Prediction of Speech Identification Score using Speech Intelligibility Index

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Contents

ABSTRACT

Speech recognition has been found to increase proportionately with speech audibility. Using measures of audibility, it has been possible to determine speech identification through measures such as speech intelligibility index (SII) with and without correction factors such as speech level distortion (SLD) and hearing loss desensitization (HLD). The present study was undertaken to investigate the relationship between speech identification performance and SII among individuals speaking different regional languages. The participants were in the age range from 15 to 60 years representing four different language groups (Kannada, Tamil, Marathi and Hindi). In order to predict speech identification scores (SIS), a non-linear transfer function was derived using all participants with an SII value of 0.0 and above. As this transfer function resulted in an error in prediction, a second non-linear transfer function was derived excluding the ears that had an SII value of 0.1 and below. The validity of the second transfer function was checked on ears having mild to severe degrees of sensorineural hearing loss with either flat or sloping configurations. The results revealed that there was a moderate positive correlation between the SIS predicted utilizing the SII measures and the measured SIS. Further, there was no significant difference between the measured and the predicted SIS from all three SII measures (SII, SII_{SLD}, $SII_{SLD, HLD}$).

Key words: speech identification scores (SIS) and speech intelligibility index measures (i.e., SII, SII_{SLD}, $SII_{SLD, HLD}$), degree of hearing loss

INTRODUCTION

It has been noted that communication problems observed in those with hearing impairment can be overcome by restoring audibility. Making sounds audible has been considered the most critical factor in providing effective amplification and thus effective communication in these individuals (Ching, Dillon, Katsch, & Byrne, 2001).

Ching, Dillon, and Byrne (1998) observed that speech recognition increased proportionately with speech audibility. Their findings were based on the audibility of speech in the form of articulation index (AI) that was calculated from hearing thresholds of listeners and the long-term average speech spectra reaching their ears. This was reported to ensure good speech perception. Thus, they advocated that speech recognition be determined by evaluating audibility of speech.

The AI measure has been used successfully to predict speech recognition performance based on audibility in listeners with normal hearing under a variety of listening conditions such as filtering, noise, distortion and low levels of speech (Pavlovic, Studebaker, & Sherbecoe, 1986). In individuals with hearing impairment too, AI has gained acceptance as a method for estimating the audibility of speech from the long-term average speech spectrum (Dubno & Dirks, 1993). From such studies, it is evident that audibility is an important component for auditory performance.

The potential of AI to predict speech recognition performance was studied by Dugal et al. (1978) in six listeners with noise induced hearing impairment and by Kamm et al. (1982) in twelve listeners with hearing impairment. The findings of these studies suggest that the AI could provide a reasonable model of relative speech recognition performance under different frequency response conditions.

Pavlovic (1984) found that for listeners with moderate hearing loss, the AI predicted speech recognition more accurately than in listeners with higher degrees of hearing impairment. It was concluded that this poor prediction in the group with higher degree of hearing impairment cannot be accounted with only a single global adjustment like the proficiency factor, but frequency dependent correction was also necessary. Kamm et al. (1982) have also found similar results in listeners with mild-to-moderate sensorineural hearing loss.

Aniansson (1974) demonstrated a higher degree of variability between the AI and speech recognition performance. As the speech recognition in two individuals with similar audiograms may vary and the recognition may not improve with intensity, Kamm, Dirks, and Bell (1985) hypothesized that AI may not precisely predict the performance in listeners with hearing impairment of high degree.

The applicability of the Articulation Index (AI) model for characterizing the speech recognition performance of five individuals with normal hearing and 11 individuals with mild-to-moderate hearing loss was determined by Kamm, Dirks, and Bell (1985). Performance-Intensity functions were obtained using a closed-set nonsense syllable test for two frequency responses (uniform and high frequency emphasis). For each individual, the fitting constant Q of the non-linear transfer function relating AI and speech recognition was obtained. The results indicated that the transfer function mapping AI was approximately the same for individuals with normal hearing as well as those with mild-to-moderate hearing impairment with high speech recognition scores. In contrast, the AI model was a poor indicator of speech performance in cases with poor speech recognition scores. The AI procedure was found to be inadequate for predicting performance of individuals with more severe loss or with reduced speech recognition performance.

Similarly, the AI model was used to predict performance of individuals with normal hearing and individuals with hearing impairment by Dubno, Dirks, and Schaefer in 1989. Eighteen individuals with normal hearing individuals and ten individuals with high frequency sensorineural hearing impairment participated in the study. The stimuli included nine synthetic consonant-vowel (CV) syllables formed by pairing three voiced, stop consonants /b, d, g/ with three vowels /a, i, u/. Three additional digitized syllables (/ba, da, ga/), spoken by a male talker taken from the CUNY Nonsense Syllable Test (Resnick et al., 1975) were included to examine the effects of acoustic cues present in natural speech. The majority of the AI predictions for the individuals with hearing impairment fell within ± 2 SD of those with normal hearing. However, the AI tended to overestimate performance of those with hearing impairment. The accuracy of the predictions decreased with the magnitude of the high frequency hearing loss. The results indicated poorer speech recognition among the listeners with hearing impairment. This resulted from reduced audibility within the critical spectral regions of the speech stimuli, with the exception of performance for individuals with severe high frequency hearing loss.

Over the years, various studies were performed to improve the predictive ability of the AI in individuals with hearing impairment (Pavlovic, 1993; Studebaker, & Sherbecoe, 1993; Ching, Dillon, Katsch, & Byrne, 2001). In the modified version of AI by ANSI S3.5 (1997), the term speech intelligibility index (SII) has been used instead of AI. In this procedure, correction factors such as speech level distortion (SLD) and hearing loss desensitization (HLD) were included in the calculation in order to improve the predictability of speech recognition from SII. The inclusion of the SLD and HLD were based on the research by Ching et al. (1997) and Pavlovic, Studebaker, and Sherbecoe (1986) respectively which indicated better predictions with these corrections. While SLD was a correction for the decrease in speech intelligibility at high level of presentation, HLD was a correction for the distortion in speech perception consequent to higher degrees of hearing loss.

Magnusson (1996) used the SII as a basis for predicting the performance of elderly individuals with hearing impairment on a speech-in-noise test. Fifty-seven individuals with sensorineural hearing loss in the age range from 61 to 88 years took part in the study. The SPBN test, consisting of the common Swedish phonemically balanced 50-word lists mixed with speech-weighted noise at a fixed speech-to-noise ratio of + 4 dB, was used for assessing speech recognition performance. The standard SII calculation scheme was compared with modified schemes, and correlations were obtained between measured and predicted scores. The results indicated that the modified calculation scheme, which included corrections for sensorineural hearing impairment and age, was appropriate for evaluating individual speech recognition scores.

Through two experiments, Ching, Dillon, and Byrne (1997) examined the relationship between audibility and speech recognition in individuals with sensorineural hearing losses ranging from mild to profound degrees. Fifty-four participants comprising of 14 listeners with normal-hearing and 40 adult listeners with sensorineural hearing loss participated in the study. Speech scores obtained using filtered sentences were compared to the predictions based on the SII. The SII was found to over-predict performance at high sensation levels, and for many listeners, it under-predicted performance at low sensation levels. In the second experiment, the

SII was modified. The data were best fitted using a method that combined the standard level distortion factor (LDF) which accounted for decrease in speech intelligibility at high presentation levels based on measurements on individuals with normal-hearing with individual frequency-dependent proficiency. This method was evaluated using broadband sentences and nonsense syllables tests. The results indicated that audibility could not adequately explain speech recognition among many listeners with hearing impairment. Considerable variations from audibility-based predictions remained, especially for people with severe losses listening at high sensation levels. The data suggested that, contrary to the basis of the SII, information contained in each frequency band was not additive. The data also suggested that for individuals with severe or profound losses, at the high frequencies amplification should only achieve a low or zero sensation level, contrary to the implications of the unmodified SII.

