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

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Abstract

Aim: *To evaluate the efficacy of SNR loss as a clinical tool for hearing aid evaluation.*

Objectives: *To compare the SNR-50 across participants with normal hearing, minimal SNHL and mild SNHL.To estimate a cut-off criterion for SNR loss to demarcate the need for amplification device. 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.*

Method: *SNR-50 and SNR loss estimation was done followed by administration of self assessment of hearing handicap questionnaire rating. A cut-off criterion to decide whether hearing aid is required or not was set based on the scores ofquestionnaire rating. Hearing aid trials using both approaches were counter balanced among the participants.*

Study Sample: *20 participants with normal hearing, 11 with minimal SNHL and 11 with mild SNHL for estimating cut-off criterion. Ten participants with moderate SNHL for comparing two approaches of hearing aid trial.*

Results: *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 betweenmean SNR-50 of ears with minimal and mild SNHL. SNR loss of 5.50 was estimated as cut-off criterion to decide hearing aid candidacy. There was no significant difference between the two hearing aids when the traditional approach was used whereas when the SNR loss approach was used there was a significant difference observed between the two hearing aids.*

Conclusion: *SNR losshas substantial clinical implication in hearing aid prescription.*

Key Words: *SNR loss, SNR 50, cut-off criterion, hearing aid trial*

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;Smoorenburg, de Laat, &Plomp, 1982). 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. 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).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% correctword 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 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).

Generally, 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 measures other than hearing thresholds that can be utilized to decide upon the need to pursue amplification.

The present study compared the traditional method of hearing aid evaluation carried out in quiet with an

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alternate method of 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.

The aim of the present study was to evaluate the efficacy of SNR loss as a clinical tool for hearing aid evaluation.

Specific objectives included

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.

Method

In order to meet the aim of the present study, the six objectives were attained by following the method given below.

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. The test ears of participants under Group 1 were taken for attainment of first four objectives and that of Group 2 for fulfilling last two objectives of the study. The division of test ears into two groups is depicted in Table 1, where N refers to number of test ears.

Table 1: Details of Test Ears

Group 1 (N=42)			Group 2 (N=10)	
			Individuals with flat moderate SNHL who were naive hearing aid users.	
			Sub-Group A	Sub-Group B
Sub-Group A	Sub-Group B	Sub-Group C	(N= 5)	(N= 5)
(N= 20)	(N=11)	(N=11)		
Those with Normal hearing	Those with minimal SNHL	Those 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

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.

Participant 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 to11.25 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 from 16 to 25 dB HL in the test ear which was the better ear. These test ears had 'A' type tympanogram. Their age ranged from 18 to 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.

Exclusion Criteria

Individuals having middle ear infections were not taken as participants. Individuals with cognitive or psychological deficits and those withauditory neuropathy spectrum disorder were excluded.

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.

Equipment and Material

A calibrated two-channel diagnostic audiometer.A calibrated middle ear analyzer.NOAH and hearing aid programming software installed in the personal computer that was connected to NOAH link. 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). A Dell Vostro 2520 laptop with intel core 2 duo processor was connected to the auxiliary input of audiometer using maxcord audio/video.Kannada four-speaker multi talker babble developed by Kumar, Ameenudin, and Sangamanatha (2012).Recorded Kannada passage (Sairam, 2002). Quality rating scale given by Eisenberg, Dirks, and Bell (1995).

Procedure

Audiological tests were administered in order to ensure that the participant criterion is met. 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 was to achieve the last two objectives.

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. The questionnaire titled Self Assessment of Hearing Handicap (SAHH) (Vanaja, 2000) was used for rating on a seven-point response scale by the participants. The seven-point i.e., 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). This was done as the three point rating scale of the original scale was not sufficient to note the slight problems in hearing.

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 routed through the auxiliary input of audiometer. 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., at 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, the 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 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 value of 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.

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 (and 15 questions including sub-parts assessing speech comprehension in noise. At the end, an open ended question was included to collect information on any other condition in which he/she had 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 (14 questions) and noise (15questions) 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.

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 for 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 H" 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 e" 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 1A participants. Whereas, the data comprised of unaided SIS in quiet, unaided SNR-50, and the hearing handicap questionnaire scores for participants under Group 1B and 1C. 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 1B and 1C were tabulated and subjected to statistical analysis using Statistical Package for Social Science (SPSS version 17.0). 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.

