುವುದರಿಂದ, ಗುಂಪಿನಲ್ಲಿ ಮಾತನಾಡುವಾಗ ಹೆಚ್ಚು ಭಾಗವಹಿಸುವುದಿಲ್ಲವೆ?
13.	ನಿಮಗೆ ಶ್ರವಣ ತೊಂದರೆ ಇರುವುದರಿಂದ, ನೀವು ಟೀವಿಯನ್ನು ಹೆಚ್ಚು ನೋಡುವುದಿಲ್ಲವೆ?
14.	ಬೇರೆಯವರು ಮಾತನಾಡುವುದು ಅರ್ಥವಾಗದೆ ಇದ್ದಾಗ ನಿರಾಶೆಗೊಳ್ಳುತ್ತೀರೆ?
15.	ನಿಮ್ಮ ಕುಟುಂಬ ಸದಸ್ಯರು ಹೇಳಿದ್ದು ನಿಮಗೆ ಅರ್ಥವಾಗದೆ ಇದ್ದಾಗ ಅವರಿಗೆ ಕಿರಿಕಿರಿಯಾಗುತ್ತದೆಯೆ?
16.	ನಿಮಗೆ ಶ್ರವಣ ತೊಂದರೆ ಇರುವುದರಿಂದ ಜನರು ನಿಮ್ಮೊಂದಿಗೆ ಹೆಚ್ಚು ಮಾತನಾಡುವುದಿಲ್ಲವೆ?
17.	ನೀವು ಜೋರಾಗಿ ಮಾತನಾಡುತ್ತೀರೆಂದು ನಿಮ್ಮ ಮನೆಯವರು ಕಿರಿಕಿರಿಗೊಳ್ಳುತ್ತಾರೆಯೆ?

18.	ನಿಶಬ್ಧವಾದ ಕೋಣೆಯಲ್ಲಿ ಸುಮಾರು 6 ರಿಂದ 8 ಅಡಿ ದೂರದಿಂದ ಈ ಕೆಳಗಿನ ಶಬ್ದಗಳನ್ನು ಕೇಳಿಸಿಕೊಳ್ಳಬಲ್ಲಿರೆ?
	1. ಫೋನ್ ರಿಂಗ್ ಆದ ಶಬ್ಧ
	2. ಬಾಗಿಲು ಬಡಿದ ಶಬ್ಧ
	3. ನಾಯಿ ಬೊಗಳುವ ಶಬ್ಧ
	4. ಕಾಲ್ನಡಿಗೆಯ ಶಬ್ಧ
	5. ನಲ್ಲಿಯಲ್ಲಿ ನೀರು ಬರುತ್ತಿರುವ ಶಬ್ಧ
	6. ಕುಕ್ಕರ್ ಕೂಗು/ಸೀಟಿ ಶಬ್ಧ
19.	ನಿಶಬ್ಧವಾದ ಕೋಣೆಯಲ್ಲಿ ಸುಮಾರು 18 ರಿಂದ 20 ಅಡಿ ದೂರದಿಂದ ಈ ಕೆಳಗಿನ ಶಬ್ದಗಳನ್ನು ಕೇಳಿಸಿಕೊಳ್ಳ ಬಲ್ಲಿರೆ?
	1. ಫೋನ್ ರಿಂಗ್ ಆದ ಶಬ್ಧ
	2. ಕುಕ್ಕರ್ ಕೂಗು/ಸೀಟಿ ಶಬ್ಧ
	3. ಬಸ್ ಹಾರ್ನ್
20.	ನಿಶಬ್ಧವಾದ ವಾತಾವರಣದಲ್ಲಿ ಸುಮಾರು 6 ರಿಂದ 8 ಅಡಿ ದೂರದಿಂದ ನಿಮ್ಮನ್ನು ಕರೆದರೆ ನಿಮಗೆ ಕೇಳಿಸುತ್ತದೆಯೆ?
21.	ನಿಶಬ್ಧವಾದ ವಾತಾವರಣದಲ್ಲಿ ಸುಮಾರು 18 ರಿಂದ 20 ಅಡಿ ದೂರದಿಂದ ನಿಮ್ಮನ್ನು ಕರೆದರೆ ನಿಮಗೆ ಕೇಳಿಸುತ್ತದೆಯೆ?
22.	ಟೀವಿಯನ್ನು ಸಾಧಾರಣ ವಾಲ್ಯೂಮ್‌ನಲ್ಲಿ ಹಾಕಿದ್ದಾಗ ಸುಮಾರು 6 ರಿಂದ 8 ಅಡಿ ದೂರದಿಂದ ನಿಮ್ಮನ್ನು ಕರೆದರೆ ನಿಮಗೆ ಕೇಳಿಸುತ್ತದೆಯೆ?

ನಿಮಗೆ ಬೇರೆ ಯಾವುದಾದರು ಸಂದರ್ಭಗಳಲ್ಲಿ ಕೇಳಿಸಿಕೊಳ್ಳಲು ಕಷ್ಟವಾಗುತ್ತದೆಯೆ? ವಿವರಿಸಿ.

ಧನ್ಯವಾದಗಳು

Appendix C: 7-point Rating scale

Participant Name:
Age/G:
Date:

Degree & Type of loss in Right:
Degree & Type of loss in left:

Q.NO	Always (99%) ಯಾವಾಗಲು	Almost Always (87%) ಬಹುತೇಕ ಯಾವಾಗಲು	Generally (75%) ಸಾಮಾನ್ಯ ವಾಗಿ	Half the time (50%) ಅರ್ಧದಷ್ಟು	Occasionally (25%) ಕೆಲವೊಮ್ಮೆ	Seldom (12%) ಅಪರೂಪ ವಾಗಿ	Never (1%) ಯಾವ ಸಂದರ್ಭದಲ್ಲು ಇಲ್ಲ.
1.							
a)							
b)							
c)							
d)							
e)							
f)							
g)							
h)							
i)							
j)							
k)							
l)							
m)							
n)							

Q.NO	**Always (99%)** ಯಾವಾಗಲು	**Almost Always (87%)** ಬಹುತೇಕ ಯಾವಾಗಲು	**Generally (75%)** ಸಾಮಾನ್ಯ ವಾಗಿ	**Half the time (50%)** ಅರ್ಧದಷ್ಟು	**Occasionally (25%)** ಕೆಲವೊಮ್ಮೆ	**Seldom (12%)** ಅಪರೂಪ ವಾಗಿ	**Never (1%)** ಯಾವ ಸಂದರ್ಭದಲ್ಲು ಇಲ್ಲ.
o)							
p)							
q)							
r)							
s)							
t)							
u)							
v)							
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							
10.							
11.							
12.							

13.							
Q.NO	**Always (99%)** ಯಾವಾಗಲು	**Almost Always (87%)** ಬಹುತೇಕ ಯಾವಾಗಲು	**Generally (75%)** ಸಾಮಾನ್ಯ ವಾಗಿ	**Half the time (50%)** ಅರ್ಧದಷ್ಟು	**Occasionally (25%)** ಕೆಲವೊಮ್ಮೆ	**Seldom (12%)** ಅಪರೂಪ ವಾಗಿ	**Never (1%)** ಯಾವ ಸಂದರ್ಭದಲ್ಲು ಇಲ್ಲ.
14.							
15.							
16.							
17.							
18.							
a)							
b)							
c)							
d)							
e)							
f)							
19.							
a)							
b)							
c)							
20.							
21.							
22.							