Research Article

Manipulation of Signal-to-Noise Ratio to Compensate for Variations in Word Identification Scores Due to Change in Masker

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Abstract

The type of masking noise is known to affect speech identification. Some maskers are known to have a greater masking effect on speech than others. Thus, the study aimed to investigate whether manipulating the signal-to-noise ratio (SNR) of a masker can compensate for variations in word identification scores obtained due to change in the type of masker. To investigate this, the scores obtained by 20 children on a speech identification test using an 8-talker babble was compared with that obtained on a word identification test in the presence of white noise. The former test was evaluated at 0 dB SNR using the 'Speech perception-in-noise in Kannada' (SPIN-K) and the latter in three different SNRs (0 dB, -5 dB, & -10 dB) using the 'Kannada Word identification-in-white noise' (WIWN-K). Speech babble was found to have a greater masking effect at 0 dB SNR, resulting in poorer speech identification scores than white noise. However, the speech identification scores obtained using white noise at -10 dB SNR was equivalent to that of scores obtained with speech babble at 0 dB SNR. The study highlights that the masking effect of continuous white noise can be made equivalent to the masking effect of an 8-talker speech babble by reducing the SNR.

INTRODUCTION

Speech identification scores, assessed in the presence of different background noises, have been found to vary depending on the type of maskers used. The spectral and temporal characteristics of the maskers were observed to result in varying amount of masking. Speech babble is reported to have relatively greater masking effect than white noise on speech recognition (Beattie et al., 1997; Danhauer & Leppler, 1979; Kalikow et al., 1977; Lee et al., 2015). The fluctuating nature of speech babble (Ben-David et al., 2012; Danhauer & Leppler, 1979; Lee et al., 2015) and the acoustic similarity between target and masker (Brungart et al., 2001; Carhart et al., 1975; Iyer et al., 2010) was reported to be the reason for the greater masking effect of speech babble. Also, speech babble was reported to have an increased cognitive load in terms of the attention and memory processes involved (Brungart et al., 2001; Carhart et al., 1975; Iyer et al., 2010; Kalikow et al., 1977).

The masking effect of speech babble and white noise have been found to also depend on the signal-to-noise ratios (SNR). Speech identification has been observed to improve with increase in SNR (Beattie et al., 1997; Chermak & Dengerink, 1981; Chermak et al., 1984; Chermak et al., 1989; Chermak et al., 1988; Danhauer & Leppler, 1979; Lee et al., 2015; Lewis et al., 2010; Olsen et al., 1975; Prosser et al., 1990; Studebaker et al., 1994). However, at a specific SNR, the amount of masking varied across the type of maskers (Danhauer & Leppler, 1979; Lee et al., 2015). Studies have revealed that at lower SNRs, the masking effect was greater for speech babble when compared to the white noise (Danhauer & Leppler, 1979; Lee et al., 2015). However, with increase in SNR, there is an increased chance for listeners to get a 'glimpse' of the target at the momentary low levels of the speech babble (Cooke, 2006; Li & Loizou, 2007), which results in an improvement in performance. Further, Danhauer and Leppler (1979) observed that scores obtained at -3 dB SNR white noise was better than that obtained with a 9-talker babble at 0 dB SNR. However, these scores were very close to the chance performance level.

