# The Developement of Hindi Sentence Test for Speech Recognition in Noise

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**Abstract:** *Background*: The aim of the study was to develop a test material in Hindi language for assessing sentence recognition threshold in noise.

*Material and Methods*: The study was conducted in two phases. First phase involved three experiments. First experiment consisted of the collection and recording of the sentence material. In the second experiment, sentence perception was assessed at five signal to noise ratios to check for the equalization of sentence material in terms of intelligibilty. This was done on 25 native speakers of Hindi language with normal hearing sensitivity. In the final experiment, 20 different lists with 10 sentences in each were formulated. The second phase of the experiment involved estimation of signal to noise ratio required to obtain 50% correct sentence identification score (SNR 50) and the test reliability of the lists was assessed. The estimation of SNR 50 was done on 30 native speakers of Hindi language with normal hearing sensitivity.

*Results*: Twenty optimized lists were formulated. Lists were found to be of almost equal difficulty and to have good test reliability in normal-hearing listeners. The average SNR50 was -4.56 dB with a standard deviation of 0.45 dB.

*Conclusions*: The developed test provides a reliable means of measuring sentence recognition threshold in noise for native speakers of Hindi.

**Keywords:** Sentence recognition threshold, Speech Shaped Noise, Psychometric function.

## BACKGROUND

Speech recognition is a measure of audibility and its assessment is an essential component of the audiological test battery, as it provides information on sensitivity to speech stimuli. Speech recognition can be measured using variety of speech stimuli such as nonsense syllables, monosyllables, spondees, sentences etc. Each stimulus has its own advantages and disadvantages. Among all, the sentences are more advantageous than any other stimuli, as they provide information regarding the contextual characteristics of conversational speech and hence, they have more face validity [1,2]. Further, the psychometric function (often referred to as performance intensity curve) was found to be steeper for sentence material than for words and phonemes. Therefore, an accurate measurement of speech recognition threshold (the speech level that corresponds to 50% intelligibility) is possible with sentence material [3,4].

The studies mentioned above suggest that the speech recognition testing should be performed using the sentence material, as they provide more reliable measures. In addition, day-to-day conversation majorly involves the use of full length sentences. However, the several advantages of using sentence material come along with a few disadvantages. Repeated use of a sentence could confound the outcome [4]. Further, to understand the sentences, multiple acoustic and contextual cues act as extrinsic redundancies. Hence, it is harder to predict which specific information was used by the listener to understand/identify/comprehend the sentence.

However the various advantages of using sentence material out weigh these disadvantages. The sentence material incline to provide a more comprehensive view of an individual's speech perception than word material. Hence, a number of recent studies have focused on the development of test material for speech recognition in noise using sentences. Some of the sentence materials developed in the past are Central Institute for the Deaf (CID) sentences in English [5], Hearing in Noise Test (HINT) sentences in English [2], test consisting of everyday sentences in German [4], Cantonese [6], Swedish [7], French [8], Mandarin [9], Polish [10].

India is a multilingual country with twenty-three constitutionally recognised languages [11] and Hindi being the official language. The audiologists in the country face great difficulty in delivering the services to a culturally and linguistically diverse client load. This is

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because of the shortage of standardized speech audiometry materials and procedures in most of the Indian languages. Moreover, the perception of speech is influenced by their first language [12]. Hence, it is ideal to test speech perception in their native language. Currently there are few word materials available in Hindi viz Hindi PB List [13], Hindi high frequency word list [14]. However, there is no sentence material available in Hindi language till date.

Currently available speech materials in Hindi language have been evaluated only in quiet and at word level. Assessing speech perception with sentences in noise will be helpful in accounting for the benefit from amplification for individuals with cochlear hearing loss. This information would be more advantageous in counseling patients regarding their expectation from hearing devices when listening in background noise [15]. Hence present study aimed at developing a Hindi sentence material for speech recognition in noise and evaluating the same on native speakers of the Hindi language.

## MATERIALS AND METHODS

The study was conducted in two phases. The first phase involved the development of sentence material while the second phase consisted of the evaluation of this developed sentence material on native speakers of the language. All the listeners who participated in the study had normal hearing, as indicated by their four-frequency (500Hz, 1000 Hz, 2000Hz& 4000 Hz) pure-tone average threshold of ≤15 dBHL,'A'Type tympanogram with acoustic reflex thresholds within normal limits (90 dB at 1000 Hz). It was ascertained from a structured interview that none of these listeners had any difficulty in understanding speech in daily listening conditions and that they did not have any history of neurologic or otologic disorder. All the listeners were native speakers of Hindi from the northern states of India where the same dialect of Hindi is spoken. Their participation was voluntary and were not paid for their participation in the study. Ethical clearance was obtained from the relevant ethics committee at the institute prior to commencement of experimentation.