Ching, Dillon, and Byrne (1998) investigated the relationship between audibility and speech recognition in individuals with different degrees of sensorineural hearing losses ranging from mild to profound. The speech scores measured using filtered sentences were compared to the predictions based on SII. At high sensation levels, the SII was found to over predict the performance whereas at low sensation levels it under predicted the performance. The discrepancy seen between the predicted and the measured scores were more drastic at high sensation levels and at high frequencies. Among the various modifications proposed, the SII incorporating a level distortion factor (LDF) did not adequately explain speech recognition in many listeners with a hearing impairment. The data were best fitted using a method that combined the standard LDF (which accounted for decrease in speech intelligibility at high presentation levels based on measurements in individuals with normal hearing) with individual frequency-dependent proficiency.

To quantify the contribution of audibility to speech intelligibility, Ching, Dillion, Katsch, and Bryne (2001) studied the data of 14 individuals with normal hearing and 40 individuals with hearing impairment. It was seen that the effectiveness of audibility decreased with hearing loss. This decrement was greater at high frequencies than at lower frequencies. Thus, they proposed a modified SII to predict speech intelligibility for people with a wide range of hearing threshold levels. They demonstrated the need to consider loudness and effective audibility in prescribing amplification. Effective audibility, defined as audibility corrected for the effects of level distortion and hearing loss desensitization, was considered as a method of estimating effective audibility from hearing threshold level at different frequencies.

The utility of AI for predicting the performance of individuals with hearing impairment with and without cochlear dead regions was evaluated by Rankovic (2002). This was carried out to see if the AI overestimated the potential benefit of amplification for listeners with dead regions, as the AI did not account for the presence of dead regions. A group of seven participants who exhibited dead regions and a group of three participants who did not exhibit dead regions were included in the study. The participants were presented with lists of vowel–consonant–vowel nonsense disyllables that were low-pass filtered with various cut-off frequencies. It was found that the AI was generally accurate in predicting the consonant recognition test scores of participants irrespective of the presence/absence of dead regions. The author suggested that the audiogram differences accounted for the observed performance differences; it was not necessary to invoke dead regions to explain the speech test results.

Hornsby (2004) noted that the SII, like the AI, quantified the proportion of speech information that was both audible and usable for a listener. A monotonic relationship between the SII and speech understanding was observed, where an increase in SII resulted in an increase in speech understanding. Further, it was also found that the SII could be used to predict speech recognition scores by means of an empirically derived transfer function based on the specific speech materials being used during testing. Though the actual speech score depended on the speech material used and the proficiency of the talker and listener, a single SII value was found to correspond to multiple speech recognition scores.

An extension to the SII model was proposed with the aim to predict the speech intelligibility in both stationary and fluctuating noise by Rhebergen and Versfed (2005). Since the SII model used the long-term averaged speech and noise spectrum as input, all temporal characteristics of the signals were lost. The author provided the extension, incorporating the temporal characteristics of masking noise. The model was adapted such that the SII was calculated within small time frames, after which the average SII was calculated. Using speech reception threshold data from literature, the extension to the SII model could account for speech recognition thresholds in stationary noise, fluctuating speech noise, interrupted noise, and multiple-talker noise. The predictions for sinusoidally intensity modulated noise and real speech or speech-like maskers were found to be better than with the original SII model, but still not very accurate.

Sherbecoe and Studebaker (2003) investigated the validity of audibility index functions based on how well they could predict data from four published studies that presented audio compact disc version of the Connected Speech Test (CST) to individuals with normal hearing and individuals with hearing impairment. The AI values were calculated for the test conditions received by 78 participants with normal hearing and 72 participants with hearing impairment from the selected studies. The observed CST scores and AI values for conditions/participants were plotted and the dispersion of the data compared to the expected range based on critical differences. The AI values for the conditions/participants were also converted into expected CST scores and subtracted from their corresponding observed scores to determine the distribution of the resulting difference scores and the relationship between the difference scores and subject age. Good predictions were obtained for participants with normal-hearing who had been tested under audio-only conditions but not those who had received audiovisual tests. The expected scores for the latter participants were too low when the AI accounted only for audibility and too high when it included the correction for visual cues from ANSI S3.5-1997. All of the individuals with hearing impairment had been tested under audio-only conditions. The mean difference between the observed and the expected scores was comparable with the audio only mean for the individuals with normal hearing when the AI included corrections for speech level distortion (SLD) and hearing loss desensitization (HLD). However, the data of the participants with hearing impairment had greater variability. The predictions also decreased in accuracy when participants age increased beyond 70 years despite the application of an AI correction for age. The results of the study suggested that the AI functions derived for the CST satisfactorily predicted the scores of participants with normal-hearing when they listened in speech babble under audio-only conditions but not when they received visual cues.

A study was carried out by Scollie (2008) with the objective to predict consonant recognition scores using SII. Four adults (aged 27 to 32 years), 15 children with normal hearing (aged 6.6 to 16.9 years), and 14 children with mild to severe hearing loss (aged 7.5 to 18 years) were studied. It was hypothesized that an adult-derived transfer function would be insufficient to predict the scores for children, and that transfer functions for listeners with normal hearing would be insufficient to predict scores for children with hearing impairment. Proficiency corrections for age and hearing loss were explored. A 21-consonant test of speech recognition was applied across 5 SNRs in a forced choice procedure. The SII was computed for each listener and each test condition using the one-third octave band method. Transfer functions were fitted to the data of each group. The results showed that the adult-derived transfer function over-predicted the scores obtained by children. Significant increases in prediction accuracy were obtained when the effects of age and hearing loss were incorporated into the transfer function as proficiency factors. The SII could successfully be used to predict speech recognition scores for both adults and children, once the effects of age and hearing loss were included in the development of a transfer function.

Manjula (2007) developed a software program to compute the SII with the frequency band importance function for CID W-22 words for prediction of speech recognition scores and the frequency band importance function for average speech for selection of hearing aids. This software also incorporated the correction factors, SLD and HLD. It was found that the mean speech recognition scores (SRS) and SII decreased with increasing degrees of hearing loss. It was observed that in case of sloping hearing loss, the mean speech recognition scores and SII value reduced as the slope decreased. It was also noted that, the changes in the SII, SII_{SLD}, $SII_{SLD,\ HLD}$ were also reflected in the speech recognition scores. Hence, it was concluded that SRS and SII provide similar information. Similar results had also been reported earlier by Byrne (1992), and Dubno and Dirks (1989).

In literature, the predictability of speech intelligibility scores in Indian context from SII has been restricted to one regional language, i.e., Kannada. Studies are warranted in order to ensure that SII does accurately predict speech recognition across different regional languages. This would confirm whether a single SII could be used to predict speech recognition scores across regional languages. If a single SII can predict speech recognition scores, speech material to evaluate the latter in different Indian languages need not be utilized. Hence, there is a need to investigate if speech recognition scores can be computed from the SII scores of individuals having hearing impairment, speaking different regional languages. Mili, Sairam, Vani, Manjula and Yathiraj (2004) found that the long-term average speech spectrum for three Indian languages (Kannada, Hindi & Malayalam) did not differ significantly in the mid-frequency range (1000 to 3000 Hz). In the low frequency region (250 to 1000 Hz), the energy was found to be least in Kannada and maximum for Malayalam. This study indicated that the energy concentration was similar in the mid frequency range across the three languages and differed only in the lower frequency range which contribute less to speech perception. The finding of this study indicates that it may be possible for a common regression equation to be used for predicting speech identification score. However, this needs to be established. Thus, the study aimed to obtain a regression equation to predict the speech identification scores from the speech intelligibility index in various degree and configurations of hearing impairment.