The use of speech noise or speech babble (Beattie et al., 1997; Buss et al., 2017; Kalikow et al., 1977) as maskers are popular in studies evaluating speech perception in noise, as they give an indication of the difficulties faced by individuals in day-to-day situations. However, the use of white noise as a masker, when recoding contralateral suppression of transient evoked otoacoustic emissions (TEOAEs), is popular (de Boer & Thornton, 2007; Graham & Hazell, 1994; Hood et al., 1996; Hood et al., 1995; Jedrzejczak et al., 2016; Killan et al., 2017; Kumar & Vanaja, 2004; Sanches & Carvallo, 2006; Stuart & Cobb, 2015; Swamy & Yathiraj, 2019; Yashaswini & Maruthy, 2019). Continuous presentation of white noise is reported to yield higher suppression amplitudes when compared to interleaved noise (Swamy & Yathiraj, 2019). Studies using speech noise or broad band noise demonstrated that higher suppression amplitude either resulted in enhancing the performance on speech-in-noise tasks (de Boer & Thornton, 2008; Kumar & Vanaja, 2004; Mertes et al., 2019) or had no correlation with speech recognition in noise (Mukari & Mamat, 2008; Wagner et al., 2008; Yashaswini & Maruthy, 2019). Only a few of the these studies (de Boer & Thornton, 2008; Mertes et al., 2019) mention that the SNR of the noise was calculated using the root-mean-square (RMS) amplitude, thereby ensuring that the SNR measurement was accurate. Hence, the lack of consensus among studies that have evaluated the association between Otoacoustic emission (OAE) suppression amplitude and speech perception in noise could be on account of the accuracy of the SNRs of the speech tests. This necessitates developing a speech identification test, superimposed with noise that is commonly used to study contralateral suppression of OAEs such as white noise. Having noise with similar RMS values as that of the speech stimuli would enable validating whether those with higher suppression amplitude do have better speech perception. One of the disadvantages of using white noise as a masker while measuring speech perception is that it does not reflect day-to-day situations unlike speech babble (Buss et al., 2017; Carhart et al., 1975; Kalikow et al., 1977; Lee et al., 2015). Hence, it also needs to be studied whether manipulation of the SNR when using white noise can bring about similar speech perception scores as that of speech babble. The present study thus aimed to determine the effect of different types of maskers (8-talker speech babble & white noise) on word identification scores. The study also aimed to establish whether variations in SNR, with white noise as the masker, could result in word identification scores similar to that obtained in the presence of speech babble presented at 0 dB SNR.

METHODS

The study was conducted in two conditions, one where speech identification was measured in the presence of two different maskers (8-talker speech babble & white noise), with the SNR kept constant (0 dB SNR). The second condition involved obtaining speech identification scores in the presence of noise, with the SNR being constant in one masker (8-talker babble) and varying in the other masker (white noise presented at -10 dB SNR, -5 dB SNR, & 0 dB SNR). The study was conducted using a within group comparison design, with a purposive sampling technique used to select the participants.

Participants

Twenty typically developing children (11 boys & 9 girls) aged 7 to 9 years (mean age of 7;7 years) were studied. All the participants had normal air conduction and bone conduction pure-tone thresholds from 250 Hz to 8000 Hz and 250 Hz to 4000 Hz, respectively. Normal middle ear function was confirmed by the presence of A or As type tympanograms with ipsilateral and contralateral acoustic reflexes being present. In addition, the participants were reported to have no history of any otological, neurological, or scholastic problems. All the children were native speakers of Kannada, a language spoken in southern India and were exposed to the language from early childhood. The children were included only if they were not at-risk for an auditory processing disorder on the 'Screening Checklist for Auditory Processing' (Yathiraj & Mascarenhas, 2004).

Procedure

The audiological evaluation was performed in a sound-treated double-room setup having noise levels as per the specifications given by American National Standard Institute (1999). Prior to evaluating the children, the material to evaluate Kannada word identification in the presence of white noise (WIWN-K) was constructed.

To construct WIWN-K, bisyllabic words of the 'Phonemically balanced word test in Kannada' (Yathiraj & Vijayalakshmi, 2005) were used as the stimuli, while white noise generated using Adobe Audition (Version 3) served as the noise. The white noise was generated at a sampling rate of 44100 Hz with a resolution of 16-bit. The 'Phonemically balanced word test in Kannada' contained four audio recorded lists with each having 25 words that had an inter-stimulus interval of 3 s. The test had an additional set of four lists, in which the words of the first four lists were randomized. Thus, the test contained a total of eight lists (1a, 1b, 2a, 2b, 3a, 3b, 4a, 4b), which were used for the construction of the WIWN-K.

Prior to superimposing white noise on the speech stimuli, the average RMS power of the white noise was determined by measuring the average RMS power of the audio recorded words of each list using Adobe Audition (Version 3). As each word in the word-lists was found to have an average RMS power of -27 dB (Figure 1A), with a range of -26.9 dB to -27.1 dB, a white noise having this average RMS power (-27 dB) was superimposed on the words to form a 0 dB SNR noise condition (Figure 1B). Additionally, the word-lists were combined with white noise having average RMS power of -22 dB and