Hearing aid evaluations using two approaches and comparison of benefit

In this phase, hearing aid benefit across two hearing aid evaluation approaches, i.e, 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 participants of Group 2. This phase was carried out to achieve the last two objectives of the study.

Hearing aids programming and optimization

To accomplish Phase 2, two four-channel digital BTE hearing aids were programmed for the test ear. The hearing aids were connected to the NOAH link which in turn was connected to the personal computer. The NOAH and hearing aid fitting software 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.

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 phonemically balanced (PB) speech test material in Kannada, (Manjula, Geetha, Kumar, & Antony, 2014) in the sound field through loud speaker of the audiometer kept at 0^o Azimuth and at a distance of one meter. Each PB word list contained 25 words, each word carrying 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 at 45 dB HL through loudspeaker of the audiometer.

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 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 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 for the recorded passage through the hearing aids. The quality rating scale used consisted of five parameters,viz., 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.

Comparison across two approaches of hearing aid evaluations

The data obtained from the Phase 2 comprised of unaided SNR-50, unaided SIS, aided SIS and SNR-50 with first hearing aid, aided SIS and SNR-50 with second hearing aidfor 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.

Results

The results of the present study are mentioned under differentheadings.

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 2. The box plot in Figure 1 represents the mean with 95% confidence interval (CI) of SNR-50 data across the degree of hearing loss.

Table 2: *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*
Ears with normal hearing (N=20)	0*	0	-2 to 2	1.16
Ears with minimal SNHL (N=11)	3.36	3	0 to 8	2.90
Ears with mild SNHL (N=11)	5.36	5	2 to 9	1.85

Note: *-For ease of calculation,0.1 was rounded off as 0.

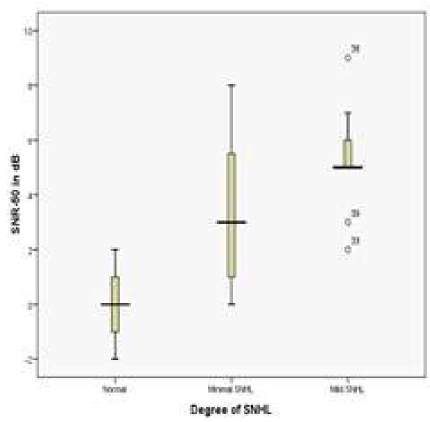

Figure 1:Box plot depicting mean with95% CI of SNR-50 data of ears with normal hearing, minimal SNHL and mild SNHL

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 3.

Table 3: *Comparison of mean SNR-50 across ears with normal hearing, minimal and mild SNHL using Dunnett's T3 multiple comparison procedure*

Groups	*Mean difference in SNR-50*	*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 in the ears with normal hearing. However, there was no significant difference betweenthe 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 loss in order to decide on the need for amplification.

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

The mean SNR-50 for ears with normal hearing as represented in Table 2 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 will 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 groups. In Figure 2, the box plot depicts SNR loss data for the two groups of ears, minimal and mild SNHL.

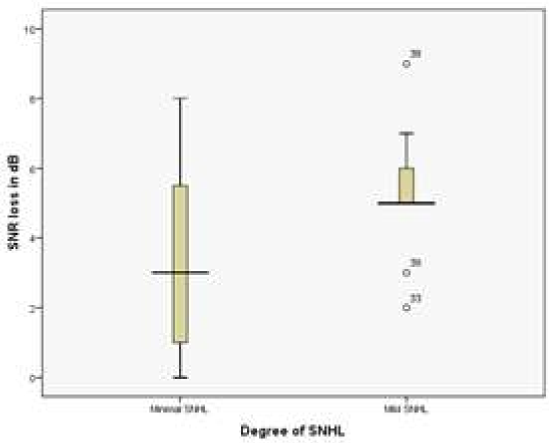

Figure 2: Box plot depicting mean and 95% CI of SNR loss for the groups minimal and mild SNHL.

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 to statistical analyses using SPSS version 17. The result of the descriptive statistics is shown in the Table4.

