Effect of Spatial Noise on Speech Identification

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ABSTRACT

Objectives: The study was carried out with the aim to determine the consistency of speech identification measured in the presence of spatial noise that varies over time in comparison speech identification measured in the presence of continuous speech noise.

Design: Using a factorial design, speech identification scores of 50 children and 50 adults were compared across test trials in presence of two different types of noise (spatial noise & continuous speech noise). The participants were tested thrice in the presence of spatial noise and twice in the presence of continuous speech noise.

Results: Significant differences in word as well as phoneme scores occurred from one test trial to another for spatial noise, but not for continuous speech noise in children and adults. Although word identification scores differed between children and adults, no such significant difference occurred for the feature errors when the 5 test trials were combined or when the test trials for each type of noise were combined. Across trials, the type of phoneme errors varied considerably when speech was presented in the presence of spatial noise but did not did differ to the same extent when presented in the presence of continuous speech noise.

Conclusion: The variations in frequency, intensity and duration of the signals in spatial noise would have led to large variations in phoneme errors from one trial to another in the presence of spatial noise. The findings of studies that have used spatial noise to evaluate the effect of noise reduction algorithms in hearing aids of cochlear implants are likely to have been influenced by the varying nature of the noise. Thus, when testing with spatial noise, the findings of the study are likely to be compromised by the co-varying effects of the noise.

INTRODUCTION

Despite speech recognition in quiet environments being good, understanding speech at low-level intensities and/or in the presence of background noise is noted to be a challenge for most individuals. The perception of speech is noted to vary depending on the type of background noise. It has been reported that the speech perception scores vary depending on the frequency, intensity or temporal characteristics of noise (Larsby & Arlinger, 1994; Papso & Blood, 1989; Prosser, Turrini, & Arslan, 1991). Speech perception has been found to vary depending on the frequency, intensity and temporal characteristics of background noise (Hygge, Ronnberg, Larsby, & Arlinger, 1992; Larsby & Arlinger, 1994; Larsby, Hällgren, Lyxell, & Arlinger, 2005).

Effect of background noise on speech identification in Cochlear implant users

Speech understanding in quiet and noise in subjects bilaterally implanted with multi-channel cochlear implants was evaluated by (Muller, Schon, & Helms, 2002). Nine adults were included in the study and were evaluated with pre-recorded sentence test, Hochmair-Desoyer, Schulz, Moser and Schmidt CD (HSM sentences) in the presence of speech shaped noise at 10 dB SNR. The speech was presented at 65 dB SPL and the noise level was varied to achieve the desired SNR. Speech was presented from 0˚ azimuth and noise was presented from 90˚ and 270˚ azimuth. It was found that higher scores were obtained with bilateral implants and the average score across subjects for sentence understanding was 31.1% and 10.7% points higher with both cochlear implants compared to cochlear implant ipsilateral and contralateral to noise, respectively. There was a significant difference seen among listening condition for sentences and for monosyllabic words. The score for recognition of monosyllabic words was 18.7% points higher with both cochlear implants than with one cochlear implant. The study concluded that bilateral cochlear implantation provides a significant benefit in speech understanding in both quiet and noise.

Blamey, Fiket, and Steele (2006) evaluated speech perception in noise in cochlear implant users. Three different microphone configurations used together with the ADRO sound processing strategy were evaluated. Eight participants with an age range of 36 to 82 years were assessed with Hearing in noise test (HINT sentences) and City university of New York (CUNY sentences). For the HINT sentences, the speech intelligibility was assessed in the presence of steady state noise presented at a level of 65 dB A. Speech was presented from the speaker located at 0˚ azimuth and the noise was presented from three speaker positions 90˚, 135˚ and 180˚ azimuth. Omnidirectional, super cardioid and adaptive directional microphone were evaluated in combination with ADRO. The results revealed that there was difference in scores for the three different noise locations with difference in SNR between the three-microphone configuration. It was found that the highest SNR (most difficult listening situation) was for noise presented at 180˚ azimuth. For the CUNY sentences, the speech intelligibility was evaluated in the presence of eight talker babble and the CUNY sentences were presented in four conditions, in quiet, in noise from 90˚ azimuth, in noise from 180˚ azimuth and in moving noise. Two lists were presented for each microphone condition with the babble from 180˚ speaker and were also presented with fixed directional microphone and adaptive directional microphone in the moving noise condition, respectively. In quiet, both the microphones produced a near perfect speech recognition scores. The results were similar to that obtained with HINT, where 180˚ azimuth was the most difficult listening condition. The authors also concluded that speech intelligibility was best when noise came from 90˚ azimuth.

