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Equivalence and test–retest reliability of Tulu sentence lists for measuring speech recognition threshold in noise among individuals with sensorineural hearing loss

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Abstract

Background The difficulty in understanding speech becomes worse in the presence of background noise for individuals with sensorineural hearing loss. Speech-in-noise tests help to assess this difficulty. Previously, the Tulu sentence lists have been assessed for their equivalency to measure speech recognition threshold in noise among individuals with normal hearing. The present study aimed to determine the equivalence and test–retest reliability of Tulu sentence lists for measuring speech recognition threshold in noise among individuals with sensorineural hearing loss.

Results The SNR-50 was measured for 13 sentence lists in 20 Tulu-speaking individuals with mild to moderate sensorineural hearing loss. Retesting was done by administering all lists to eight participants after an average of 25.25 days (*SD* = 19.44). Friedman test was administered to check for the list equivalency. Intraclass correlation coefficient was measured to assess test–retest reliability. A regression analysis was performed to understand the influence of pure-tone average on SNR-50. A Kruskal–Wallis test was administered to check the statistical significance of the SNR-50 obtained across different configurations and degrees of hearing loss. Nine of the 13 Tulu sentence lists (lists 2, 4, 5, 6, 9, 10, 11, 12, and 13) were equivalent in individuals with sensorineural hearing loss. The mean SNR-50 for these nine lists was 1.13 dB (*SD* = 2.04 dB). The test–retest reliability was moderate (*ICC* = 0.727). The regression analysis showed that a pure-tone average accounted for 24.7% of the variance in SNR-50 data ($p = 0.026$). Individuals with mild to moderate hearing loss obtained the worst SNR-50, followed by mild and high-frequency hearing loss.

Conclusion Nine Tulu sentence lists are equivalent and reliable and can be used to measure speech recognition threshold in noise among individuals with sensorineural hearing loss who are Tulu speakers.

Keywords Speech understanding in noise, Equal lists for hearing loss, Speech perception in hearing loss, Indian language

Background

People with sensorineural hearing loss (SNHL) have difficulty perceiving speech in quiet, which, however, gets more exacerbated in the presence of background noise, which may be due to loss of speech clarity and loudness [1], reduced dynamic range [2], reduced frequency selectivity, loudness recruitment, and dead regions [3]. This difficulty in speech perception cannot be explained with a pure-tone audiogram [4] and can be affected in individuals with mild hearing loss as well [5]. Speech-in-noise

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(SIN) tests can help patients who struggle to understand speech in noisy environments. Few studies have attempted to simulate real-life listening scenarios like living room, office, and restaurants [6]. The test results can guide the selection of suitable hearing aids and help manage expectations. Low SIN scores may suggest the need for more substantial noise reduction programming, extra signal processing, or directional microphones [7].

Speech-in-noise tests using sentences is used to diagnose signal-to-noise ratio (SNR) loss. The SNR loss refers to the increase in signal-to-noise ratio required for a listener to obtain 50% correct words, sentences, or words in sentences, compared to a performance by normal-hearing listeners [8]. These tests are essential since pure-tone audiometry, as well as routine speech audiometry in quiet, may not determine SNR loss [9]. Therefore, speech recognition in noise tests is an essential part of the audiological test battery on a daily basis, as it helps to communicate the potential benefits of hearing aids for speech perception in noisy situations [8]. The SNRs in everyday situations vary vastly in range [10]. There is significant variability in performance across individuals, even when they are of similar age and hearing status. This emphasizes the importance of determining an individual's hearing abilities in challenging listening environments accurately [11].

Testing speech recognition in a person's native language ensures that the results accurately reflect the individual's ability to comprehend speech in real-world situations [12, 13]. Various speech-in-noise tests using sentence materials have been developed to assess speech understanding difficulty in the presence of background noise including English [8, 14, 15], Polish [16], Russian [17], Italian [18], Turkish [19], Finnish [20], and Mandarin Chinese [21]. Sentence materials have been developed in various Indian languages like Hindi [22], Kannada [23], Malayalam [24], Telugu [25], Tamil [26], and Tulu [27]. Tulu is a Dravidian language spoken in the southern part of Karnataka and the northern part of Kerala state and has 1,846,427 native speakers [28].