-17 dB, to generate material having -5 dB SNR (Figure 1C) and -10 dB SNR (Figure 1D), respectively. To confirm that these changes in RMS values brought about a corresponding alteration in absolute intensity, the output from the computer through an audiometer (Piano Inventis, Italy with TDH-39 headphones), was measured using a sound level meter (Larsen-Davis 824) with a 1-inch pressure microphone (Larsen-Davis 2575) and a 6 cc coupler (AEC 201). The intensity levels of the speech tokens in quiet was 60 dB SPL (±2, depending on the word), while the dB SPL of the white noise with RMS powers of -27 dB, -22 dB and -17 dB were found to be 60 dB SPL, 65 dB SPL, and 70 dB SPL, respectively. The duration of the white noise was maintained at 105 s, which started 3 s before each list and ended 3 s after each list. A 10 s gap was introduced in each list, between 60 s to 70 s, to avoid adaptation that may occur due to the continuous white noise. Continuous noise was used to make the material comparable with other measures that make use of similar noise. This includes tests such as contralateral suppression of TEOAEs that often makes use of continuous white noise as the masker.

The participant selection was done by measuring their pure-tone thresholds using a Piano dual-channel clinical audiometer (Inventis audiology equipment, Italy) with TDH-39 headphones. It was confirmed that their thresholds were less than 15 dB HL. Further, it was ensured that they obtained an A-type or an As-type tympanogram, with ipsilateral and contralateral reflexes present using a GSI-tympstar middle ear analyzer (Grason-Stadler, Eden Prairie, Minnesota). They were selected only if they obtained scores of 90% or higher on a speech identification test, measured in the absence of noise using one of the lists of the 'Phonemically balanced word test in Kannada'. Additionally, the participants were required to obtain scores of less than six on the 'Screening Checklist for Auditory Processing', administered by their class teachers. The absence of an auditory separation problem was confirmed by administering the 'Speech-in-noise test in Kannada (SPIN-K) developed by Vaidyanath and Yathiraj (2012) using the normative values given by Mamatha and Yathiraj (2019). All the participants achieved age matched scores within -2 SD of the normative values. The scores on the speech identification in quiet and SPIN-K were also used for later analysis.

The participants who met the selection criteria were evaluated using the WIWN-K, developed as part of the current study. Both SPIN-K and WIWN-K made use of similar stimuli (bisyllabic words of the 'Phonemically balanced word test in Kannada'), but differed in terms of the noise use. The SPIN-K made use of 8-speaker noise segments that were absent during the inter-stimulus intervals and the test was designed to evaluate speech identification at 0 dB SNR. On the other hand, the WIWN-K made use of continuous white noise and was designed to test at three different SNRs (0 dB, -5 dB, & -10 dB).

The speech stimuli for the speech identification tasks were presented using Adobe Audition (Version 3.0), loaded in a personal computer with an Intel Core i7 processor. From the computer, the stimuli were routed through a dual-channel calibrated audiometer (Inventis Piano) to TDH-39 headphones. The stimuli were presented at 40 dB SL (ref. to PTA). The VU meter of the audiometer was adjusted to 0 dB using the 1 kHz calibration tone, present in the start of each word-list. The 1 kHz calibration tone had the average RMS of the speech tokens. The participants were instructed to listen carefully to the speech stimuli and repeat what was heard. The testing was performed only in the right ear to avoid fatigue influencing the test results.

The 20 children were first tested using SPIN-K (Vaidyanath & Yathiraj, 2012), with half of them being tested with one list (List 1a) and the other half tested with another equivalent list (List 2a). WIWN-K was tested at -10 dB, -5 dB, and 0 dB SNRs, on all 20 children. However, in half the participants, WIWN-K was not measured using one of the lists (List 1a) and the other half were not evaluated using another list (List 2a), as these lists had been used in the measurement of SPIN-K. To avoid familiarity playing a role, the lists (1a and 2a) presented while measuring SPIN-K were not repeated while measuring WIWN-K. Thus, the children were tested with three lists at each SNR while measuring WIWN-K. It was made sure that no list was heard more than once by the participants at a particular SNR. Across the three SNRs of WIWN-K, the children heard randomized versions of the lists.