METHOD

Participants:

Data were collected from 345 ears of 248 participants representing two Dravidian (Kannada & Tamil) and two Indo-Aryan languages (Marathi & Hindi). Of these, the number of ears for the native languages Kannada, Tamil, Marathi and Hindi were 114, 70, 106 and 55 respectively. The participants for the four language groups were selected from four different centres across the country where the native language was spoken. The native speakers of Kannada, Tamil, Marathi and Hindi were selected from Mysore in Karnataka, Chennai in Tamil Nadu, Pune in Maharashtra and New Delhi respectively. All the participants considered in the study had sensorineural hearing loss and were in the age range from 15 to 60 years with a mean age of 42.87 years. The participants were sub-grouped, based on the three-frequency (500, 1000 & 2000 Hz) pure tone average (PTA), into those having mild (PTA of 26 to 40 dB HL); moderate (PTA of 41 to 55 dB HL); moderately-severe (PTA of 56 to 70 dB HL) and severe (PTA of 71 to 90 dB HL) hearing loss. In addition, two other groups, one with gradually sloping audiogram configuration with a 5 to 12 dB per octave increase in thresholds and sharply sloping configuration with 15 to 20 dB per octave increase in thresholds (Carhart, 1945; Lloyd & Kaplan, 1978), were also considered.

The participants had post-lingually acquired hearing loss, with the ability to perform open-set speech identification tasks. In addition, none of the participants considered had complaints of any psychological or cognitive problem. Informed consent was obtained from the participants, prior to carrying out any evaluation on them.

Instruments and speech material:

Calibrated dual channel audiometers were used for obtaining air-conduction and bone-conduction thresholds. The make and model of audiometers used varied from centre to centre (Table 1).

Table 1: Audiometers and transducers used at the four different centres

Centre	*Audiometer*	*Headphone*	*Bone Vibrator*
Mysore	Madsen Orbiter 922 (Ver. 2)	TDH 39	B-71
Chennai	Madsen Orbiter 922 (Ver. 2)	TDH 39	B-71
Delhi	Madsen Itera-II	TDH 39	B-71
Pune	Madsen Orbiter 922 (Ver. 2)	TDH 39	B-71

A calibrated immittance meter was used to rule out the middle ear pathology. A personal computer, connected to the auxiliary input of the audiometer, was used for the presentation of the recorded speech material as well as for calculating the Speech Intelligibility Index (SII).

To determine the Speech Identification Scores (SIS) in Kannada, Tamil, Marathi and Hindi, recorded phonemically balanced tests were presented at 40 dB SL (reference PTA). The tests used were 'Phonemically balanced (PB) Kannada word test' (Yathiraj &Vijayalakshmi, 2005), 'Picture speech identification test for children in Tamil' (Bhoominathan, 1999), 'Monosyllabic word list in Marathi' (Vanaja & Singh, 2009) and 'Speech identification test for Hindi speaking children' (Choudary, 2003). Although some of the speech tests used had been developed for children, they were used on the adults evaluated in the study, as all the test items were familiar to and in the the vocabulary of adults. All the four tests had at least two equivalent phonemically balanced lists with 25 words in each list. The familiarity of the test items and normative data had been established at the time of development of the tests.

To calculate the Speech Intelligibility Index (SII), the software program developed by Manjula (2007) was utilized. The software program used a formula similar to that developed by French and Steinberg (1947), with frequency band importance functions for CID-W 22 words (SII). The procedure for computer application was derived from the methods adopted by Popelka and Mason (1987) and Pavlovic (1991). The information on audibility of speech for the participant was determined by using information regarding the hearing thresholds, long-term average speech spectra and speech dynamic range. This was obtained in decibel (dB) for nine different frequencies. These frequencies bands were 250, 500, 750, 1000, 1500, 2000, 3000, 4000 and 6000 Hz. In addition to calculating the basic SII, the software program was also used to compute the SII_{SLD} to correct for speech level distortion (SLD), as well as the $SII_{SLD,\ HLD}$ to correct for both speech level distortion as well as hearing loss desensitization (HLD).

Test environment:

All the audiological tests were carried out in sound treated double-room suites. The noise levels in the test facilities were reported to be as per the recommendations of ANSI standards (S3.1-1991).

Procedure:

The evaluation was carried out in two phases, Phase I and Phase II. The former phase consisted of three steps that included Selection of participants; Obtaining Speech Identification Scores; and computation of Speech Intelligibility Index. Phase II, included two steps, development of transfer function for prediction of SIS from SII measures and verification of the transfer function.

Phase I:

Step 1: Selection of participants

The participants were selected based on their air-conduction pure-tone thresholds obtained using a Modified Hughson-Westlake procedure (Carhart & Jerger, 1959). For each of the participants, the air-conduction thresholds were established for pure tones between 250 Hz and 8000 Hz, at octave and mid-octave intervals. The bone-conduction thresholds were obtained between the 250 Hz and 4000 Hz. This was done for each test ear of the participants. Based on the pure-tone thresholds, the participants were classified into different subgroups. The participants with a flat audiogram configuration (less than 5 dB rise or fall per octave) were classified into four groups based on the degree of hearing loss (mild, moderate, moderately-severe & severe) using Clark's classification (Katz, 1985). Additionally, those with a sloping audiogram were classified into two groups (gradual and sharply sloping). Using the classification given by Carhart (1945), audiograms were considered as having a gradual slope if there was a 5 to 12 dB threshold increase per octave and a sharp slope if there was a 15 to 20 dB threshold increase per octave. Details of the participants from the four centres are given in Table 2.

Table 2: Number of ears in each evaluated in the four language groups

Sub-Groups	**Number of Ears per Language Group**				
	Kannada	**Tamil**	**Marathi**	**Hindi**	**Total**
Mild	20	20	20	10	70
Moderate	20	1	20	7	48
Moderately-Severe	20	9	20	5	54
Severe	20	6	20	3	49
Gradual Slope	20	20	19	20	79
Steep Slope	14	14	7	10	45
Total	**114**	**70**	**106**	**55**	**345**

Step 2: Procedure for determining the Speech Identification Scores

Each language group was tested using the appropriate speech identification test. The CD version of the PB word test was presented at 40 dB SL (reference PTA) via headphones. Wherever the stimuli could not be presented at 40 dB SL (reference PTA) due to restrictions posed by the audiometric limits, it was presented at the maximum level of the audiometer, provided it was 10 dB below the uncomfortable level (UCL) of the participant. The calibration tone of each test was used to adjust the VU meter to ‘0’ prior to the presentation of the test items. When data were collected from both the ears of the participants, half of the participants were tested in their right ear first and the other half in the left ear first to avoid any ear order effect. Different equivalent lists of the particular speech identification test were used to test each ear of the participants to avoid familiarity of the list playing a role. The participants were instructed to repeat the words heard and their responses were noted by the tester. A score of ‘1’ was given for every correct repetition of the word and a score of ‘0’ for every wrong response. The total number of words correctly repeated in the list was calculated for each ear to determine the speech identification score, maximum score being 25.