The sentence lists need to be equivalent to obtain similar scores across the lists. Also, multiple lists are required to evaluate people in diverse scenarios. These include examining their ability to comprehend amidst loud surroundings, choosing and adjusting hearing devices, and measuring progress post-training or rehabilitation. McArdle and Wilson studied the equivalence of 18 QuickSIN lists in individuals with normal hearing (NH) and SNHL. These authors observed variability in list equivalency among individuals with NH and hearing impairment [29]. On the other hand, some authors have found lists to be equivalent among both groups [30, 31].

Test–retest reliability means a test is expected to produce consistent and valid results during repeated test administration. The tests frequently used for research and assessment purposes must have higher test–retest reliability to accurately interpret the results [32]. Tulu sentence lists developed by Bhat et al. [27] consist of 13 lists, equivalent among individuals with NH. However, these lists have not been assessed for equivalency and test–retest reliability in the hearing-impaired population. Hence, the objectives of the present study were to determine the equivalence of Tulu sentence lists developed by Bhat et al. [27] to measure the SNR-50 among individuals with SNHL and to determine the test–retest reliability of the sentence lists to measure speech recognition threshold in noise among individuals with SNHL.

Materials and method

Participants

This cross-sectional study was initiated after obtaining approval from the institutional ethical committee. The sample size for the study was calculated to be 20 using the values of mean SNR-50 among individuals with NH and individuals with SNHL from the reference study [29]. The purpose of the study and the procedure were explained to the participants. All those who agreed voluntarily signed a written consent form. The participants were not paid for their participation. The participants were native Tulu speakers from any dialect, with a proficiency rating of 7 or greater in understanding spoken language for Tulu in the Language Experience and Proficiency Questionnaire (LEAP-Q) [33]. Individuals with a history of middle ear disorders and with a history or complaints of neurological impairment were excluded from the study.

A total of 20 individuals (11 males, 9 females) with SNHL whose pure-tone average thresholds (PTA: average of thresholds at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz) in the test ear were in the range of 26.25 to 55 dB HL and air–bone gap less than 10 dB HL participated. The mean pure-tone average was 37.06 dB HL ($SD = 8.40$). All the participants had an 'A'-type tympanogram [34, 35] with acoustic reflexes present or absent according to the degree of hearing loss. Five participants had unilateral SNHL, and the remaining 15 had bilateral SNHL. For the participants with unilateral hearing loss, the SNR-50 was measured in the ear with hearing loss. For participants with bilateral hearing loss, the ear that met the inclusion criteria was tested. If both ears met the inclusion criteria, one ear was randomly chosen as the test ear. The age of the participants ranged between 23 and 85 years (mean = 56.2 years and $SD = 14.59$).

Materials

The 13 Tulu sentence lists developed by Bhat et al. [27] that have been recorded by a young adult female native Tulu speaker were used. The speech spectrum-shaped noise generated has the RMS level matched to that of the sentence. Each of the sentence list consists of 10 sentences. The average number of words in a sentence ranges from 3.8 to 4.3, the average number of syllables per sentence among the 13 lists ranges from 9.8 to 10.9 syllables, and the average number of phonemes in a sentence ranges between 20.2 and 22.2 [27].

Procedure

To assess the candidacy for the study, pure-tone audiometry testing using the modified Hughson-Westlake procedure using a calibrated GSI-61 audiometer (Grason-Stadler, Eden Prairie, MN) with standard accessories was carried out. An immittance evaluation was done using calibrated GSI TympStar (Grason-Stadler, Eden Prairie, MN) equipment. The stimulus for the measurement of SNR-50 was presented via APEX software version 3 [36] in a Lenovo ThinkPad L480 laptop. Sennheiser HD 280 Pro headphones connected to the laptop were used to present the sentences.

The SNR-50 testing was done in a distraction-free, quiet room. The sentence stimuli were presented at the most comfortable level (MCL). To identify the MCL of the participant, sentences were presented at different levels, and the participant was instructed to indicate when the speech was comfortably audible. Since MCL is a range of levels rather than a fixed point, this procedure was repeated a few times to identify the lower and upper limits of MCL. The midpoint of the measured range was used for testing [37]. The first sentence was presented at − 8-dB SNR. If the participant could not identify all the words in the sentence correctly, then the same sentence was presented by increasing the SNR in each presentation by 2 dB until the participant correctly identified all the words in the first sentence. Following this, a one-down and one-up procedure was employed with a 2-dB step size for each sentence depending on the accuracy of the response from the participant. The testing took approximately 45 min and was done in one session with breaks when required. The order of presentation of the list was random across the participants. Before presenting the actual 13 lists, a practice list was presented to familiarize the participant with the task. The participants were instructed to repeat the sentences they heard and encouraged to guess if they were unsure what they heard. A sentence was correct if all the words were repeated correctly, except for dialect-related variations. The SNR-50 was calculated from each list's average of the last four reversals of the up-and-down procedure.