Prior to the administration of the tests, five children who were not a part of the participants evaluated in the study, were tested with both speech tests (SPIN-K & WIWN-K). It was observed that all five of them obtained least scores on SPIN-K presented at 0 dB SNR, and WIWN-K presented at -10 dB SNR, followed by WIWN-K presented at -5 dB SNR and 0 dB SNR. Hence, while evaluating the participants of the study, the most difficult conditions were tested first and the easier conditions were tested later. This was done to minimize word familiarity affecting the results. SPIN-K was also administered first as it was used to rule out the presence of an auditory separation problem. The lists were randomized within a test / SNR, to prevent a list order effect.

The responses of the participants were documented in a response sheet. Each correct response was given a score of '1' and each incorrect response was given a score of '0'. The maximum possible score was 25 for each list. The total scores for each participant in each of the noise conditions and in quiet were tabulated.

Statistical analyses

The data were statistically analyzed using IBM SPSS Statistics (Version 20.0). Using a Shapiro-Wilk

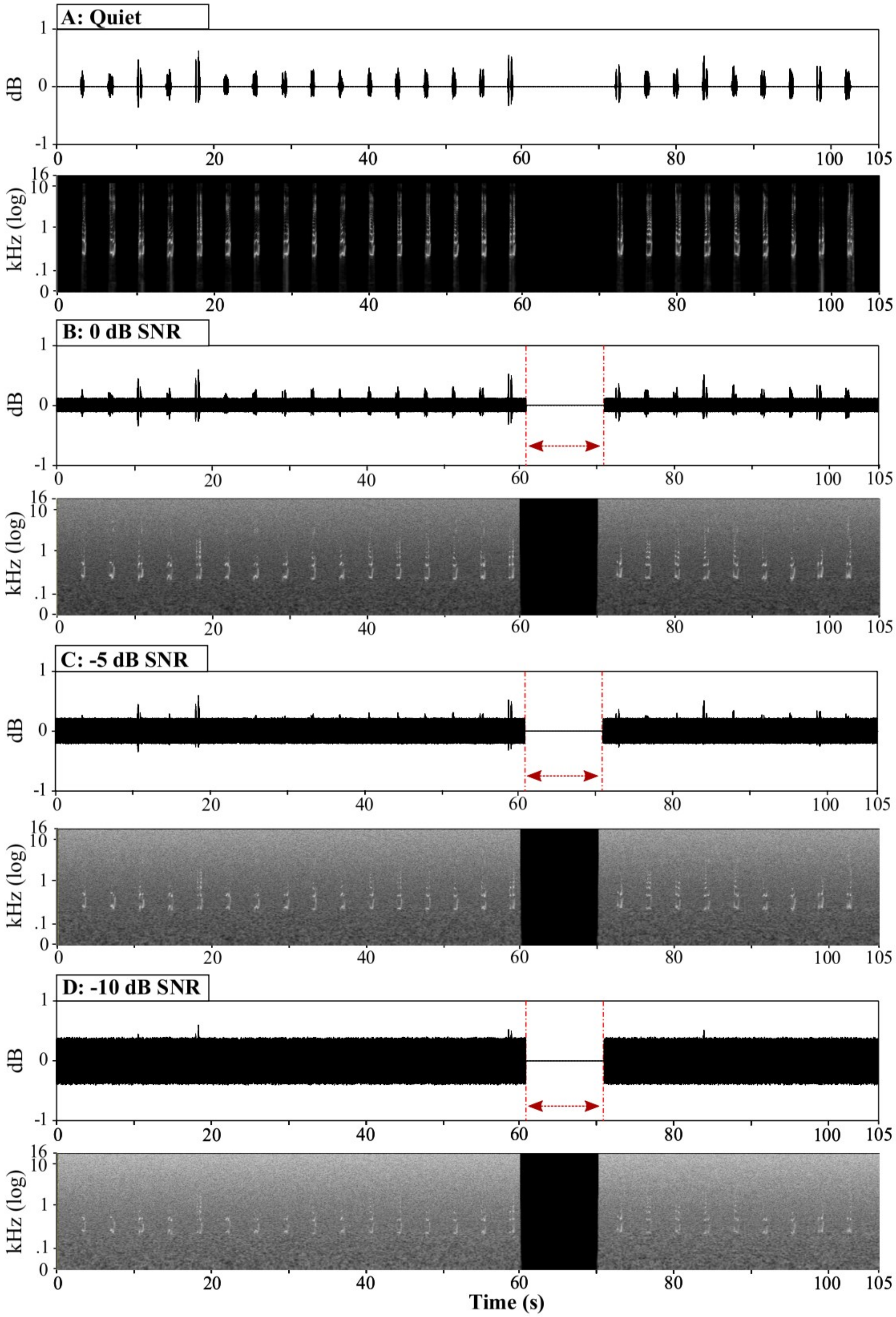

Figure 1: Waveforms and spectrograph of a word-list in quiet (panel A) and mixed with white noise at 0 dB SNR (panel B), -5 dB SNR (panel C) and -10 dB SNR (panel D).