Step 3: Procedure for computation of Speech Intelligibility Index (SII)

The software program developed by Manjula (2007) was employed for calculating the SII. This was done independently for each ear that was evaluated by entering the air-conduction thresholds established for the frequencies 250 Hz, 500 Hz, 750 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz, 4000 Hz and 6000 Hz into the software program. The SII, SII_{SLD}, as well as the $SII_{SLD, HLD,}$ were tabulated for each ear.

Phase II

Step 1: Development of the transfer function for prediction of SIS from SII measures:

The pure-tone air-conduction thresholds and the SIS measured for the test ears of the participants were utilized for derivation of a transfer function. A set of nonlinear transfer functions was obtained for from 75% of the data obtained that represented all the four languages and the different degrees and audiogram configurations. This transfer function was used to predict the SIS.

Step 2: Verification of the transfer function:

The nonlinear regression equations obtained to predict the SIS were verified on the remaining 25% of the data that had been collected. These data were not included while deriving the transfer functions. This 25% of the data however, was representative of all the degrees and configurations of hearing impairment in the four languages considered in the study.

Analyses

The tabulated data were subjected to statistical analysis using SPSS version 18. Initially, descriptive statistics were obtained to compare the degree of hearing loss and the configuration with the SII, SII_{SLD} and $SII_{SLD, HLD}$. Correlation of the measured SIS with SII, SII_{SLD} and $SII_{SLD, HLD}$ was obtained to evaluate if the SIS could be predicted from the measures of SII. Further, the correlation and paired sample t-test were done to find the agreement and difference between the measured and the predicted SIS. The agreement and difference between the measured and the predicted SIS were evaluated for both the transfer equations that were derived (one including all the participants and one excluding those with SII scores of 0.01 and below).

RESULTS

For the prediction of speech identification scores (SIS) from speech intelligibility index (SII), the data obtained from 345 ears of 248 participants with sensorineural hearing loss were initially analyzed. The pure-tone thresholds and the SIS obtained from 75% of the test ears of the participants from the four regions studied (Mysore, Chennai, Pune, and Delhi) were employed to derive a common regression equation for prediction of SIS in different languages considered in the study. The SII, SII_{SLD} and $SII_{SLD,\ HLD}$ were computed from the hearing thresholds of the participants. The correction factors such as SLD and HLD were incorporated to the SII to check their influence on speech perception. Before deriving the regression equation, correlation analysis between the SII measures and SIS was done.

The mean and standard deviation (SD) for the SII measures and the SIS for the participants were determined. This was done for the data of all four language-groups combined (Table 3) and separately for the participants belonging to each language group (Table 4a, 4b, 4c, & 4d).

Table 3: Mean and SD of SII, SII_{SLD}, $SII_{SLD,\ HLD}$ and SIS for all participants

Degree / configuration		*N (ears)*	*SIS*		*SII*		*SII_{SLD}*		*$SII_{SLD,\ HLD}$*	
			Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Degree of hearing loss	Mild	70	22.84	2.03	0.85	0.14	0.77	0.13	0.66	0.12
	Moderate	48	18.87	3.19	0.36	0.15	0.33	0.13	0.27	0.12
	Moderately Severe	54	16.89	4.17	0.11	0.2	0.1	0.18	0.09	0.16
	Severe	49	13.86	4.71	0.04	0.20	0.04	0.19	0.04	0.17
Configuration of audiogram	Gradual sloping	79	19.28	3.23	0.38	0.27	0.35	0.24	0.31	0.22
	Steeply Sloping	45	17.63	5.17	0.41	0.2	0.38	0.19	0.36	0.17
Total		345	18.56	4.61	0.39	0.33	0.35	0.3	0.31	0.2

Table 4a: Mean and SD of SII, SII_{SLD}, $SII_{SLD, HLD}$ and SIS for participants tested in Marathi

Degree / configuration		*N (ears)*	*SIS*		*SII*		SII_{SLD}		$SII_{SLD, HLD}$	
			Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Degree of hearing loss	Mild	20	22.6	1.98	0.71	0.25	0.64	0.24	0.65	0.11
	Moderate	20	18.3	2.81	0.37	0.1	0.33	0.09	0.28	0.07
	Moderately Severe	20	15.45	2.58	0.06	0.05	0.06	0.05	0.05	0.04
	Severe	20	10.9	2.22	0.0	0.0	0.0	0.0	0.0	0.0
Configuration of audiogram	Gradual sloping	19	18.68	2.67	0.48	0.19	0.44	0.17	0.39	0.15
	Steeply Sloping	7	17.42	4.19	0.29	0.14	0.46	0.12	0.43	0.1
Total		106	17.19	4.56	0.34	0.3	0.3	0.27	0.28	0.25

Table 4b: Mean and SD of SII, SII_{SLD}, $SII_{SLD, HLD}$ and SIS for participants tested in Kannada

Degree / configuration		*N (ears)*	*SIS*		*SII*		SII_{SLD}		$SII_{SLD, HLD}$	
			Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Degree of hearing loss	Mild	20	22.05	2.37	0.83	0.11	0.76	0.1	0.64	0.10
	Moderate	20	18.1	3.65	0.32	0.15	0.29	0.13	0.24	0.11
	Moderately Severe	20	16.8	4.91	0.06	0.06	0.05	0.06	0.04	0.05
	Severe	20	15.55	3.42	0.0	0.0	0.0	0.0	0.0	0.0
Configuration of audiogram	Gradual sloping	20	18.55	3.07	0.34	0.27	0.31	0.24	0.28	0.2
	Steeply Sloping	14	17.93	3.27	0.31	0.16	0.29	0.15	0.28	0.14
Total		114	18.17	4.03	0.31	0.31	0.28	0.28	0.24	0.24

Table 4c: Mean and SD of SII, SII_{SLD}, $SII_{SLD, HLD}$ and SIS for participants tested in Tamil

Degree / configuration		*N (ears)*	*SIS*		*SII*		SII_{SLD}		$SII_{SLD, HLD}$	
			Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Degree of hearing loss	Mild	20	23.85	1.84	0.87	0.08	0.78	0.07	0.68	0.08
	Moderate	1	23	0	0.27	0	0.24	0	0.19	0
	Moderately Severe	9	20.78	4.24	0.05	0.06	0.04	0.06	0.04	0.05
	Severe	6	16.67	8.26	0.0	0.0	0.0	0.0	0.0	0.0
Configuration of audiogram	Gradual sloping	20	21.5	3.98	0.44	0.35	0.39	0.31	0.36	0.27
	Steeply Sloping	14	17.07	8.42	0.34	0.24	0.31	0.22	0.29	0.2
Total		70	20.8	5.73	0.45	0.37	0.41	0.34	0.36	0.29

Table 4d: Mean and SD of SII, SII_{SLD}, $SII_{SLD, HLD}$ and SIS for participants tested in Hindi

Degree / configuration		*N (ears)*	*SIS*		*SII*		*SII_{SLD}*		*$SII_{SLD, HLD}$*	
			Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Degree of hearing loss	Mild	10	22.9	0.74	0.94	0.03	0.85	0.03	0.76	0.04
	Moderate	7	20.71	1.70	0.4	0.15	0.35	0.11	0.29	0.11
	Moderately Severe	5	16	1.73	0.08	0.09	0.08	0.08	0.07	0.07
	Severe	3	16.67	7.23	0	0	0	0	0	0
Configuration of audiogram	Gradual sloping	20	18.35	1.93	0.33	0.23	0.3	0.21	0.28	0.19
	Steeply Sloping	10	19.3	1.49	0.55	0.12	0.5	0.11	0.47	0.09
Total		55	19.34	2.94	0.45	0.32	0.41	0.29	0.37	0.26

To verify the extent of relationship of the SIS with the SII, SII_{SLD} and $SII_{SLD, HLD}$ as well as to determine if this relation was statistically significant, Pearson's product-moment coefficient of correlation was measured. Table 5 gives the correlation of the SII, SII_{SLD}, $SII_{SLD, HLD}$ with SIS.