Table 4: *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*	*SD*
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)		Minimal	3.36	2.90
		Mild	5.36	1.86
SNR loss (in dB)		Minimal	3.36	2.90
		Mild	5.36	1.86
Hearing Handicap Questionnaire (Higher the score, more is the handicap)	Speech compre-hension in quiet (Out of 98)	Minimal	22	8.21
		Mild	35.09	13.12
	Speech compre-hension 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). All the parameters followed normal distribution (i.e., p > 0.05),except for SIS 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 two samples t-test. The result of independent two samples t-test is reported in the Table5.

Table 5: *Significant difference between minimal and mild SNHL on different audiological measures, based on independent twosamples 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 twosamples t-test revealed that the PTA and ratings on questionnaire (i.e., speech comprehension in quiet score, speech comprehension in noise score and also the 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,are also represented in Figure 3.

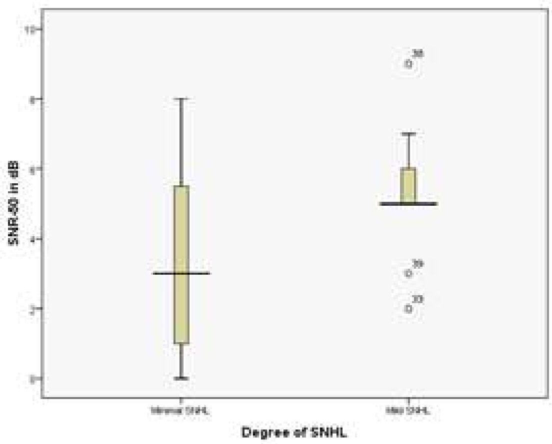

Figure 3: Box plot depicting mean with95% CI of SNR-50 for ears with minimal and mild SNHL.

To compare the 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 6.

Table 6: *Significant difference in SIS between minimal and mild SNHL using Mann-Whitney U test*

Groups	Mean difference in SIS	Z	p
Minimal SNHL group vs. Mild SNHL group	2.00	-3.479	0.001*

Note: *- significant at p < 0.05

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 7.

Table 7: Relationship between SNR loss and SIS with rating on hearing handicap questionnaire using Spearman's rho correlation

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

Note: * - significant at $p < 0.05$

There was a moderate to strong negative correlation between SIS and rating on hearing handicap questionnaire for speech comprehension in quiet and noise. That is, the participants who had higher SIS rated significantly lesser difficulty on the hearing handicap questionnaire and this correlation was more with hearing handicap ratings for quiet than that in noise condition.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. That is, the participants with more SNR loss rated significantly more difficulty on hearing handicap questionnaire; and this correlation was more with ratings for speech comprehension in noise than that with quiet.

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

The data from participants with minimal and mild SNHL comprising of SIS,SNR loss, rating scores on 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 8. The cut-off total score on the hearing handicap questionnaire in order to say that a person requires a hearing aid was set as 80as explained before.That is, a person with a score of 80 and above was a candidate for hearing aid.

Table 8 Mean and standard deviation ofSNR loss of participants across the two groups divided based onhearing handicap scores

Hearing aid required based on hearing handicap questionnaire	*SNR loss*	
	Mean	*SD*
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 twosamples 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 data on SNR loss across two groups of participants divided based on decision of hearing aid candidacy on the questionnaire is depicted in the form of box plot in the Figure 4.

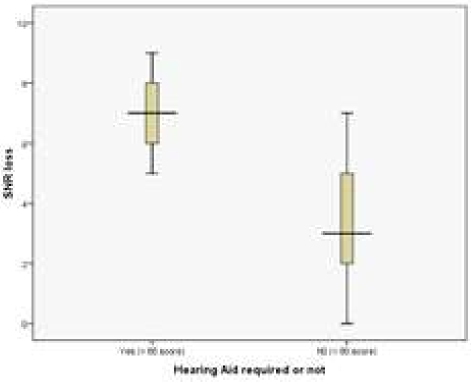

Figure4: Box plot showing SNR loss data of those who require hearing aid and those who do not require hearing aid based on questionnaire score.

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 based on questionnaire score. 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 SNR loss is represented in Figure 5.

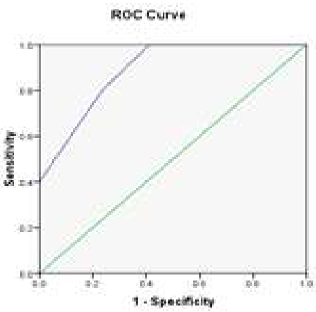

Figure 5:ROC curve for the SNR loss as an approach for deciding hearing aid candidacy criterion.