### Phase I

Phase I involved three experiments, first experiment comprised of collecting and recording suitable sentences in Hindi; second experiment consisted of selecting the sentences that had comparable difficulty in noise, and the final experiment involved making of optimum lists, all having sentences of comparable difficulty.

### Experiment I

#### *Collection of Sentence Material*

The available literature shows that there are no formally standardized sentence tests or suitable sentence collections in Hindi. Therefore, 650 sentences were collected from children's textbooks, magazines and day to day conversation. The following criteria were used in the selection of the sentences [16]: (1) the sentence chosen composed of three to seven words (2) the total number of syllables in a sentence ranged from eight to nine (3) any of the words in a sentence did not contain more than three syllables (4) no duplicate sentences were selected and (5) the sentences were syntactically correct and semantically neutral. The structure and the grammatical difficulty of the sentences were kept as similar as possible. Semantic neutrality was achieved by avoiding material related to politics, war, or gender topics. Questions, proverbs, proper names, and exclamations were eliminated.

The naturalness of these sentences was evaluated by administering it on ten native Hindi speakers who were asked to rate the naturalness of the sentences on a five point rating scale and the predictability on a three point rating scale. Only those sentences that were rated '4' or '5' on naturalness rating scale and '2' or '3' on the predictability rating scale by ≥ 80 % of individuals were selected for recording. Naturalness was assessed based on the semantic naturalness and whether the sentence is encountered on an everyday basis. All the sentences for the naturalness and predictability rating were presented in the written form to the participant. A total of 512 sentences met the inclusion criteria on naturalness and predictability rating.

#### Recording and Editing of the Sentences

The selected 512 sentences were recorded digitally in a sound-proof booth, using a Computerized Speech Lab (CSL) (Computerized Speech Lab; KayPENTAX, Lincoln Park, NJ) at a sampling rate of 44.1 kHz with 24-bit resolution. A microphone (Shure SM-48) was placed at a distance of 20 cm from the speaker's mouth and the speaker was informed to articulate all words clearly, while still retaining a native intonation pattern and maintaining equal vocal effort throughout each sentence. These sentences were spoken by a young adult female, with an F0 of 190 Hz, who was a native speaker of Hindi, in a standard Hindi dialect among the many dialects present in Hindi (standard and non-standard). These sentences were high-pass filtered at a cutoff frequency of 50 Hz and split into individual waveforms, by eliminating the unwanted silences preceding and following the recorded sentence. The individual wave files were stored on to a computer hard-disk. These individual wave files were normalized by adjusting the RMS level to -20 dB (with respect to maximum digital output). The above described manipulations were performed using Adobe Audition, V3 (Adobe Systems Incorporated, San Hose, CA) software.

### Generation of Background Noise

A speech spectrum shaped background noise was generated to match the long-term average spectrum of the sentence material. In the presence of speech spectrum shaped noise, slope of the psychometric function for sentences is maximized and hence, the accuracy of the speech recognition threshold determination is high [17].

The noise was generated by randomizing phase of the Fourier spectrum of concatenated sentences. The sentence sound files were concatenated in random order and Fast Fourier Transformer (FFT) was performed for these concatenated sentences. The phase of the FFT was randomized and converted back to wave file by means of inverse FFT (IFFT). The noise generated had only little amplitude variation and a frequency spectrum that corresponded with the long-term average spectrum of the sentences. The RMS level of the noise was matched to the same level as that of the sentences. The one third octave spectra of the speech spectrum shaped noise and concatenated sentences are presented in Figure **1**.