test for normality, it was observed that most of the data were normally distributed, hence the parametric tests were performed. Descriptive statistics and inferential statistics were carried out.

RESULTS

The data were analyzed to compare the scores obtained across the word-lists for the two speech and noise tests (SPIN-K & WIWN-K) as well as across the two tests. The two tests were compared for each of the SNRs that were measured and between gender.

The mean and standard deviation for the word scores obtained in quiet, along with scores obtained using SPIN-K and WIWN-K are provided in Table 1. From the table, it can be seen that the mean scores obtained in quiet and that got using WIWN-K at 0 dB SNR were the highest, followed by the -5 dB SNR and the -10 dB SNR conditions. The mean scores of WIWN-K at 0 dB SNR were similar to the mean scores obtained in the quiet condition, whereas the mean scores of WIWN-K at -10 dB SNR were similar to that of SPIN-K obtained at 0 dB SNR. This trend was seen for the scores obtained across the word lists administered as well as the two genders.

The equivalence of the lists in the presence of noise was checked for the two lists that were tested using SPIN-K and the four lists that were administered using WIWN-K. This was checked using independent t-test for the two lists of SPIN-K. The results revealed no significant difference in scores between List 1 and List 2 at 0 dB SNR, measured using SPIN-K, t (18) = -.14, p = .88.

The scores obtained in WIWN-K were analyzed to study the effects of lists, SNRs, and gender, using a repeated measures ANOVA (4 lists x 3 SNRs x 2 gender). As List 1 and List 2 were tested on only half the participants using WIWN-K, ANOVA was first carried out with the data of the 10 participants who were tested with all four lists. The repeated measure ANOVA revealed no significant main effect of lists, $F(2, 24) = .77$, $p = .52$, $\eta_p{}^2 = .08$, and gender, $F(1, 8) = 3.3$, $p = .1$, $\eta_p{}^2 = .29$ but a significant main effect of SNRs, $F(2, 16) = 377.33$, $p < .001$, $\eta_p{}^2 = .97$. However, there existed no significant interaction between the three variables. As there was a main effect of SNRs, post hoc comparisons with Bonferroni corrections were done. Significant differences were obtained between the -10 dB and -5 dB SNR conditions, t = -5.1, p = < .001; the -10 dB and 0 dB SNR conditions, t = -9.91, p < .001; and the -5 dB and 0 dB SNR conditions, t = -4.81, p < .001.

Additionally, a repeated measures ANOVA (4 lists x 3 SNRs x 2 gender) was done with the data of 20 participants who were tested using two of the lists of WIWN-K (List 3 & List 4). For this analysis, the missing data of List 1 and List 2 were replaced by duplicating the existing data of the 10 participants who were tested using these lists. Similar to what was observed while analyzing the data with only 10 participants, the results revealed no significant effect of lists $F(3, 54) = .317$, $p = .81$, $\eta_p{}^2 = .01$, and gender $F(1, 18) = 4.02$, $p = .06$, $\eta_p{}^2 = .18$, but a significant main effect of SNRs $F(2, 36) = 651.52$, $p < .001$, $\eta_p{}^2 = .97$. Likewise, no significant interaction was observed between the lists, SNRs, and gender. To determine which of the pairs of SNRs differed from each other, post hoc comparisons with Bonferroni corrections were measured. Significant differences were observed between the -10 dB and -5 dB SNR conditions, t = -5.31, p = < .001; the -10 dB and 0 dB SNR conditions, t = -10.0, p < .001; and the -5 dB and 0 dB SNR conditions, t = -4.69, p < .001.

Thus, ANOVA measured using only 10 participants and 20 participants with duplicated missing data resulted in similar findings. Both measures indicated that the four lists in the presence of white noise did not differ. As no significant difference was observed between the lists while using SPIN-K or when using WIWN-K, the scores obtained across the lists were combined for each of the tests for further evaluation.