Spriet et al. (2007) determined the benefit of the two-microphone adaptive beam former for speech understanding in background noise. They evaluated five adults using Nucleus cochlear implant. Speech reception threshold with sentences and the percentage correct phoneme score for CVC words were measured in quiet and in the presence of background noise presented from different sources. The desired speech and noise signals were presented through identical loudspeakers, with the speech source in the front and the noise source at an angle θ with respect to the speech source. The evaluation included stationary speech weighted noise and multitalker babble noise presented as, single noise source at 90˚ and three noise sources at 90˚,180˚ and 270˚. The beam former benefit was significantly larger for a single noise source than for multiple noise sources. The speech reception thresholds were significantly better for stationary noise than multitalker babble noise. The latter noise was more disturbing than stationary noise that lead to significant reduction in speech intelligibility.

Hersbach, Arora, Mauger, and Dawson (2012) evaluated a combination of single channel and multichannel noise reduction algorithms in complex listening conditions. Fourteen adults with unilateral cochlear implants (Cochlear Nucleus) were evaluated. Speech perception in quiet was assessed using open-set monosyllabic consonant-nucleus-consonant words presented at 60 dB SPL and speech perception in noise was assessed using open-set Bamford-Kowal-Bench sentences. Three noise sources, two speech weighted noises, four-talker babble and twenty-talker babble were used. The target sentences were presented from the loudspeaker in front, and noise from remaining loudspeakers from 90° to 270° azimuth. Standard, Zoom and Beam directionality settings were evaluated with and without noise reduction algorithm. With noise reduction algorithm switched-on, the speech perception scores showed significant difference in spatially separated speech weighted noise. Both the twenty-talker babble and four-talker babble showed no significance over speech perception. The speech reception threshold benefit over the standard setting was 3.7 dB for Zoom and 5.3 dB for Beam, which demonstrated a strong benefit of directional processing. The addition of the noise reduction algorithm provided an additional benefit of 1.3 dB across the three directionality settings. It was found that the multichannel noise reduction could reduce noise based on the direction of arrival. Thus, the authors concluded that single channel and multichannel noise reduction algorithms can work together to produce combined benefit in specific noisy environments.

The influence of microphone directionality cochlear implant users was studied by Kordus, Tyler, Żera, and Oleson (2015). They explored the differences among omni-directional, directional and beamforming microphone configurations. Seven adults (27 to 68 years) implanted bilaterally were tested with spondee words in the presence of background female-male babble noise. The stimuli were presented from an eight-loudspeaker array at angles of -54° to -8°, and 8° to 54° corresponds to locations on the left and right side of the median plane. The subjects were presented with twelve spondees introduced with a carrier phrase in the presence of babble noise. The level required to obtain a score of 50% on spondees identification differed in SNR among subjects by about 20 dB when speech was presented from front. A 3 dB SNR improvement in speech intelligibility was observed in three subjects for beamforming system compared to directional and Omni-directional microphone settings.

A comparison between Opus 2 and Rondo speech processor on speech intelligibility for different directions of the noise incidence was assessed by Wimmer, Caversaccio, and Kompis (2015). Twelve participants with hearing impairment were evaluated with SPIN test in the presence of speech babble presented at 65 dB SPL. The setup included a twelve-loudspeaker array. The test sentences were presented from front and the noise was presented from the front (S_0 N_0), from the side ipsilateral to the cochlear implant (S_0N_{IL}), from the side contralateral to the cochlear implant (S_0N_{CL}) and from the back (S_0N_{180}). The performance was measured once with Opus 2 processor and once with Rondo processor in all the noise configurations. The results revealed no statistical significant difference between the speech intelligibility for the signal came from front and the noise came from the frontal, ipsilateral or contralateral side. The average SNR was significantly worse with the Rondo than with the Opus 2 processor, and it was significantly worse with the Rondo processors placed further behind the ear than closer to the ear. It was inferred that cochlear implant user with single-unit audio processor have higher difficulties in noisy situation when the receiver or stimulator is implanted in positions further behind the ear.