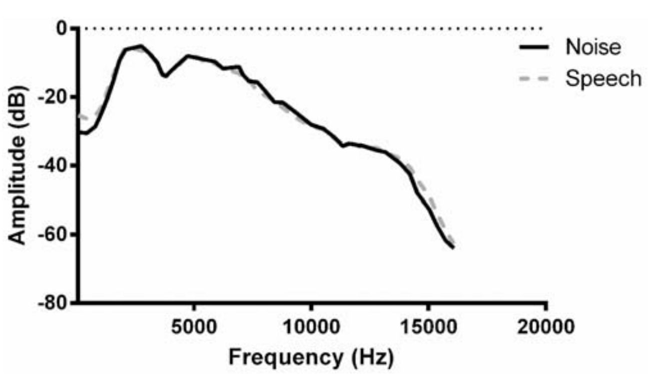


**Figure 1:** One third octave spectrum of noise (black) and concatenated sentences (in grey).

### Experiment II: Selecting an Equivalent Subset of Sentences

The second experiment aimed at selecting the sentences that had comparable intelligibility in the presence of noise. This was ensured through the selection of sentences that yielded similar performance and psychometric function (percentage intelligibility as a function of SNR) in the presence of noise.

### Stimuli

The stimuli consisted of a corpus of 512 sentences and the corresponding speech-shaped noise. Each sentence was digitally mixed with speech spectrum-shaped noise at required SNR using the MATLAB software (MathWorks USA). The noise onset preceded the onset of a sentence by 600 ms and continued till 600 ms after the end of the sentence. The noise was ramped using the Cosine square function with ramp duration of 200 ms. It is believed that the initiation of the noise before the speech will guard against unintended onset effects. A similar protocol has been used for determination of normative data for the development of sentence material in various languages [e. g.18].

### Procedure

A pilot experiment was conducted initially to decide the value of signal to noise ratio (SNR) at which 50% identification score was achieved. This was assessed by presenting the entire collection of 512 recorded sentences to four subjects, natve speakers of hindi with normal hearing listeners, in the presence of -6 and -4 dB SNR. The level chosen here is in accordance with the findings of previous investigators [4,2,8]. The mean percentage of intelligibility was calculated at each SNR for each sentence and an overall mean of all the sentences was calculated based on the number of correctly repeated words. It was observed that the 50% score was obtained at around -4 dB SNR and thus for the equalization procedure, the SNRs selected were -8 dB, -6 dB, -4 dB, -2 dB and 0 dB.

Later equalization was done on 25 subjects. Each subject was seated in a sound-proof room with the test administrator (a qualified audiologist). One subject was tested only at one SNR using all the 512 sentences and a total of 5 subjects were tested at each SNR. The sentences were assigned to nine different play lists and the order effect was counter balanced by testing each subject with a different list each time. The sound files were presented using TOKEN software and routed through the Tucker Davis Technology system using auxiliary input. They were played using a sampling rate of 44.1 kHz with 24-bit resolution. The sound was presented binaurally, using Sennheiser-HD200A headphones, at an intensity of 70 dBSPL. No sentence was repeated and presentation of play-lists was controlled by the test administrator. Breaks were given at appropriate intervals to prevent the influence of fatigue on the results. The subject's task was to repeat the heard sentences or parts of sentences verbally every time. They were also encouraged to guess the content if uncertain.

The percent correct score at five different SNRs (-8, -6, -4, -2, and 0dB) were used to give good psychometric function. Each sentence was presented at all the five SNRs and hence psychometric function was obtained for each sentence. The above SNRs covered the percent correct score from 20% to 90% for each sentence which enabled to estimate the sentence-specific psychometric curve. The psychometric curve was fitted with logistic function, which was similar to the one used by Kollmeier *et al*. [4]. The equation used for logistic function is given below:

$$P = \frac{100}{1 + e^{\frac{-(SNR - SNR\,50)}{S}}}$$

In the equation, SNR 50 denotes the SNR at which 50% score was achieved and *'S'* indicates the spread of the psychometric curve for each respective sentence. The sentences with the psychometric slopes and SNR 50 that fell within one standard deviation from the mean were selected and used in subsequent phases.

### Results

The mean and standard deviation of percentage of words correctly identified at 0,-2, -4, -6 and -8 dB SNR are shown in Table **1**. From the psychometric function, slope m (m=S/25, S is spread of the psychometric curve) and SNR 50 were estimated [4]. The SNR 50 of 512 sentences varied from -12.5 dB to -0.5 dB with a mean of -5.5 dB and standard deviation of 4.0 dB. The estimated slope of these 512 sentences ranged from 3.4% per dB to 38.13% per dB, with an average of 10.5% per dB and a standard deviation of 7.37% per dB. A subset of 200 sentences with slopes and SNR50 that were within one standard deviation from the mean value were selected. These 200 sentences that fell within the stipulated criteria were used in the subsequent phases.