The area under the ROC curve was 0.88 (p value= 0.01) propounding the fact that SNR loss is a measure with good accuracy in discriminating those who require hearing aid from those who do not. The obtained coordinates of the curve along with sensitivity and1-specificity for each coordinate or point are mentioned in Table 9.

Table 9: Trade-off in sensitivity and specificity across all SNR loss coordinates

Note: *Cut-off value of SNR loss with maximum specificity and minimum 1- sensitivity

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

As depicted in Table 9, 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.

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 analyses. Shapiro-Wilk's 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 10.

Table 10: Efficacy of the two 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 10, 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 between the two trial 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's product moment correlation revealed a negative relationship between aided SIS and aided SNR loss measure. Such that, for both the trial hearing aids with increase in SIS there was reduction in SNR loss.However, this was not statistically significant($p > 0.05$).

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 results revealed 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.

Discussion

The aim of the present study was to assessefficacy of SNR loss measure as a clinical tool for hearing aid evaluation.The results of the present study are discussed below under each heading.

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 dB, considered to be 0 dB for all practical purposes. Comparing the findings with existing literature, Manjula and Megha (2012) obtained much lower SNR-50 (mean SNR-50 = -7.23 dB) for individuals with normal hearing. A similar procedure was used in the present study; much poorer SNR-50 for participants with normal hearing in the present study could be accounted by difference in noise used in the two studies. In the present study, a four speaker multi-talker babble was utilized instead of speech shaped noise which was used by Manjula and

Megha (2012). The use of four-speaker multi-talker babble in the present study is presumed to have led to a more complex task.

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). 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. 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 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.

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. However, this difference was not statistically significant. Regardless of a statistically significant difference seen in speech identification scores (SIS) across minimal and mild SNHL on 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. Killion (1997) has also opined that as the degree of hearing loss becomes greater; greater is the SNR that is required on an average; though large individual variability exists.

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 higher 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 loss of clarity due to SNR loss which is increasing with the degree of loss. But there has 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), and 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 by improving the signal to noise ratio.

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 that 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 in quiet. This is an expected finding since SNR loss reflects the speech performance in noisy listening condition than in the quiet. Similar findings have been reported in literature (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) 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 SIS 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.

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

The date from two groups of test ears, with minimal and mild SNHL,were divided based on the total score on hearing handicap questionnaire rating and this was compared with SNR loss. The test ears presumed to require an amplification device had significantly higher SNR loss than the ears not considered 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 the value of SD from mean value of 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 of a test ear is lesser than the cut-off criterion, then the individual is not a hearing aid candidate. Hence, based on this finding, the SNR loss can be utilized as a 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. In the present study, 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 of 5.50 dB yielded maximum sensitivity (0.80) and minimum 1-specificity (0.23).Thereby, and SNR loss of 5.5 dB was set as the cut-off criterion. Both sensitivity as well as specificity being greater than 75%, it paves the way for using SNR loss as a measure for deciding whether a person is a candidate for hearing aid.

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

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-samples t-test. The results revealed that the aided SIS measure i.e., traditional hearing aid evaluation procedure,was not as efficient as SNR loss in differentiating the two trial hearing aids. Whereas, the alternate method of hearing aid evaluation i.e., measuring aided SNR loss was an efficient tool in significantly differentiating the two trial hearing aids. Therefore, this finding indicates that though similar performance was achieved in quiet with both the trial hearing aids, there was a significant difference in performance under 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; thus 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 less effortful and thus more beneficial in multiple environments.

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, and this 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).

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 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 from thehearing aid. Apart from this, there could have been different yardstick set by each individual for rating the performance in aided condition. A similar trend of correlation was observed for individual quality parameter (i.e., loudness, fullness, naturalness and clearness). Experience with the hearing aid of only a short duration of ten minutes might also have resulted in variability in the quality rating.

Conclusions

The present study aimed at evaluating the efficacy of SNR loss as a clinical tool for hearing aid evaluation. It was observed that 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.

Further, the aided SIS measure was less efficient 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. Hence, 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 about SNR loss with 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. Thus the SNR loss is a measure that can be useful in deciding candidacy for hearing aid as well as in differentiating the trial hearing aids.

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