The speech intelligibility performance of post lingual cochlear implant users was assessed by Polat, Bulut, and Atas (2016) in the presence of noise at different SNR. Thirty post-lingual implant adult users with an age range of 20 and 66 years were tested with Turkish matrix test and SRT was tested with Turkish polysyllabic words in the presence of babble noise presented at 65 dB SPL. The stimuli were delivered through two speakers at 0˚ and 180˚ azimuth and at different SNRs of -10 dB, -5 dB, 0 dB and +5 dB SNR. The results revealed a significant difference in intelligibility scores between rear and front direction presentation of noise across all four SNRs. The matrix test speech recognition threshold values in quiet and matrix speech recognition threshold values in noise had no correlation. Further, the pure tone average values and intelligibility scores in noise were not significant.

Thus, the review of literature revealed that multitalker babble noise has greater adverse effects on speech perception compared to other maskers such as speech shaped noise, white noise, stationary noise and steady state noise. Additionally, perception of speech varied with reverberation, SNR, the level of noise and the number of talkers in the babble. With increase in reverberation time, level of noise and the number of talkers in speech-babble, speech perception difficulty increased. Whereas, with increase in SNR the performance improved. Compared to adults, children needed more SNR and more listening effort to perceive speech in the presence of multitalker babble.

Effect of real world noise on speech identification

The fitting of hearing aid and evaluation of speech intelligibility often takes place in an audiometric room which is smaller, quieter and less reverberant than typical rooms. This is reported to make it difficult to predict the accuracy of speech intelligibility in daily life (Cox, Alexander, & Rivera, 1991). Therefore, attempts have been made to develop noise that will provide accurate speech perception in daily living situations.

Validity of three simulated real-world listening environments was evaluated by Cox et al. (1991) which was created in an audiometric test room. The speech intelligibility of 20 normal hearing individuals were measured using a speech pattern contrast test. Noise from three different real environments such as living room noise, cocktail party noise and classroom noise were recorded and presented through loudspeakers. The target speech was presented through a loudspeaker, 1m in front of the subject. Multi-talker babble was delivered through four loudspeakers mounted at 45˚, 135˚, 225˚ and 315˚ at appropriate levels monaurally, with the non-test ear being plugged. On comparing the intelligibility of real world environment with that of the simulated environment it was found that few significant intelligibility differences were observed in the simulated environment than the real environment. It was concluded that scores obtained in real environment could be reproduced in simulated environment with simple procedures like appropriate adjustments of presentation level, signal to noise ratio and reverberation.

The effect of different real-world noises on speech identification in adults was studied by Prosser et al. (1991). They evaluated 15 subjects including young normal hearing adults (< 31 years), older adults with normal hearing thresholds (65 to 85 years), older adults with hearing impairment (65 to 85 years) and young adults with hearing impairment (< 45 years). The participants were tested with 20 tape-recorded lists, each having 10 sentences, in the presence of different competing noise that included speech noise, cocktail party noise, traffic noise and continuous discourse at SNR between -10 and 10 dB. The sentences were delivered through a frontal loudspeaker and the tape-recorded noise were simultaneously delivered from the front and a rear loudspeaker at 1m distance. The different noises showed varying results on speech discrimination of the subjects. The identification of the older participants with hearing impairment was significantly poorer than that of the young adults with normal hearing and hearing impairment. On the other hand, the older adults with normal hearing thresholds had identification scores that were only slightly reduced compared to the young individuals. The researchers also noted that the speech identification difficulty was more pronounced in the presence of hearing loss. Among the different types of noise, the competing continuous discourse had a greater adverse effect on speech identification as a function of age. Further, at the lower SNR, the participants obtained poorer scores in the presence of speech noise and cocktail party noise compared to traffic noise and continuous discourse. Such a difference was not seen at the higher SNR.

Wouters, Litière, and van Wieringen (1999) studied speech intelligibility in the presence of three background noises (speech weighted noise, traffic noise, & restaurant noise) with one omnidirectional microphone and a two-microphone configuration. Ten participants with bilateral symmetrical mild-to-moderate sloping sensorineural hearing loss aged 12 to 77 years were assessed. The participants were tested with sentences and disyllabic words at 65 dB (A) in the presence of noise. Significant difference was obtained across the four speech-noise conditions studied (bisyllabic words in the presence of speech-weighted noise, traffic noise, multi-talker babble, & sentences in speech weighted noise). The mean SNR improvement of 3.4 dB of speech recognition was seen in background noise presented at 90˚ azimuth. Neither the speech material nor the noise type led to differences in the speech-in-noise intelligibility between omnidirectional and directional microphone.