To check if any of the SNRs used while measuring WIWN-K resulted in scores that were equivalent to the 0 dB SNR condition of SPIN-K, paired sample t-test was performed. The results of the t-test indicated that the SPIN-K scores measured at 0 dB SNR had no significant difference with the WIWN-K scores measured at -10 dB SNR, t (19) = 1.63, p = .11. However, there existed a significant difference with the scores measured at -5 dB SNR, t (19) = -12.2, p < .001, and 0 dB SNR, t (19) = -26.02, p < .001.

Additionally, the word identification scores obtained in the quiet condition was compared with the WIWN-K scores obtained at each of the three SNRs using a paired sample t-test. The scores obtained in the quiet condition were significantly different from the WIWN-K scores at -10 dB SNR, t (19) = 38.55, p < .001; -5 dB SNR, t (19) = 18.85, p < .001; and 0 dB SNR, t (19) = 4.22, p < .001.

Thus, the results revealed that the lists of the 'Phonemically balanced word test in Kannada', continued to be equivalent in the presence of white noise. This was seen for both the boys and the girls who were studied. However, the WIWN-K scores measured at the three different SNRs differed significantly from each other. Among the three SNRs of WIWN-K, the scores obtained at -10 dB SNR were similar to the scores measured using SPIN-K at 0 dB SNR.

DISCUSSION

The findings of the study are discussed with regard to the equivalence of the lists of the 'Phonemically balanced word test in Kannada' in the presence of speech babble and white noise; the effect of maskers on speech identification scores; and the

Table 1: Mean and standard deviation (SD) of word scores obtained in quiet, as well as with SPIN-K and WIWN-K (at three SNRs), across word-lists and gender

Lists	**Gender**	**n**	**Mean (SD)**	**SPIN-K 0 dB SNR Mean (SD)**	**WIWN-K -10 dB SNR Mean (SD)**	**WIWN-K -5 dB SNR Mean (SD)**	**WIWN-K 0 dB SNR Mean (SD)**
1	Male	4	24.00 (0.81)	13.25 (0.50)	13.00 (0.81)	18.00 (2.16)	22.50 (2.08)
	Female	6	23.83 (0.98)	13.83 (1.47)	13.66 (0.81)	18.83 (1.16)	23.66 (1.21)
	Total	10	23.90 (0.87)	13.60 (1.17)	13.40 (0.84)	18.50 (1.58)	23.20 (1.61)
2	Male	7	24.14 (0.89)	13.57 (1.98)	12.71 (1.79)	18.42 (2.29)	23.00 (1.41)
	Female	3	25.00 (0.00)	14.00 (1.73)	14.00 (1.00)	19.33 (0.57)	23.33 (1.52)
	Total	10	24.40 (0.84)	13.70 (1.82)	13.10 (1.66)	18.70 (1.94)	23.10 (1.37)
3	Male	11	—	—	12.90 (1.75)	18.54 (2.29)	23.00 (1.09)
	Female	9	—	—	14.00 (1.58)	18.88 (.78)	23.77 (1.09)
	Total	20	—	—	13.40 (1.72)	18.70 (1.75)	23.35 (1.13)
4	Male	11	—	—	12.54 (1.29)	18.36 (1.50)	23.36 (0.80)
	Female	9	—	—	13.88 (1.16)	18.55 (1.01)	23.55 (1.13)
	Total	20	—	—	13.15 (1.38)	18.45 (1.27)	23.45 (0.94)

Maximum possible word score = 25

equivalence of WIWN-K and SPIN-K as a function of SNR.

Equivalence of the lists of the 'Phonemically balanced word test in Kannada' was found to be maintained in the presence of speech babble as well as in the presence of white noise. Although the equivalence of the lists in the presence of speech babble was checked with only two of the lists, it reflects the consistency of the findings observed by Vaidyanath & Yathiraj (2019) in adults and Mamatha and Yathiraj (2019) in children. They too reported that the lists of the 'Phonemically balanced word test in Kannada' were not significantly different in the presence of speech babble. Thus, testing SPIN-K in different groups of participants yielded similar results, indicating that the 8-talker babble masked the words in a similar manner across the lists.