**Table 1: Mean and Standard Deviation (SD) of Word Scoring for Sentence at Five Different SNRs**

| | -8dB | -6 dB | -4 dB | -2dB | 0 dB |
|---|---|---|---|---|---|
| Mean | 25 | 44 | 62 | 82 | 90 |
| SD | 29 | 36 | 36 | 29 | 19 |

### Experiment III: Composition of Optimized Lists

The selected 200 sentences in the previous phase were submitted to an expert in speech analysis for phonetic transcription. The total number of occurrences of each phoneme was determined and then divided by the total number of lists to be compiled (20). The care was taken so that the total number of occurrence of each pnoneme was same across lists and also mean SNR 50 for each list was also more or less same across lists. The final set of sentences consists of 20 lists each lists consisting of 10 sentences. A sample list is provided in the Apendix.

### Results

The total number of phonemes for each list ranged from 187 to 215. Thus, the optimized test lists appeared to be fairly homogeneous with respect to the number of phonemes. The frequency distribution of the phonemes within the test list is plotted in Figure **2**, as average values across test lists and minimum and maximum values of the respective phoneme frequency across all test lists. For comparison, the average phoneme frequency distribution of the Hindi language [19] is plotted as a dashed line.

The chi - square test was done to statistically compare the phoneme distribution of the test lists with that of the reference average phoneme distribution of the Hindi language. Results showed that the phoneme distribution for all the lists is similar to the phoneme distribution in the Hindi language with chi- square values ranging from 370 to 470 and a *p* value showing no significance (p>0.05). This is also evident from Figure **4** where it is seen that no test list deviates substantially from this frequency distribution. One exception is the frequency distribution of phoneme /ha/ which is over-represented in the present speech material. The reason for this could be that the sentences in the present material majorly include

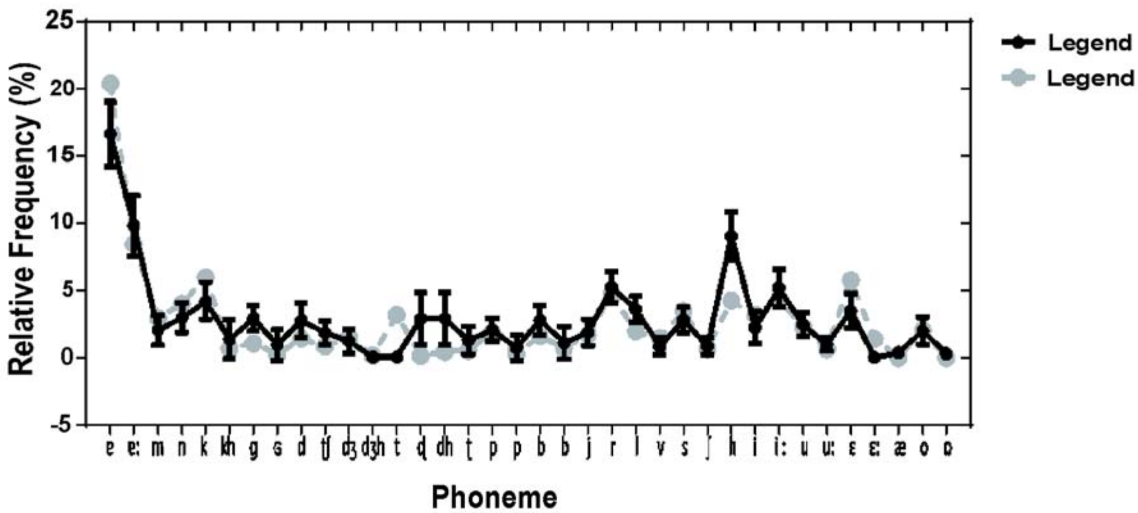


**Figure 2:** The frequency distribution of the phonemes within the test list as average values across test lists and minimum and maximum values of the respective phoneme frequency across all test lists (dark line) in comparison with the average phoneme frequency distribution of the Hindi language (dash line).

statements in the present tense which in Hindi language normally ends with /h/.

### Phase-II: Empirical Evaluationof the Test Material

In order to evaluatethe test material optimized in Phase I of the study, SNR 50 was assessed using adaptive procedure. The test reliability of the developed lists was also assessed.