The abilities of young children to understand speech heard in classroom noise at different levels were evaluated by Jamieson, Kranjc, Yu, and Hodgetts (2004). The participants were 40 kindergartens (aged five) and elementary students, selected from grade 1 (aged six), grade 2 (aged seven) and grade 3 (aged eight). Sixty words (24 monosyllables, 12 spondees, 12 trochees, & 12 disyllables) were mixed with classroom noise at different SNR to create 4 conditions (quiet, 0 dB, -6 dB and -12 dB). The participants heard the signal and noise through supra aural headphones. Out of twelve trials for each set of word stimuli and SNR condition, the performance in quiet was good for children at all grade levels and as the SNR decreased, the performance also declined. The kindergarten and grade 1 children had more difficulty than older children at an intermediate SNR level (-6 dB) and children's performance accuracy was highest for trisyllables. They concluded that the youngest children in the school system, whose classrooms also tend to be among the noisiest, are the most susceptible to the effects of noise.

Effect of R-SPACE^{TM} real world noise on speech identification:

To study the effect of different noise reduction algorithms in a natural set-up, a popular form of noise used in research studies is 'R-SPACETM noise'. It is claimed that this noise provides accurate information about speech perception in noise that is compared to real-world conditions (Revit, Killion, & Compton-Conley, 2007). As described by Revit, Schulein, and Julstrom (2002), the noise is presented through eight different loudspeakers in a sound field situation, resulting in the listener hearing eight discrete, yet partially correlated signals that occurs in a life-like acoustic environment. The noise presented from each loudspeaker has different environmental sources of noise that vary in terms of frequency, and temporal characteristics over a period. As the noise varies from time to time, it is possible that the masking effect of the noise for standard speech stimuli would vary from one test session to another, in the absence of any other change. Thus, the test-retest reliability could be compromised due to the varying effect of the noise source. Thus, this variation could be co-variable affecting the findings of studies reporting of performance with different algorithms on listening devices. The extent of this variable needs to be investigated to determine how valid it is to utilise noise like 'R-SPACE^{TM} noise'. This noise has been used in the evaluation of several devices such as hearing aids and assistive devices, cochlear implants, computer voice recognition systems, noise-cancelling listening systems, cellular telephones, and other communication systems (Brockmeyer & Potts, 2011; Compton-Conley, Neuman, Killion, & Levitt, 2004; Gifford, Olund, & Dejong, 2011; Gifford & Revit, 2010a; Valente, Mispagel, Tchorz, & Fabry, 2006).

Directional microphone benefit was measured for clinical and laboratory accuracy by Compton-Conley et al. (2004) using R-SPACE^{TM} noise. Three pairs of hearing aid microphones with different polar pattern and directivity indices were used (ITE omnidirectional microphone, ITE super cardioid microphone & five element end fire array microphone with hyper cardioid characteristics). A KEMAR was used to record as well as to measure the electroacoustic characteristic of the microphone in different listening conditions. The R-SPACE^{TM} simulation method was compared with typically conditions used to test speech perception in noise (noise generated from a single loudspeaker from the rear of the listener and noise generated from a single loudspeaker placed overhead). Scores obtained for a modified version of HINT in the presence of the three noise conditions were compared with a live condition. It was observed that R-SPACE™ simulation yielded an accurate estimate of absolute performance of all three microphones in live condition. The authors observed that the HINT scores with R-SPACE™ were not significantly different from a live restaurant condition. Neither of the single source of noise (behind the listener nor above the listener) provided accurate predictions of real-world performance for all three microphone conditions. The results indicated that R-SPACE™ simulation technique is superior to traditional methods of evaluating directional microphone.