Table 5: Correlation of SII, SII_{SLD}, $SII_{SLD, HLD}$ with SIS.

	Pearson's Correlation
SII & SIS	0.568**
SII_{SLD} & SIS	0.565**
$SII_{SLD, HLD}$ & SIS	0.554**

**$p < 0.05$

Since a statistically significant, moderate positive correlation was obtained between the SIS and the SII measures, regression equations relating the latter to the former were derived. In addition, the validity of the regression equation that was derived was verified. Thus, the results are provided under the two headings:

I. Derivation of regression equation for prediction of SIS from SII.

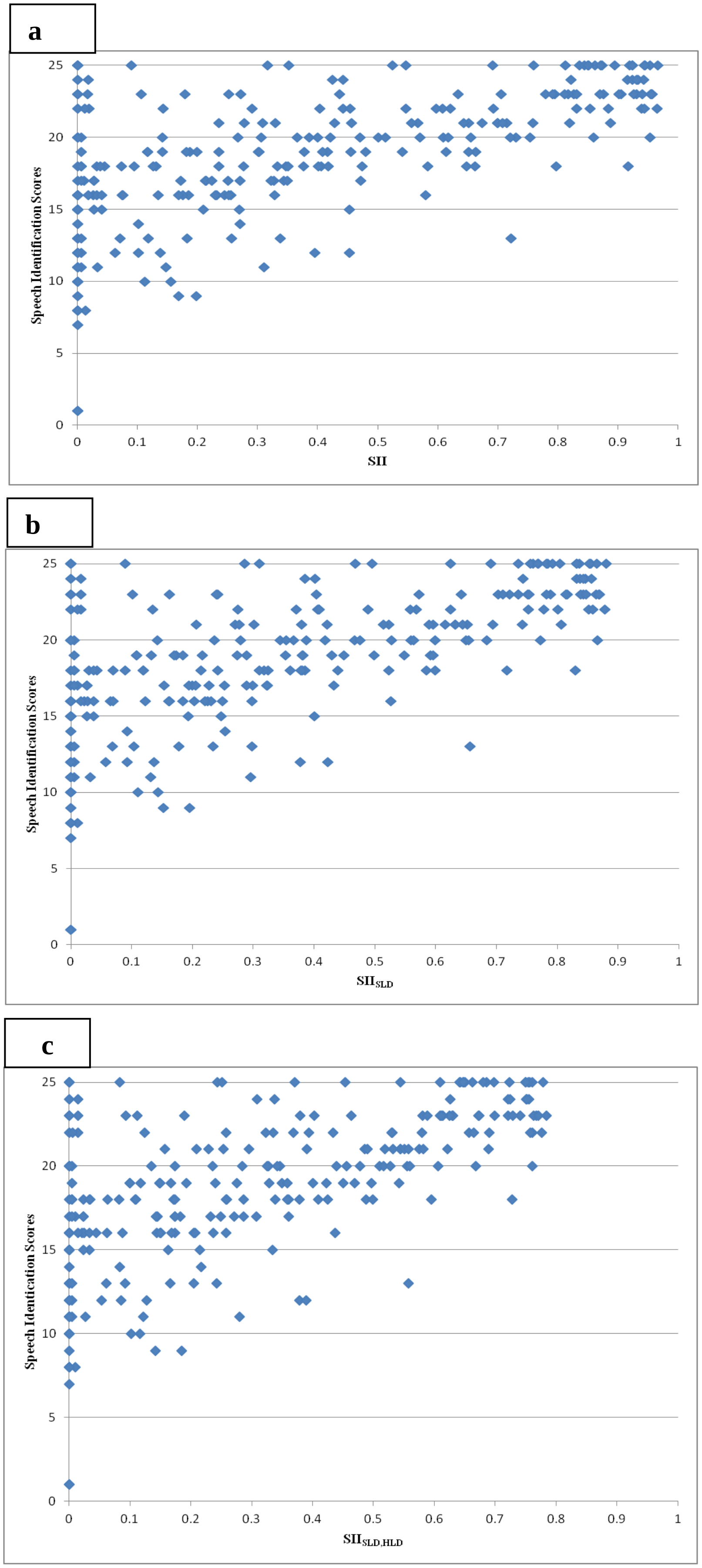
II. Verification of the validity of the regression equation (comparison of the measured SIS with the predicted SIS).

I. Derivation of regression equation for prediction of SIS from SII, SII_{SLD} and $SII_{SLD, HLD}$:

Non-linear regression analysis was done to derive three equations to predict SIS from SII, SII_{SLD} and $SII_{SLD, HLD}$ respectively. A least square procedure was used to minimize the root mean square errors between the observed and predicted SIS. The regression equations, for 75% of the data from the four centres grouped together, were derived using the Table Curve 2D (version 5.01) of the Systat software.

Two sets of regressions equations were derived. The initial set of regression equations were derived using the data of 260 ears (75% of the ears) that included all those who had SII of 0.0 and above. This regression equation resulted in an error wherein the minimum predicted SIS was equal to 14 (approximately 50%) even in those who obtained an SII value of 0.00. This error occurred due to the presence of a coefficient 'a' that had a value of 14 and was added to the remaining part of the equation [$SIS = a+b\ (SII)^c$; $SIS = a+b\ (SII_{SLD})^c$; and $SIS = a+b\ (SII_{SLD, HLD})^c$]. Hence, a second regression equation was derived that included only the data of those with SIIs above 0.1 from among the same 75% of the ears. This included the data of 178 ears as the data of 82 ears was excluded. Those with an SII value of ≤ 0.1 were eliminated as they had highly variable SIS, as can be seen in Figure 1a, b, and c. As this second non-linear power regression equation did not result in an error as was seen in the first regression equation, it was retained. From Figure 2 it is evident that with the elimination of the ears with SII values of 0.1 and less resulted in the majority data fitting into the 95% bounds.

Figure 1: Relationship between SII & SIS (a), SII_{SLD} & SIS (b) and $SII_{SLD, HLD}$ & SIS (c) for those with SII values from 0.0 and above