Retesting was done on eight participants with the test–retest interval range between 4 and 62 days (mean = 25.25 days, *SD* = 19.44). The air conduction pure-tone thresholds were reassessed before performing the second testing. During each session, the order of sentence lists was randomly chosen and presented. All 13 sentence lists were presented in both sessions. The SNR-50 data was tabulated for each list and each session separately.

Data analysis

The data obtained was tabulated, and descriptive statistical analysis was done. Data was analysed in SPSS software version 29 [38]. Out of 13 lists, the SNR-50 of 5 lists followed nonnormal distribution according to the Shapiro–Wilk test (provided in the supplementary Table 1). In addition, large standard deviations were observed for all the lists. Hence, a decision was made to perform a nonparametric test. Friedman test was carried out for SNR-50 with lists as the repeated measure for determining list equivalency. To determine the test–retest reliability of Tulu sentence lists, intraclass correlation coefficient was calculated for SNR-50 measured across two test sessions using two-way mixed-effects model. The 95% confidence intervals were calculated on both single measures and absolute measures for absolute agreement. Since PTA and the average SNR-50 of nine lists followed a normal distribution, Pearson correlation coefficient was run between PTA and SNR-50 followed by a linear regression analysis. The Kruskal–Wallis test was administered to check the statistical significance of the difference between SNR-50 obtained across different configurations and degrees of hearing loss. A nonparametric test was performed in this case because of the small sample size across each group.

Results

Equivalence of the Tulu sentence lists among individuals with hearing loss

The mean SNR-50 and standard deviation of the 13 sentence lists among individuals with SNHL are shown in Table 1. The mean of SNR-50 across all 13 lists was 1.1 dB (*SD* = 1.97 dB). Friedman test for SNR-50 with lists as within the subject factor was done. The results showed significant difference [$F(12) = 34.616$, $p < 0.001$] among 13 lists. Further, pairwise comparison with Bonferroni correction for multiple comparisons was made to understand which lists are significantly different. The results showed that the SNR-50 of three pairs of lists, that is, L1–L7 ($p = 0.047$), L7–L8 ($p = 0.006$), and L3–L8 ($p = 0.022$), were significantly different. Thus, list 7 is equivalent to all the lists except for lists 1 and 8. Further,

Table 1 The mean SNR-50 and standard deviation of 13 lists among all individuals with SNHL and for each subgroup of hearing loss separately

List number	Mean SNR-50 (dB) (standard deviation)			
	Across all individuals with SNHL	High-frequency hearing loss	Mild hearing loss	Mild to moderate hearing loss
List 1	2.13 (3.22)	4.38 (1.89)	1.29 (3.63)	1.78 (3.17)
List 2	1.8 (2.9)	−0.75 (0.65)	2.71 (4.17)	2.11 (1.62)
List 3	−0.23 (1.91)	−0.25 (1.50)	−1.07 (1.90)	0.44 (1.99)
List 4	1.65 (3.33)	0.63 (3.33)	0.57 (2.15)	2.94 (3.92)
List 5	1.73 (2.63)	0.13 (2.02)	1.43 (3.36)	2.67 (2.03)
List 6	0.9 (3.66)	0.13 (2.36)	−0.57 (2.32)	2.39 (4.59)
List 7	−0.63 (1.78)	−2.25 (0.96)	−0.79 (1.25)	0.22 (1.97)
List 8	2.93 (4.63)	−0.13 (1.84)	0.64 (1.63)	6.06 (5.23)
List 9	0.85 (3.07)	1.5 (5.21)	−0.57 (2.42)	1.67 (2.25)
List 10	0.9 (3.68)	−1.5 (2.55)	−0.21 (3.13)	2.83 (3.77)
List 11	0.8 (2.82)	−1.63 (2.06)	0.00 (2.72)	2.50 (2.25)
List 12	0.9 (2.39)	0.5 (2.92)	−0.50 (2.16)	2.17 (1.82)
List 13	0.7 (2.99)	−0.38 (1.70)	−0.57 (2.11)	2.17 (3.54)
Average across all 13 lists	1.1 (1.97)	0.03 (1.65)	0.18 (1.10)	2.30 (1.40)
Average across nine equivalent lists	1.13 (2.04)	−0.15 (1.17)	0.25 (1.91)	2.38 (1.83)

SNHL Sensorineural hearing loss

list 8 is significantly different from list 3. The remaining comparisons were not statistically significant ($p > 0.05$). Hence, lists 2, 4, 5, 6, 9, 10, 11, 12, and 13 can be considered equivalent among individuals with SNHL. Hence, for further statistical analysis, the average SNR-50 of nine lists were considered. The mean SNR-50 among the equivalent nine lists is 1.13 dB ($SD = 2.04$).