### Method

The selection criteria for the listeners in this experiment is same as stipulated for participants in Phase1 of the study. A set of 30 new listeners (14 males & 16 females) who had an average age of 24 years (ranging from 19 to 28years) participated in experiment I. Speech recognition in noise was measured using adaptive procedure in an acoustically treated room. Stimulus presentation was controlled using the APEX 3.1 program and was routed through the Tucker Davis Technology system using auxiliary input and they were played at a sampling rate of 44.1 kHz with 24-bit resolution. The sound was presented binaurally, using standard Sennheiser-HD200A headphones as transducers, at an intensity of 70 dBSPL.

The adaptive up-down procedure [20] was employed, where the first sentence in a list was presented at an SNR that would result in recognition below 50% (-8dB in this case). The same sentence was repeatedly presented at higher SNR levels by increasing the intensity (improving) of the sentence in 2dB steps until an entire sentence was repetition correctly. The test administrator compared the text version of the sentence with the listener's repetition and the sentence was rated as correct, if all the words in the sentence were repeated correctly. Once the first sentence was correctly repeated, the next sentence was presented at the same SNR. The presentation levels of subsequent sentences were determined each time by the correctness of the preceding sentence's repetition. If a sentence was repeated correctly, the following sentence was presented at a lower SNR (speech level decreased by 2dB with noise levels kept constant). If a sentence was repeated incorrectly, the following sentence was presented at a higher SNR (speech level increased by 2dB). After the presentation of 10 sentences, the software calculated the SNR 50 as an average of the presentation levels of the fifth to eleventh sentence (even if an eleventh sentence was never presented, its presentation level could be determined according to the correctness of the tenth sentence's repetition). All the 20 test list was presented to each subject and the presentation of the test lists was randomized across participants.

### Results

The average SNR 50 for the 20 lists measured across subjects (N=30) using the adaptive procedure and sentence scoring was -4.5 dB, with a standard deviation of 0.43dB. The list specific average SNR 50 values varied from -4.4 to -4.7 dB with standard deviations ranging between 0.31and 0.53 dB. The list specific SNR 50 relative to the overall SNR 50 across test lists is shown in Figure **3**. To assess whether the mean difference across the lists reached significance,

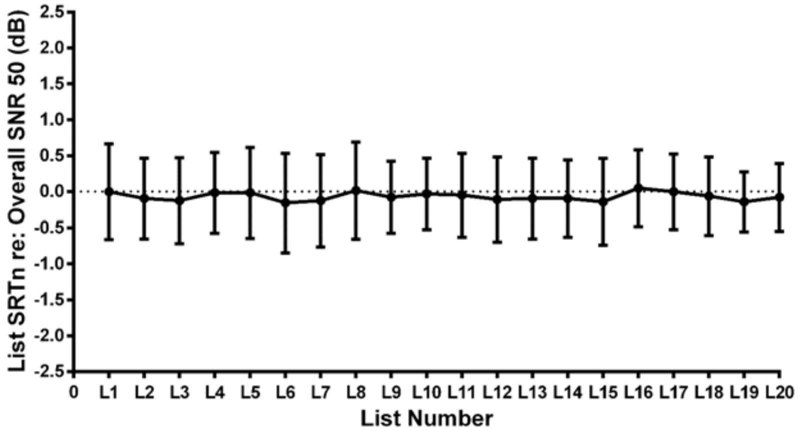


**Figure 3:** The list-SNR50 relative to the overall mean (-4.56 dB). The bars indicate ±1 standard deviation. The overall standard deviation is 0.56 dB.

repeated measures analysis of variance (ANOVA) was performed. The analysis showed that there was no significant difference across lists [F (19,589) =1. 16,p=0. 281].

### Test Reliability

To assess the reliability of SNR 50 measured, a mean of SNR 50 for each listener across 20 lists was calculated. The SNR 50 for each of the 20 lists for each participant was subtracted from the overall SNR 50. The obtained differences can be treated as the deviation of measured SNR 50 from the true SNR 50 for the listener. Figure **4** shows these deviations (N=20×20=400) collected in bins of 0.5 dB. It can be noted that seventy-five percent of the deviations are within ±0. 5 dB of the 'true' SNR 50 and ninety-three percent are within ±1. 0 dB and 99% are within ±1. 5 dB.