The derived transfer functions relating the SIS with the SII, SII_{SLD} and $SII_{SLD, HLD}$ i.e., after the elimination of the data points with an SII, SII_{SLD} and $SII_{SLD, HLD}$ of 0.1 and less, are given below:

$$SIS = a*(SII)^b$$

$$SIS = a*(SII_{SLD})^b$$

$$SIS = a*(SII_{SLD, HLD})^b$$

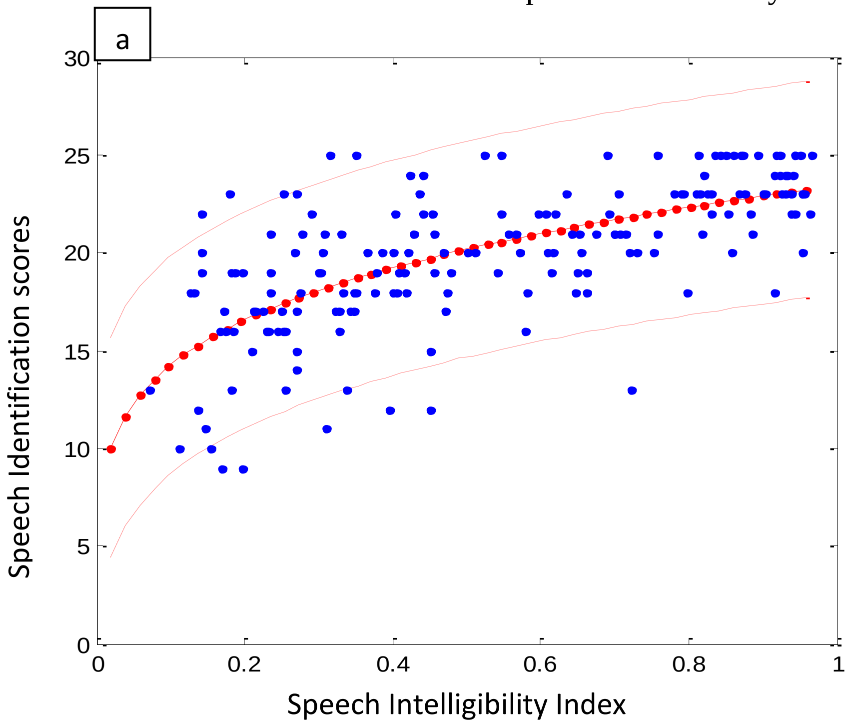
The values of the constants a and b used in the equations are given in Table 6.

Table 6 : Values of fitting constants, F Ratio, Standard error estimate (SEE) for deriving SIS from SII, SII_{SLD} and $SII_{SLD, HLD}$ for all language groups combined

	a	*b*	r^2	*F ratio*	*SEE*
SIS from SII	23.42	0.22	0.44	142.87	2.78
SIS from SII_{SLD}	23.93	0.22	0.44	138.52	2.8
SIS from $SII_{SLD, HLD}$	24.55	0.21	0.42	130.22	2.83

From Table 6, it can be observed that similar r^2 values were obtained from the SII without and SLD correction factor. However, when both SLD and HLD were incorporated, the r^2 value dropped.

Figure 2: Relationship between SII & SIS (a), SII_{SLD} & SIS (b) and $SII_{SLD,\ HLD}$ & SIS (c) for those with SII values from 0.1 and above with the 95% prediction boundary



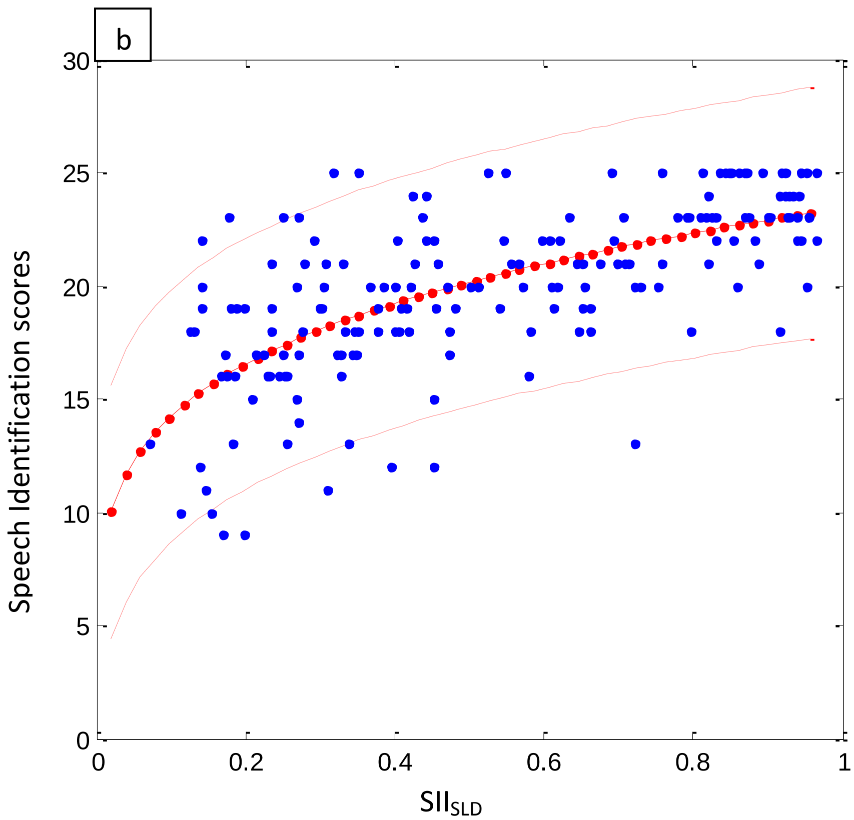
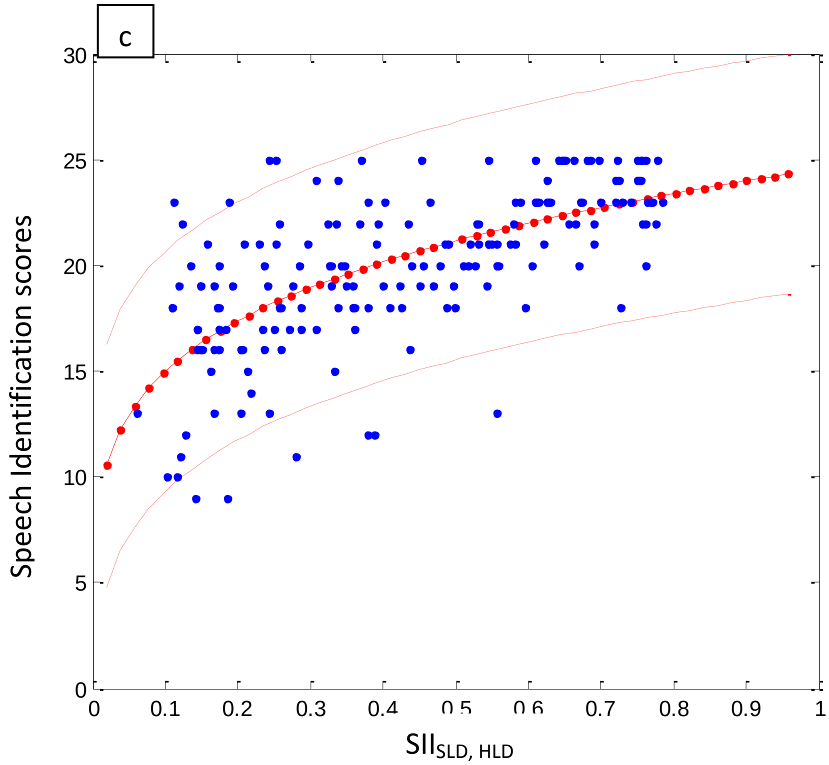


Figure 2 continued….



II. Verification of the validity of the regression equation

The transfer functions that were obtained were verified by predicting the SIS from the SII, SII_{SLD} and $SII_{SLD, HLD}$ from the remaining 25% of the data. Initially, this verification was done for the each of the four languages separately. The Bland-Altman test of association and difference indicated that though the association was high for each of the languages, the bias was also high (Kannada: -0.8 to -0.9; Marathi: 1.7 to 1.8; Tamil: -1.6 to -1.7; Hindi: 0.9 to 1.1). The variability in the bias across the four language groups could have occurred due to the heterogeneity in the population studied. Despite the participants in the four language groups having similar degrees and audiogram configurations, the pathophysiology could have varied resulting in the variable bias. However, when the data of the four languages were combined, the bias was reduced while the association level was maintained. This probably occurred since some language groups had a positive bias (Marathi & Hindi) and others had a negative bias (Kannada & Tamil). This reduction could have been on account to the increase in sample size, and other variables. On account of this, it was decided to combine the data of the four languages for further analyses. The mean and SD of the measured SIS and the SIS predicted from SII, SII $_{SLD}$ and SII $_{SLD, HLD}$ for the combined data are provided in Table 7.