Effect of PTA on SNR-50 among individuals with hearing loss

The correlation between the mean SNR-50 of nine equivalent lists with four-frequency PTA was measured. The Pearson correlation results suggested a significant positive correlation of 0.497 ($p = 0.026$) between PTA and SNR-50. Hence, to understand the role of PTA on SNR-50, a linear regression analysis was done with SNR-50 as the dependent variable and PTA as the predictor variable. The results showed that PTA accounted for 24.7% of the variance in SNR-50 data ($p = 0.026$). Figure 1 shows the scatter plot between PTA and SNR-50.

Test–retest reliability of Tulu sentence lists

Table 2 shows the mean and standard deviation of SNR-50 between the two test sessions for the nine equivalent lists among eight individuals with SNHL. The mean difference between the two test sessions across all the lists was 0.73 dB ($SD = 0.93$). Table 2 also indicates that the SNR-50 was better in the second test session than in the first, except for list 6. The intraclass correlation coefficient was calculated for the averaged SNR-50 across the nine lists measured across two sessions. The 95% confidence intervals of intraclass correlation analysis showed poor to excellent reliability (Table 3) [39]. Table 3 also shows each list's ICC values with 95% confidence intervals.

Effect of degree and configuration of hearing loss on SNR-50

Based on the configuration of the audiogram and the PTA, individuals with SNHL were categorized into three subgroups: high-frequency hearing loss (HFHL), mild SNHL, and mild to moderate SNHL. Of the 20 participants, 4 had HFHL, 7 had mild hearing loss, and 9 had mild to moderate hearing loss. The mean SNR-50 across different subgroups of SNHL for each of the 13 lists as well as averaged across 9 equivalent lists is shown in Table 1. While comparing the average SNR-50 across nine equivalent lists, the HFHL group had the best SNR-50 among the three groups, followed by the mild hearing loss group, while the mild to moderate hearing loss group had the worst SNR-50. A Kruskal–Wallis test was run with SNR-50 as the dependent variable and three subgroups as the independent variable.

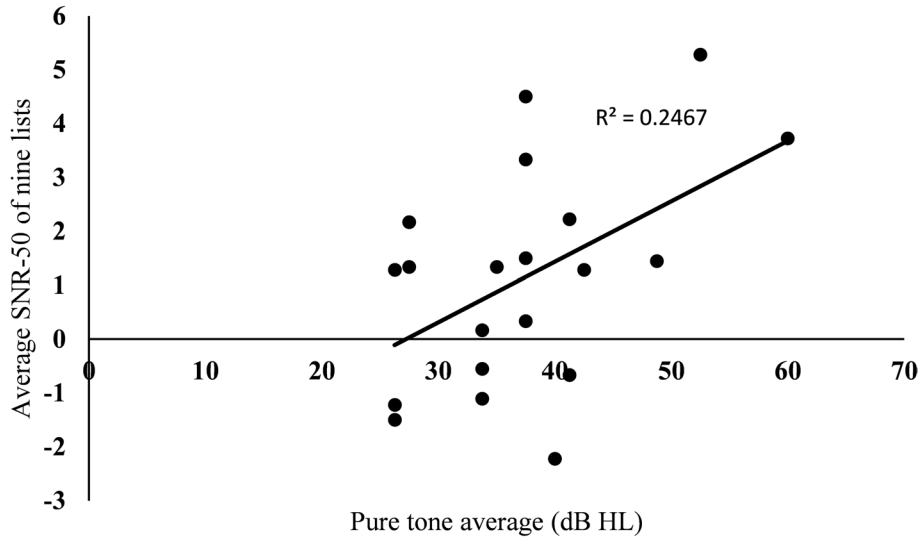

Fig. 1 Scatter plot between four-frequency pure-tone average and average SNR-50 of nine sentence lists