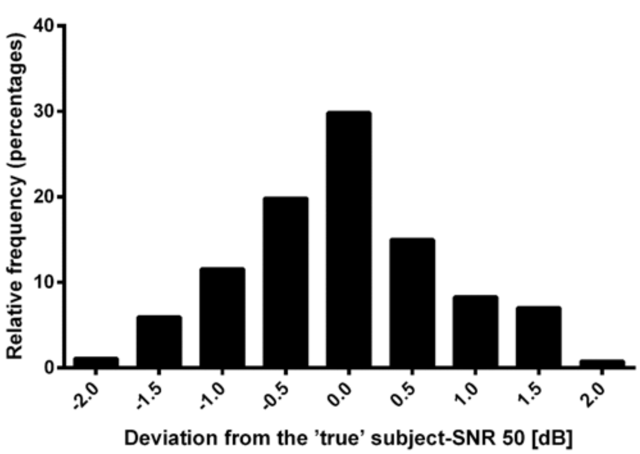


**Figure 4:** Percentage deviation of each single SNR50 assessment from the 'true' SNR50for the listener. Bars show the percentage of measurements with the indicated deviation. Bin size is 0.5 dB.

## DISCUSSION

The aim of the present study was to develop sentence material in Hindi for the assessment of SNR 50. The intelligibility of the selected sentence from the first phase was estimated at 5 different SNR's in the present study. This provided the means to derive the psychometric function parameters, i.e. the slope and the SNR 50. Majority of the previous studies have used these psychometric slopes as an indication of the SNR adjustments needed to equate the intelligibility of the sentences [2,6,8,21] and have found slopes in the range of 9% to 17.9% / dB. Unlike the previous studies, in the present study, the psychometric slopes and SNR 50 were used to identify sentences with similar performance, which enabled the researchers to exclude sentences that differed more than one standard deviation from the mean SNR 50 and psychometric slope. The procedure employed was similar to the procedure employed by Versfeld *et al.* [16]. The procedure of excluding sentences using above method reduced the number of subjects being tested. Whereas, rescaling intensities for sentences to equate intelligibility and verifying the effect of the rescaling, increased the number of testing sessions and subjects [2,8,8,21]. The mean sentence psychometric slope observed in the present study (determined using word scoring) was 10.5% / dB. The results of the present study showed that average SNR 50 is -4.56 which was similar to the score noted by Wong *et al*. [9], who employed method of re-scaling of intensities. Similar results were also noted by Theunissen *et al*. [22] in their study.

The psychometric slope (word scoring) derived in the present study was used for the selection of sentences with similar intelligibility in noise. However in the final test format, sentence scoring was used instead of word scoring. In the final test format, an adaptive procedure with sentence scoring was employed to estimate SNR 50. It should be noted that these lists should not be used in different formother than that evaluated in the present study, i.e. estimating intelligibility at different SNR across lists. This is because the developed lists equivalency was estimated only for SNR 50 and not at other SNRs.Therefore the developed lists should be used only in adaptive procedure and it has to be evaluated before using them at other SNRs and procedures.

The overall SNR 50 of the present study was compared with previous studies in terms of mean and standard deviation are presented in Table **2**. It was noted that the mean SNR 50 across the subjects and for all 20 lists obtained in the present study was -4.56 dB, which is well within the range of SNR 50 obtained across different studies. Moreover, the results of the present study showed a good correspondence with the findings of Versfeld [16] and Wong *et al*., [9] in terms of average SNR 50 and standard deviation. The average standard deviation across lists give an indication of the variability between the lists. The current study found a standard deviation of 0.43 dB, which is well within the range noted in the previous studies (0.27 to 1.2 dB) as presented in Table **2**.

The difference from the overall mean SNR 50 was also calculated for all the 20 list (shown in Figure **4**) to estimate the test reliability. In the present study, the average deviations of all the lists were found to be well within ±0.5 dB (ranging between −0.3 and 0.57) from the overall mean of SNR 50. These results were in close agreement with some of the previous studies [4,18]. Whereas, they are slightly lower than the overall mean reported in the other studies [2,6,7,8,23]. The variability observed across studies could be attributed to the optimization procedure used for creating homogeneous lists.