Table 7: Mean and SD values of measured and predicted SIS

SIS	**Combined scores (N = 62)**	
	Mean*	**SD**
Measured	19.61	3.52
Predicted from SII	19.82	2.52
Predicted from SII_{SLD}	19.89	2.48
Predicted from $SII_{SLD, HLD}$	19.89	2.52

* Maximum value of SIS = 25

In order to evaluate whether the equations predicted the SIS adequately, the measured and predicted SIS were compared. Agreement and difference between the predicted and measured SIS were evaluated using Pearson's correlation and paired t-test.

The correlation between the measured and predicted SIS was measured using Pearson's product moment correlation. From Table 8, it is observed that there is a moderate positive correlation between the measured and predicted SIS.

Table 8: Correlation between measured SIS and predicted SIS

	r
Measured SIS and SIS Predicted from SII	0.65**
Measured SIS and SIS Predicted from SII_{SLD}	0.64**
Measured SIS and SIS Predicted from $SII_{SLD, HLD}$	0.6**

**: $p < 0.001$

The mean difference between the measured and predicted SIS was evaluated using the paired samples t-test. The result indicated that there was no statistically significant difference between the measured and predicted speech identification scores when the prediction was done using the transfer functions for SII, $SII_{SLD,}$ and $SII_{SLD, HLD}$ [SII: $t(61) = -0.606$, $p > 0.05$; SII_{SLD}: $t(61) = -0.8$, $p > 0.05$; $SII_{SLD, HLD}$: $t(61) = -0.762$, $p > 0.05$].

Figure 3: Results of Bland-Altman test for agreement / scatter plot (a, c, e) and difference (b, d, f) for the 25% of the overall data with values < 0.1 excluded

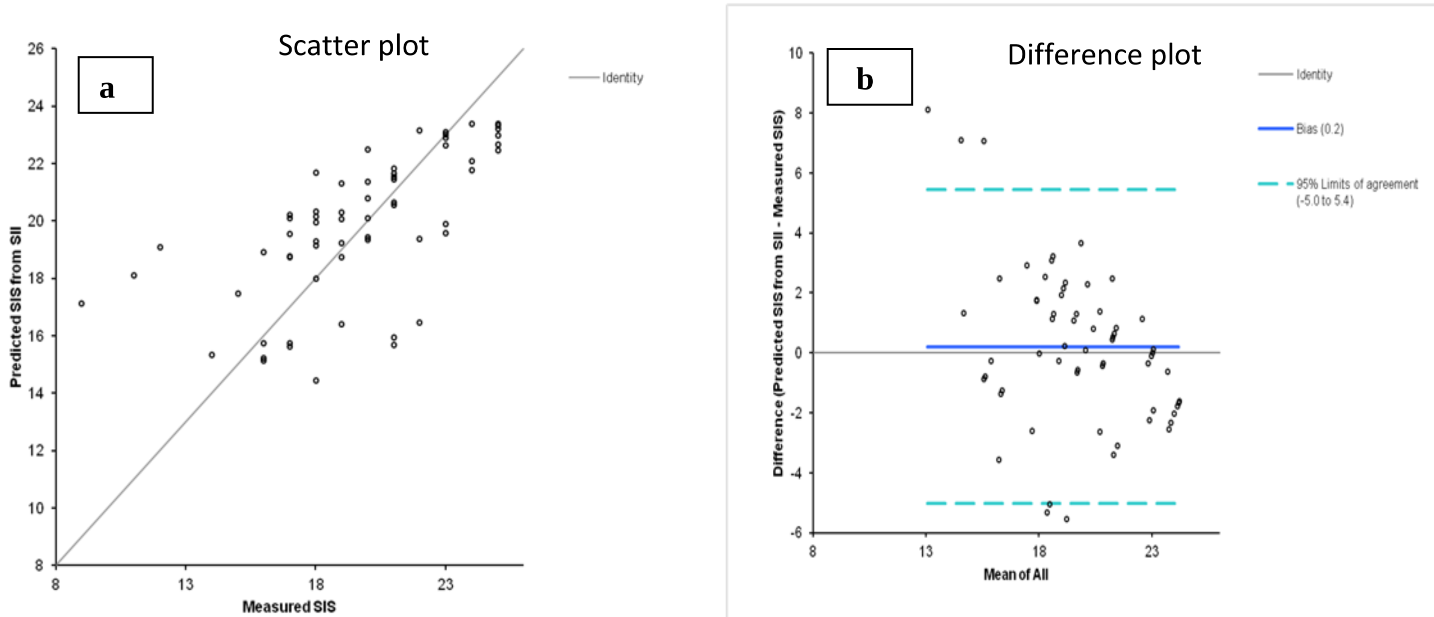
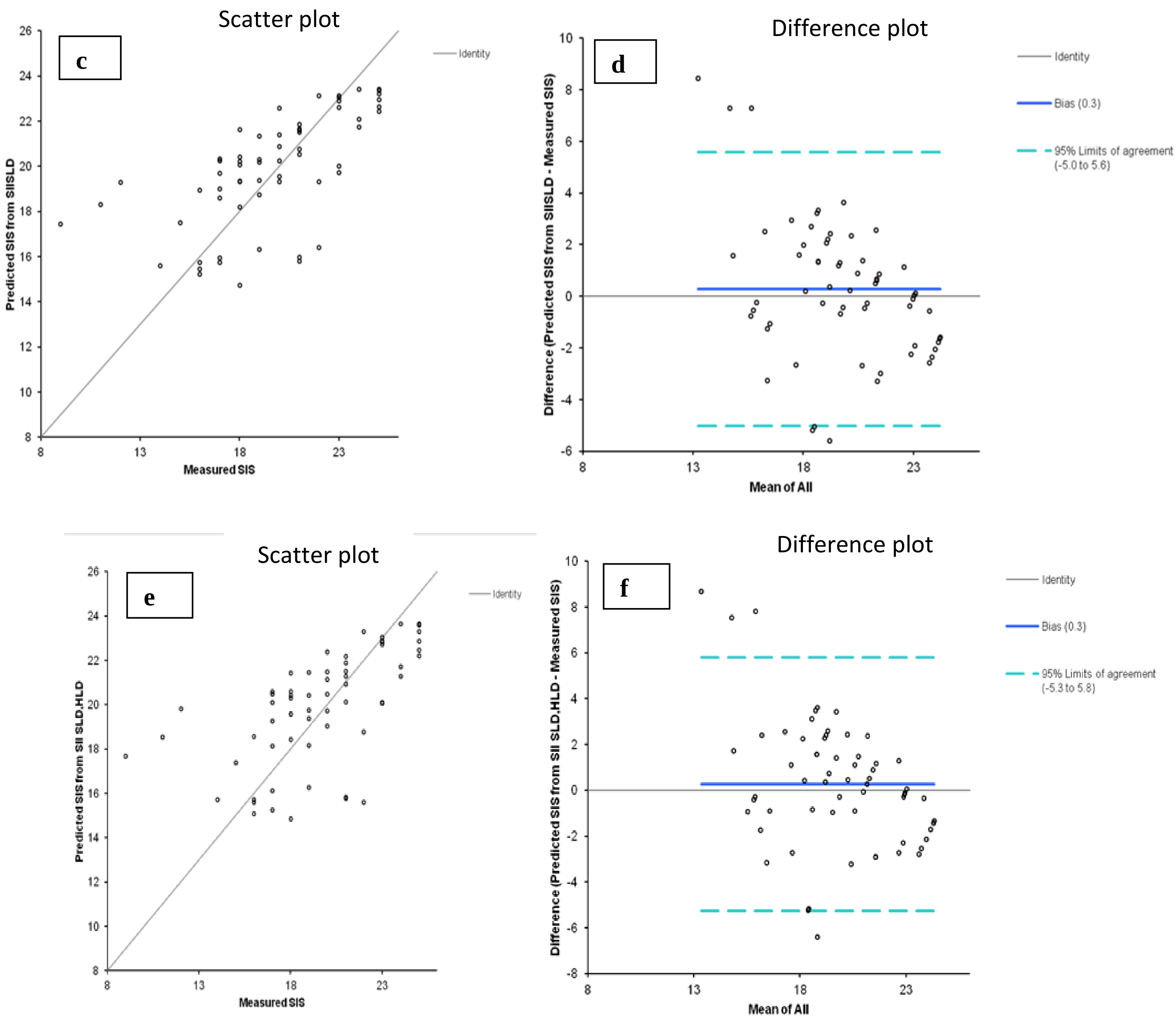