Table 2 Mean and standard deviation of SNR-50 obtained in two test sessions for nine equivalent lists for individuals with sensorineural hearing loss

List number	SNR-50 in the first test session (mean ± SD)	SNR-50 in the second test session (mean ± SD)	Mean difference in SNR-50 (mean ± SD)
List 2	0.56 (1.14)	0 (1.9)	0.56 (0.97)
List 4	1 (4.27)	−0.31 (2.23)	1.31 (2.57)
List 5	1.25 (2.18)	−0.06 (1.56)	1.31 (1.66)
List 6	−0.62 (2.69)	−0.43 (2.51)	−0.18 (1.36)
List 9	1 (3.86)	0.56 (2.02)	0.43 (2.74)
List 10	−0.68 (2.44)	−2.06 (1.54)	1.37 (1.43)
List 11	−0.5 (1.36)	−1.31 (1.71)	0.81 (1.22)
List 12	0.56 (2.14)	−0.31 (1.73)	0.87 (1.94)
List 13	0.5 (2.43)	0.43 (2.04)	0.06 (1.11)

The results showed that SNR-50 did not significantly differ across the groups [H(2) = 0.307, $p = 0.858$].

Discussion

SNR-50 among individuals with sensorineural hearing loss

The SNR-50 indicates the SNR required to perceive the speech 50% of the time. The literature shows that the mean SNR-50 across 13 Tulu sentence lists among individuals with NH was −4.19 dB ($SD = 0.21$) [27]. The difference in SNR-50 between the average of 9 lists among individuals with SNHL and 13 lists among individuals with NH [27] is 5.32 dB. In literature, different studies have obtained different values of SNR-50 among individuals with SNHL. For example, Mc Ardle and Wilson (2006) found a difference of 8.7 dB among individuals with NH and individuals with high-frequency SNHL. A 5-dB difference between individuals with NH and those with severe sloping high-frequency SNHL was observed by Killion et al. [8], and a 6.46-dB difference between individuals with NH and those with sloping SNHL with PTA less than 70 dB was found in a study by Hanilou et al. [40]. The difference in SNR-50 between NH listeners and listeners with hearing loss is similar in the present study compared to that obtained in the literature.

Across three subgroups of individuals with hearing loss, the SNR-50 among individuals with HFHL was the best, followed by the group with mild hearing loss, which had slightly poorer SNR-50, and the third group with mild to moderate loss that had the poorest SNR-50. Better SNR-50 in the group of HFHL could be because of the normal low-frequency hearing thresholds. Loukzadeh et al. [41] found that SNR loss had a direct and significant correlation with the high-frequency hearing thresholds of both ears. The present study found a significant positive correlation ($r = 0.497$) between PTA and SNR-50. This explains the poorer SNR-50 among individuals

Table 3 Results of intraclass correlation coefficient with 95% confidence intervals for each list as well as for average SNR-50 across nine equivalent lists using two-way mixed-effects model with absolute agreement definition

List number		Intraclass correlation	95% confidence interval		*F*-test with true value 0			
			Lower bound	Upper bound	Value	df1	df2	Sig
Average 9 lists	Single measures	0.799	0.283	0.956	8.945	7	7	**0.005**
	Average measures	0.888	0.442	0.978	8.945	7	7	**0.005**
List 2	Single measures	−0.410	−0.959	0.413	0.450	7	7	0.843
	Average measures	−1.390	−47.147	0.585	0.450	7	7	0.843
List 4	Single measures	0.736	0.199	0.939	7.432	7	7	**0.008**
	Average measures	0.848	0.332	0.969	7.432	7	7	**0.008**
List 5	Single measures	0.526	−0.090	0.876	4.315	7	7	**0.036**
	Average measures	0.689	−0.199	0.934	4.315	7	7	**0.036**
List 6	Single measures	−0.268	−0.857	0.509	0.589	7	7	0.749
	Average measures	−0.733	−11.996	0.675	0.589	7	7	0.749
List 9	Single measures	−0.157	−0.825	0.590	0.742	7	7	0.648
	Average measures	−0.374	−9.399	0.742	0.742	7	7	0.648
List 10	Single measures	0.258	−0.326	0.768	1.838	7	7	0.220
	Average measures	0.410	−0.969	0.869	1.838	7	7	0.220
List 11	Single measures	0.012	−0.628	0.667	1.025	7	7	0.487
	Average measures	0.024	−3.374	0.800	1.025	7	7	0.487
List 12	Single measures	−0.040	−0.726	0.652	0.925	7	7	0.539
	Average measures	−0.083	−5.291	0.789	0.925	7	7	0.539
List 13	Single measures	0.932	0.725	0.986	29.787	7	7	**< 0.001**
	Average measures	0.965	0.841	0.993	29.787	7	7	**< 0.001**

in the mild to moderate group compared to those in the mild hearing loss and HFHL group. Other studies also support the findings that SNR loss is affected in individuals with SNHL and is positively correlated with the degree of hearing loss [42, 43]. However, on statistical analysis, the difference in SNR-50 across groups was not significant. This was probably because of the high standard deviation and the small size. This is the limitation of the present study.