In majority of previous studies, optimized lists were created based on phonemic balancing [18,24]. However, Theunissen *et al*., [24] observed that the lists prepared with balanced phoneme distribution did not always result in performance equivalence; rather they observed high degree of variability through the use of such a method. On the contrary, results of the present study and those reported by Kollmeier &Wesselkamp [4] have indicated that the sentences selecting by numerical optimization using SNR50, psychometric slope and phonemic content would result in less variance across lists. Hence, in future it is suggested that the development of sentence-based speech tests could use this optimization procedure for the construction of lists.

**Table 2: Overall SNR 50 and Standard Deviation (SD) of Sentence Lists Across Different Studies**

| Authors | Overall SNR 50 (dB) | Average Standard deviation (dB) |
|---|---|---|
| Nilsson *et al*., (1994) | -2.9 | 0.78 |
| Kollmeier & Wesselkamp (1997) | -6.2 | 0.27 |
| Bevilacqua *et al*., (2008) | -4.6 | 0.8 |
| Versfeld *et al*., (2000) | -4.1 | 0.27 |
| Vaillancourt *et al*., (2005) | -3.3 | 0.5 |
| Wong & Soli (2005) | -3.9 | 1.0 |
| Wong *et al*., (2007) MHINT-M | -4.3 | 0.62 |
| Wong *et al*., (2007) MHINT-T | -4.0 | 0.94 |
| Van Wieringen & Wouters (2008) | -7.8 | 1.2 |
| Nielsen & Dau (2009) | -3.15 | 0.5 |
| Hallgren *et al*., (2006) | -3.0 | 1.1 |
| Theunissen | -2.73 | 0.64 |
| Average | -4.2 | 0.72 |
| Minimum | -7.8 | 0.27 |
| Maximum | -2.73 | 1.2 |
| Current Study | -4.56 | 0.43 |

## CONCLUSION

The sentence material developed in Hindi contains highly homogeneous test material. It consists of 20 sentence lists which are highly equivalent with ten short sentences each. The developed test is in many aspects are comparable to sentence lists developed for other languages and it has a comprabale overall SNR 50 (-4.5 dB) and standard deviation (0.43 dB). The deviations of the list SNR 50 from the overall mean is also well within the ±0.5 dB which is considerably lower than that obtained in other sentence list. These lists may be useful for clinical audiology, hearing aid fitting and assessing the communication systems. It should also be noted that the developed material should only be used for assessing SNR 50 using the adaptive procedure.

## ACKNOWLEDGEMENTS

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The authors declare no conflict of interest.

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## APPENDIX

### LIST 1

<table>
<tr><th>Sl. No.</th><th>Sentences in Hindi</th><th>IPA</th></tr>
<tr><td>1.</td><td>प्रवेश द्वार उत्तर दिशा में है।</td><td>prave:ʃ|dva:r|ut̪t̪ar|diʃa:|mẽ| hai</td></tr>
<tr><td>2</td><td>नक्शे में एक नई सड़क है।</td><td>nakʃe| mẽ| ek| nai:| saɽak| hai</td></tr>
<tr><td>3</td><td>ट्रक सड़क से लुढक गया।</td><td>ʈrak| saɽak| se| luɖak| gaja:</td></tr>
<tr><td>4</td><td>दोनो दोस्त हाथ मिला रहे हैं।</td><td>d̪o:no:|do:st̪|ha:t̪h|mila:|rahe|haĩ</td></tr>
<tr><td>5</td><td>लड़का सीढियाँ चढ गया।</td><td>laɽaka:| si:ɖhijã:| tʃaɖh| gaja:</td></tr>
<tr><td>6</td><td>भिखारी को कुत्ते ने काट लिया।</td><td>bhikha:ri:| ko|kut̪t̪e|ne|ka:ʈ| lija:</td></tr>
<tr><td>7</td><td>झिंगुर जंगल में बोल रहे हैं।</td><td>dʒhiŋgur|dʒaŋgal|mẽ|bo:l|rahe|ha ĩ</td></tr>
<tr><td>8</td><td>ादमी सीढियो से फिसल गया।</td><td>a:d̪ami:|si:ɖhijo:| se| phisal| gaja:</td></tr>
<tr><td>9</td><td>च्चे की पाठशाला बहुत दूर है।</td><td>batʃtʃe|ki:|pa:ʈhʃa:la:|bahut̪|du:r|hai</td></tr>
<tr><td>10</td><td>बर्फ पर चलना अच्छा लगता है।</td><td>barph|par|tʃalna:|atʃtʃha:|lagt̪a:|hai</td></tr>
</table>

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