Figure continued …..



From Figure 3 a, c, and e it can noted that the agreement between the measured and predicted SIS was high. Further, from the difference plots (Figure 3 b, d, & f) it is evident that the difference between the measured and the predicted SIS was less since the bias values were close to zero, ranging from 0.2 to 0.3.

DISCUSSION

From the mean and SD of all the participants, categorised in terms of the degree of hearing loss and the audiogram configuration, (Tables 3, 4a, 4b, 4c, & 4d) it is evident that the trend observed in the mean SIS and mean SII scores were similar. The mean SII and the SIS values reduced as the degree of hearing loss increased. This proportionate change was observed for all three SII measures that were calculated (SII, SII_{SLD} and $SII_{SLD, HLD}$). A similar pattern was seen for each of the language groups that were studied (Kannada, Tamil, Marathi & Hindi). These results confirm that variations in audibility (SII) are reflected by variations in SIS and this occurs immaterial of the languages considered in the study. This occurs when the SII is greater than 0.1 (Figure 1).

These results are in consensus with that reported in literature. It has been noted by Dubno, and Dirks (1989), Dirks, Bell, Rossman, and Kincaid (1986), Humes (1991) and Pavlovic (1984) that improved audibility is strongly related to SIS. Dillon (1993) had reported that as the degree of hearing loss increases above the moderately-severe level, the presence of distortions such as reduced frequency and temporal resolution makes it less likely that the audible energy will continue to be equally useful. This finding is consistent with the results of Byrne (1992), Rankovic (1991) and that of the present study.

In the present study, similar r^2 values were obtained from the SII without and with SLD correction factor. However, the r^2 values reduced when both SLD and HLD were incorporated. This occurred because the transfer functions were derived using the data from SII values of greater than 0.1. Ching et al. (2001) recommended that HLD be used for individuals with hearing loss greater than 70 dB HL. In the current study, the elimination of those with SII values of 0.1 and below, would probably have excluded the majority of individuals with losses greater than 70 dB HL, thus making it unnecessary to use the HLD correction.

In contrast, unlike what was seen for the different degrees of hearing loss, in individuals with gradual and steeply sloping audiograms, variations in the SIS were not reflected in the SII measures. With increase in the slope of the audiogram, while the SIS decreased, the SII increased. This was seen for the overall scores (Tables 3). This variation differed depending on the regional language (Tables 4a, 4b, 4c, & 4d).

Verification of the validity of the regression equation done by comparing the measured SIS with the predicted SIS, indicated that the mean values of the measured and the predicted SIS varied (Table 7). However, the measured SIS had a larger SD when compared with the predicted SIS, indicating that the variability in scores were more in the former. This indicates that when the SIS is predicted, an exact duplication of the scores does not take place. This variation may be on account of variables such as the pathophysiology of the condition and the inherent heterogeneity in the population that were not accounted for in the transfer function that were derived.

The difference between the measured and the predicted SIS was least when predicted from SII and most when predicted from $SII_{SLD,\ HLD}$. This suggests that from the SII, without incorporation of the correction factors, the SIS can be predicted the best in those having degrees of hearing loss and audiogram configurations included in the present study.

The correlation between the measured and predicted SIS was positive, moderately-strong and was highly significant. This was seen for predictions from the SII with and without the SLD correction factor. However, the correlation reduced with addition of the HLD correction factor. This indicates that in the population studied, the SII can predict the SIS without any correction factor unlike that recommended by Ching et al. (2001) and Studebaker, Sherbecoe, McDaniel, and Grey (1997).

The difference between the measured and predicted SIS was found not to be statistically significant when predicted from SII and SII_{SLD} and $SII_{SLD, HLD}$. This once again highlights that the non-linear power functions were able to predict the SIS in individuals with a hearing impairment, even when the SLD and HLD correction factor were not included in the transfer function. The HLD correction factor, recommended by Ching et al. (2001) was meant only for those with severe and profound hearing losses. In the present study, by eliminating those having SII scores of 0.1 and below, most of the individuals with severe hearing loss were excluded. Hence, the HLD correction had no impact and resulted in no difference between the measured and the predicted scores using the three SII measures.

The results of the Bland-Altman test of agreement indicted that the difference between the measured and the predicted speech identification scores were with in the 95% limits of agreement.

The findings of the present study are in consensus with that reported in the literature. Similar findings have also been reported on participants with a mild to moderate hearing loss (Kamm, Dirks, & Bell, 1985). Kamm et al. noted that in all but one subject with a moderate hearing loss and reduced speech identification scores, the AI was a good predictor of performance. Similar findings have been observed in listeners with moderate, severe and profound hearing losses (Pavlovic, 1984; Ching, Dillon & Byrne, 1998) and listeners with steeply sloping high-frequency hearing losses (Skinner, 1980; Rankovic, 1991). Magnusson, Karlsson, and Leijon (2001) also noted a good agreement between the predicted and measured speech intelligibility, substantiating the utility of SII in predicting SIS.

The findings of the present study and that of research available in the literature, highlight that SII with or without correction factors, is useful in predicting SIS. In the present study, it was found that the SII measures were good predictors for those individuals with an SII score > 0.1, as the variability in SIS was found to be high in those with scores ≤ 0.1.

CONCLUSION

The study aimed to investigate if speech identification scores can be predicted using a non-linear transfer function relating SIS and SII scores of individuals having sensorineural hearing impairment. The study also aimed to see if the same transfer function could be used for individuals speaking different regional languages. From the data collected from 345 ears of individuals speaking Kannada, Tamil, Marathi, and Hindi, it was found that the mean SII and the SIS values reduced as the degree of hearing loss increased. This was seen in the combined data as well as the language specific data studied. However, in individuals with gradual and steeply sloping audiograms with increase in the slope of the audiogram the SIS decreased but the SII increased. The SIS predicted using the transfer function derived from 75% of the data was found to have a moderately-strong positive correlation with the predicted SIS that was highly significant in the remaining 25% of the data. Further, no significant difference was found between the measured and the SIS predicted from SII, SII_{SLD}, $SII_{SLD, HLD}$.

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