Equivalence of Tulu sentence lists among individuals with hearing loss

Out of 13 sentence lists equivalent among individuals with NH, 9 were equivalent among individuals with SNHL. The average SNR-50 across nine lists among individuals with SNHL was 1.13 dB ($SD = 2.04$ dB). The SIN test [44] had 12 equivalent lists for individuals with NH and hearing impairment [8]. Thirty of the 33 FrBio sentence lists were equivalent among individuals with NH and individuals with mild to severe hearing impairment [31]. Similarly, the equivalence of sentence lists has been measured among NH individuals and individuals with Cochlear implants (CI). Schafer et al. [30] found 10 of the 15 AzBio Sentence Test lists equivalent among individuals with NH and CI. Twenty-six out of 30 CMnBio sentence lists were found to be equivalent for individuals with CI [45]. In the above-mentioned studies, individuals with NH and hearing loss have the same equivalent lists. On the contrary, McArdle and Wilson [29] found that 18 sentence lists were homogenous in individuals with NH, but only 9 lists were equivalent in individuals with hearing loss. This is similar to the findings of the present study.

Test–retest reliability of Tulu sentence lists

The mean SNR-50 difference during test and retest sessions was 0.73 dB ($SD = 0.93$) among individuals with SNHL. In the literature, the test–retest SNR-50 among individuals with hearing impairment has shown a difference of 1.4 dB [8]. Thus, the result of the present study is similar to that in the literature. Statistically, in the present study, intraclass correlation coefficient for the test–retest reliability among individuals with SNHL was moderate ($\alpha = 0.727$). A correlation coefficient 0.97 for the hearing-impaired group was obtained when the retest session was within 2 weeks [46]. The reason for this difference could be the use of different statistical measures of reliability in these two studies.

In the present study, there was an improvement among all lists except list 6 in the second test session.

This improvement could have been due to familiarity with the sentence material, as the same test stimuli were presented a second time to measure the test–retest reliability. The number of days between the two test sessions was small, an average of 25.25 days. Hence, the participants could have remembered the sentences, which led to better performance. The main reason for choosing a shorter retest duration was to avoid any possible changes in the hearing thresholds with long retest durations. One way to eliminate the memory effect in these conditions is by measuring SNR-50 for different equivalent lists in two sessions [47].

Conclusions

The nine equivalent Tulu sentence lists are reliable. They can be used in the audiometric evaluation of individuals with SNHL, to assess speech perception, and during hearing aid fitting, to provide realistic expectations to patients who are native Tulu speakers on hearing aid benefits. The sentence lists could help assess speech perception across different conditions, pre- and post-aural rehabilitation, different amplification devices, etc. The present study was limited to a sample size of 20 individuals with mild to moderate hearing loss. Future studies could be done in a larger population with different degrees and configurations of hearing loss. The scoring in this study was sentence based. Future studies could assess the effect of different types of scoring.

Abbreviations

SNHL	Sensorineural hearing loss
HFHL	High-frequency hearing loss
NH	Normal hearing
SIN	Speech in noise
SNR	Signal-to-noise ratio
PTA	Pure-tone average

Supplementary Information

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Supplementary Material 1: Supplementary table: Supplementary Table 1: Results of the Shapiro-Wilk test of normality for the SNR-50 obtained for the 13 sentence lists.

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Authors' contributions

ABM contributed by collecting and interpreting the data, writing, and revising the manuscript. MKK and US contributed by designing the study, data analysis, data interpretation, and writing and revising the manuscript. All the authors have approved the submitted version of the manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The approval for the study was obtained from the Institutional Ethics Committee of Kasturba Medical College, Mangalore (Protocol number: IEC KMC MLR 03/2023/104). Written informed consent was taken from all the participants for participation in the study after explaining the objectives of the study. Confidentiality of participants was maintained.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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