Responses to HINT sentences in the presence of R-SPACE™ restaurant noise was compared with steady state HINT noise by Valente et al. (2006). They compared the performance between omnidirectional and directional microphones on 25 adults having a mean age of 71.2 years. The participants with mild to moderate-severe bilateral symmetrical sensorineural hearing loss were evaluated with HINT sentences in the presence of two types of noise, and R-SPACE™ restaurant noise. It was found that performance in 180˚ (single loudspeaker) condition was significantly better than the diffused condition. The mean reception threshold for sentences with omnidirectional microphones was significantly poorer than that obtained with directional microphone. The HINT noise showed significantly better performance compared to R-SPACE™ noise. The authors concluded that the directional performance was significantly better than omnidirectional performance. They also reported that the reception threshold for sentences in the presence of stead state HINT noise was significantly better than that obtained with R-SPACE™.

Gifford and Revit (2010a) assessed the speech perception of adult cochlear implant recipients in the presence of R-SPACE™ restaurant noise. They aimed to determine whether the pre-processing strategies and/or external accessories yield improved sentence recognition in noise. The speech reception thresholds of 34 adults with cochlear implants (18 to 90 years) was assessed in the presence of noise. The participants were evaluated with their preferred listening programs as well as with either BEAM of Cochlear corporation or the T-mic accessory option of Advanced bionics. Adaptive speech reception thresholds with HINT sentences were obtained in all 34 subjects. In addition, 16 of the 20 Cochlear Corporation subjects were reassessed using a combination of noise reduction algorithms (ADRO, ADRO+ASC, & ADRO+ASC+BEAM). It was found that the scores varied depending on the pre-processing strategy used in the Cochlear Corporation recipients. Further, it was also observed that the T-Mic accessory option in Advanced Bionics significantly improved the speech reception threshold when compared to the BTE mic.

Similar to the previous study, Brockmeyer and Potts (2011) measured the speech recognition in the presence of R-SPACE™ background noise with four processing options in cochlear implants. Twenty-seven unilateral and three bilateral adult Nucleus Freedom cochlear implant recipients with a mean age of 60 years were included in the study. Speech recognition was evaluated with HINT sentences presented at 0˚ azimuth with R-SPACE™ restaurant noise at 60 and 70 dB SPL. The evaluation was done using four processing options that included a standard dual-port directional, adaptive dynamic optimization range (ADRO), auto sensitivity control (ASC), and adaptive beam forming algorithm (BEAM) at two noise levels. The reception threshold for sentences were obtained for each processing condition and noise level. The results showed that the scores varied as a function of the process used and the noise level. At 60 dB SPL, the BEAM processing resulted in the best reception threshold compared to the standard dual-port directional and ADRO processing. Whereas at 70 dB SPL, both ASC and BEAM were significantly better than STD and ADRO processing. The authors suggested that the use of processing options involving noise reduction would improve a cochlear implant recipient’s ability to understand speech in a noisy environment.

Further, Gifford et al. (2011) assessed speech perception of paediatric cochlear implant recipients using HINT sentences in the presence of R-SPACE™ noise. The children were tested with their everyday program ADRO as well as with ASC. Twenty-five children with normal hearing (3.9 to 17 years) and twenty-two children with cochlear implantation (5.6 to 16.8 years) were assessed with the HINT sentences in quiet and in R-SPACE™ noise, as well as with monosyllabic words at 65 dB (A). The HINT sentences in quiet and monosyllabic word were presented using a single loudspeaker at 0˚ azimuth and R-SPACE™ noise was presented through eight loudspeakers. In the experimental group, speech reception threshold improved significantly with the addition of ASC with ADRO. The study also revealed that even the best performing subjects required significantly higher SNR to understand speech in the presence of noise.

The effect of noise on speech understanding and performance intensity function of steady state speech spectrum noise with real life noises was examined by Wong, Ng, and Soli (2012). Thirty normal hearing participants with an age range of 18 to 25 years were evaluated with the Cantonese hearing in noise test sentences presented through loudspeaker at 0˚ azimuth. The noise conditions included steady-state speech spectrum shaped noise and six types of real life noise, such as upper deck bus noise, lower deck bus noise, cafeteria noise, subway train noise, Chinese restaurant noise and busy street noise. In each noise condition, the participants were tested with three SNRs. Various real-life noises exhibited differential effects on speech understanding. The SNR for 50% speech intelligibility for steady state speech spectrum shaped noise was -8.21 dB SNR. The SNR was elevated by 4 dB for 50% intelligibility for noise from the upper and lower deck of bus and cafeteria noise and SNR was elevated by 2 dB for street, subway train and Chinese restaurant noise. Four out of six noises yielded performance intensity function slopes like steady-state speech spectrum shaped noise. The authors concluded that steady state speech spectrum shaped noise was able to predict the performance in most of the real-life noise conditions.