Likewise, the equivalence of the four word-lists in the presence of white noise in the present study indicates that the masker masked the four lists in a similar manner. This was observed at each of the three SNRs tested in WIWN-K. Thus, it can be inferred that increase in SNR brought about a uniform enhancement in speech identification scores across the four word-lists. Similarly, a decrease in SNR brought about a uniform reduction in scores across the lists. Thus, at a particular SNR, white noise results in a constant form of masking. This indicates that the four word-lists of 'Phonemically balanced word test in Kannada' can be used interchangeably at a particular SNR.

The effect of maskers on word identification scores in the present study revealed that the 8-talker speech babble had a greater masking effect than white noise at 0 dB SNR. Similar to this finding, Danhauer and Leppler (1979) also reported that at 0 dB SNR, white noise resulted in significantly higher scores than speech babble. The greater masking effect of speech babble can be attributed to the acoustic similarity between the target and masker, as was noted in earlier studies (Brungart et al., 2001; Carhart et al., 1975; Iyer et al., 2010). However, the effect cannot be ascribed to an increase in informational masking reported in literature (Best et al., 2020; Brungart, 2001; Brungart et al., 2001; Carhart et al., 1975; Freyman et al., 2004; Iyer et al., 2010; Kalikow et al., 1977; Kidd et al., 2002), as the use of the 8-speaker babble would have not allowed this to take place. This was also noted earlier by Simpson and Cooke (2005). The 'glimpses' of the signal, enabling it to be perceived, would have been difficult as the difference in the poles and zeros was less. Also, the use of isolated words as stimuli, in contrast to sentences or phrases (Brungart, 2001; Brungart et al., 2001; Freyman et al., 2004; Kalikow et al., 1977) would have made it unlikely that informational masking played a role. Thus, although both speech-babble and white noise resulted in acoustical masking, the similarity in the former to the target stimuli would have resulted in more masking compared to the latter, when presented at the same SNR.

The effect of SNR on WIWN-K (-10 dB, -5 dB, & 0 dB SNR) in the present study brought about the expected finding, where a decrease in SNR resulted in a significant decrease in word scores. This finding is in consensus with that reported in literature (Chermak & Dengerink, 1981; Chermak et al., 1984; Chermak et al., 1988; Olsen et al., 1975; Studebaker et al., 1994). As expected, with increase in SNR, the audibility of the signal increases, leading to improved perception of the target stimuli.

Equivalence of SPIN-K and WIWN-K was found to occur in the present study between the scores of the former test at 0 dB SNR and the latter test at -10 dB SNR. However, the scores of WIWN-K at -5 dB SNR and 0 dB SNR were significantly better than that of SPIN-K at 0 dB SNR. This indicates that white noise can bring about similar acoustical masking as that of speech babble only when its amplitude is increased considerably higher with reference to the target speech stimulus. Thus, the difference in frequency spectrum between white noise and speech stimuli, resulting in the former having a lesser masking effect on the latter, can be compensated by decreasing the SNR. As seen in the current study, Danhauer and Leppler (1979) observed that white noise at -3 dB SNR continued to be better than speech babble presented at 0 dB SNR, although the scores were close to the chance performance level. However, they did not report whether this difference was significant or not.

Thus, based on the findings of the current study, it is recommended that in the presence of white noise any of the lists of the 'Phonemically balanced word test in Kannada' can be used. This is recommended as the masker brought about a uniform masking effect across the lists. Further, for white noise to have an equivalent masking effect on words as an 8-speaker speech babble presented at 0 dB SNR, it should be presented at -10 dB SNR.

CONCLUSIONS

The findings of the 20 children who were evaluated using two tests that had similar stimuli but different maskers, confirmed that speech identification scores vary as a function of the masker. Eight-speaker babble was found to have a greater masking effect than white noise when both were presented at 0 dB SNR. Each of the maskers had a similar masking effect across the word-lists that were studied, indicating that the lists were equivalent even in the presence of noise. While the masking effect of white noise having SNRs of 0 dB and -5 dB differed significantly from that of speech babble presented at 0 dB SNR, the two were equivalent when speech babble was presented at 0 dB SNR and white noise at -10 dB SNR. Thus, reduction of the SNR of white noise can yield similar masking effect as that of speech babble presented at 0 dB SNR.

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