The preservation of acoustic hearing in the presence of noise in cochlear implant users was determined by Gifford et al. (2013). The speech reception threshold using HINT sentences in the presence of R-SPACE™ background noise was assessed in 21 English speaking, and 17 Polish speaking participants cochlear implant users as well as 16 listeners with normal hearing. The speech stimuli were presented from one of the eight loudspeakers at a fixed level of 72 dB(A) and the noise as presented from all 8 speakers at two fixed SNRs (+6 & +2 dB). The results suggested the preserved low frequency hearing in the implanted ear improved speech understanding in realistic restaurant and reverberant noise situations for cochlear implant recipients. The authors stressed the importance of testing in complex listening environments, where binaural timing cues of the signal and noise vary, as it measures the value of low frequency residual hearing in the two ears.

Potts and Kolb (2014) examined the effects of processing options in a cochlear implant speech processor (CP180) by using R-SPACE™ test system, to simulate an acoustic environment of a real-life restaurant. The speech recognition in quiet using CNC words, and speech reception using HINT sentences in the presence of R-SPACE™ noise was measured in 32 adult cochlear implant recipients (36 to 92 years). In the presence of R-SPACE™, sentence recognition was the better (lowest reception threshold) with Beam only and Zoom+ ASC. The Beam+ADRO, Zoom only and Zoom +ADRO resulted in the poorest performance. Larger differences were noted between Beam only compared to Zoom only. It was also observed that the best processing option varied across subjects, but the overall performance was best with Beam or Zoom in combination with ASC. It was also concluded that the noise reduction processing is very beneficial for speech recognition in loud diffuse noise environment.

Kolberg, Sheffield, Davis, Sunderhaus, and Gifford (2015) investigated the physical level differences which exist for the T-Mic as compared to the integrated processor microphone for various source azimuths. They also aimed to determine the effect of cochlear implant processor mic location on speech recognition in semi-diffuse noise with speech originating from various source azimuths using R-SPACE™ noise. Eleven adult cochlear implant recipients with an age range of 19 to 67 years were assessed with sentences presented at 60 dBA at 0˚ azimuth in the presence of R-SPACE™ noise delivered through eight loudspeaker array. The participants were tested with T-Mic only, the BTE mic only and in the both 50/50 condition. The results revealed that microphone location significantly affected sentence recognition as a function of source azimuth. T-mic yielded significantly higher speech understanding in diffuse noise than the BTE mic for speech originating at 0˚ azimuth.

Comparison of paediatric speech perception performance across various pre-processing strategies in quiet and in noise was carried out by Rakszawski, Wright, Cadieux, Davidson, and Brenner (2016). Eleven participants (8.08 to 17.33 years) were evaluated with CNC words in quiet at 50 and 70 dB SPL and adaptive HINT sentences in the presence of 60 and 70 dB SPL R-SPACE™ noise. The stimuli were presented at 0˚ azimuth while the participant was sitting 1m away in each of the four conditions (no pre-processing, ADRO, ASC, & ASC+ADRO) and noise was presented from eight loud speakers in 360˚ azimuth. The results revealed that with CNC words in quiet at 50 dB SPL, ASC+ADRO resulted in best speech perception scores and with CNC words in quiet at 70 dB SPL there was no significant differences between the pre-processing strategies. The results of HINT sentences in R-SPACE noise at 60 dB SPL revealed that ADRO yielded the lowest mean SNR and 70 dB SPL, ASC+ ADRO was significantly better than ADRO. The study also revealed that the adaptive HINT sentences in the presence of R-SPACE™ noise presented a more challenging task compared to listening in quiet, even at low presentation levels.

To assess the hearing aid outcomes, Oreinos and Buchholz (2016) verified two common methods for creating virtual simulating environments. Eighteen listeners between ages of 66 and 78 years with moderate sloping sensorineural hearing loss were assessed with automated speech in noise test. They were also tested with an acceptable noise level speech test in the presence of cocktail party scene, which was created and was reproduced with a 41-channel loudspeaker array. Two directional hearing aid algorithms were tested in all three acoustic environments that included a real environment, room acoustic model-based sound reproduction and mixed-order ambisonics sound field reconstruction. It was found that the subjective performance seen in the real environment was preserved in the two virtual simulating environments for both directional hearing aid algorithm.

From the review of literature, it is evident that several studies have utilized R-SPACE™ noise or similar noise to reconstruct a real-world condition while evaluating the utility of devices / programmes / noise reduction algorithms. The majority of the studies report of variations in perception as a function of change in devices / programmes / noise reduction algorithms. It was noted that noise reduction algorithms and microphone configurations influenced speech identification in the presence of R-SPACE™ noise. Based on these studies, the use of specific algorithms or settings have been recommended. Real-world noises like classroom noise, traffic noise, cafeteria noise and cocktail party noise have also been found to influence speech identification.

It is hypothesised that the acoustical parameters of real-world noise or spatial noise would vary from one test situation to the other, unlike constant noise sources such as multi-talker babble or continuous speech noise. Such real-world noise with variations in acoustic characteristics, which are used to make judgment about specific algorithms or features in listening devices, are likely to act as covariables and contaminate the findings of studies using such noise. It is essential to determine the extent to which such variations in noise influence speech identification in the absence of any other variable. Thus, the study was carried out with the aim to determine the consistency with which speech identification scores can be measured in the presence of spatial noise that varies over time in comparison to constant speech noise.

METHODS

The study was conducted using a factorial design with the aim to determine the effect of spatial noise and continuous speech noise on speech identification in children and adults. Initially, the material for the study were developed / recorded. While spatial noise was developed, monosyllabic words from existing tests were recorded. Following this, speech identification was tested in the presence of spatial noise as well as speech noise.

Participants

Two groups of participants, each having 50 participants, were recruited for the study using a purposive sampling technique. While one group consisted of children aged 6 to 7 years (mean = 6.52; SD = 0.35), the other consisted of adults aged 18 to 25 years (mean = 21.6; SD = 2.32). The children were selected from regular schools in Mysuru city where the language of instruction was English. The children had been educated in Indian-English for at least 3 years. It was ensured that the young adults selected for the study were fluent speakers of Indian-English. All the participants had thresholds less than 25 dB HL from 250 to 8000 Hz; normal middle ear functioning, as determined by immittance evaluation; presence of TEOAEs; speech identification score greater than 75% in quiet; no report of otological or neurological problem; and no history of speech and language problems. Additionally, none of them had any symptoms of an auditory processing disorder, when assessed using the 'Screening checklist for auditory processing' developed by (Yathiraj & Mascarenhas, 2004).

Material development

The study was carried out using with existing material as well as material that were developed for the purpose of the study. To select the participants for the study, existing material were used. The material that was developed specifically for the study included 'monosyllabic words' for evaluation of speech identification in 'spatial noise'. The former was developed by extracting words from a corpus of existing words while the latter was developed as a part of the study. Details of the development of the material are provided below.

Procedure for development of monosyllabic word material:

The monosyllabic Indian-English words used for speech identification in the study were selected from an existing corpus of words. These words had been earlier established to be familiar / highly familiar to children aged 6 years and above who had studied in English medium schools for at least 3 years. From this corpus, 240 monosyllabic words were selected to reconfirm that they were highly familiar to children as young as 6 years, the youngest age group included in the study. Ten children who had been exposed to Indian-English for at least 3 years were required to provide the meaning of each word or describe the word either orally or through action. From the initial 240 words, 200 words that were highly familiar to 90% of the children were shortlisted. It was ensured that all the phonemes of Indian-English (Ramakrishna et al., 1962) were represented in the shortlisted words. As the words were highly familiar to the youngest age group, they were considered to be highly familiar to the older age groups included in the study.

Procedure for development of spatial noise:

The spatial restaurant noise that was recorded in a quick-service restaurant located adjacent to a busy street with light motor vehicles plying. Restaurant noise was chosen as noise emanates from different directions and is a combination of speech as well as non-speech signals that occur randomly. The restaurant selected was a busy, small one, without air-condition. The noise, recorded during lunch time, represented a typical quick-service Indian restaurant/cafeteria. The noise consisted of random noise, including sounds of people talking, dishes clanking, roadside traffic noise and other sounds typically heard in a restaurant. The nature of the noise was judged to be diffuse, and it was difficult to distinguish specific words spoken by the patrons / waiters.

The recording was done using Sennheiser ME 66 short gun microphones having a super cardioid polar pattern, frequency response between 40 to 20000 Hz and maximum SPL of 126 dB at a strategic point in the restaurant. The strategic point enabled recording of the noise emanating from the kitchen, pantry, street, waiters and the patrons. The microphones were placed on stands at a height of 45 inches, to be at the ear level of patrons having average height. The noise was recorded at +45˚, -45˚, +90˚, -90˚, 180˚, +135˚, -135˚ and 0˚ at a constant radius of one meter, with two adjacent azimuths being measured at a point of time. The azimuths were calculated with reference to one mic position which was labelled as 0º. Thus, to record the eight azimuths, the recordings were done 4 times. The noise could be recorded from two microphones at a time as the audio interphase MOTU Microbook II permitted only two microphones being connected at a time. The noise fluctuations were repetitive and similar over a period of time during the measurement, thus, although the recording was done four time, the noise picked-up were similar to what would have been picked-up if all eight microphones were active at a point of time.

The noise picked-up by the microphones were routed to the audio interface, MOTU Microbook II via a three-pin split female XLR cable. A computer loaded with Cuemix Fx application served as an audio mixing console for the signals received from the Microbook. The audio interface was connected to a personal computer (Hewlett Packard, with Intel core processor 5 and 4 GB RAM) loaded with Abode Audition (Version 3), a digital audio workstation used to record the noise in eight tracks and for further used for waveform editing. The noise on each tract was scaled such that the average amplitude was similar on the eight tracts.

In addition to the restaurant noise, a continuous speech-noise was generated using Adobe Audition (version 3.0) software. It was ensured that the average RMS value of the continuous speech-noise was similar to that of the spatial noise.

Test environment

All audiological evaluations to select the participants were carried out in an air-conditioned acoustically treated double-room that met the specifications of ANSI S3.1, 1999 (R2013). The speech identification testing in the presence of spatial and continuous speech noise was carried out in a quiet room with facility to evaluate with an eight-loudspeaker array. All the test facilities were free from visual disturbances.

Procedure for selection of the participants

Those who meet the inclusion criteria were screened with SCAP to rule out auditory processing disorder. A case history was taken to know any relevant information related to their hearing. The information regarding the presence of hearing loss, family history of hearing loss, history of ear infections/ surgery and any other history positive related to hearing was obtained. The individuals who had no positive history indicating that they had a hearing loss were subjected to further investigation for the inclusion into the study.

All the equipment that required calibration were calibrated prior to the data collection. The calibration of the audiometer was done as per the guidelines of ANSI S3.6, 2004 (R2010). The equipment used to assess the hearing status of the participants included a calibrated dual channel diagnostic audiometer (MA 52 with TDH-39 headphones) to determine the pure-tone thresholds of the participants as well as their speech identification abilities. Pure-tone air conduction and bone conduction testing was carried out using a modified Hughson-Westlake procedure (Carhart & Jerger, 1959). The air conduction and bone conduction testing were established for frequencies between 250 to 8000 Hz and 250 to 4000 Hz, respectively. The individuals with pure-tone thresholds $\leq$ 25 dB HL between 250 to 8000 Hz were included for further evaluation. Speech identification scores were measured using a phonemically balanced word identification test in English (Yathiraj & Muthuselvi, 2009). The recorded words were presented at 40 dB SL (Reference speech reception threshold). The individuals with speech identification scores greater than 75% in quiet were selected for the study.

Immittance Audiometry was carried out to determine the middle ear function using a calibrated immittance meter. A tympanogram was obtained with 226 Hz probe tone. Ipsilateral and contralateral reflexes were measured for 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. The individuals indicating normal middle ear function were retained for the study.

Transient otoacoustic emissions were measured to rule out any cochlear pathology. The click stimuli were presented at 85 dB SPL. Only those with otoacoustic emissions having an amplitude of 3 dB above the noise floor were further evaluated.

Fifty children with an age range of 6 to 7 years and fifty adults with an age range of 18 to 25 years, who met the above inclusion criteria were selected for the testing of speech identification in the presence of spatial noise and speech noise.

Procedure for testing speech perception in the presence spatial noise

The recorded noise from the restaurant was used to produce the spatial noise condition. This system consists of eight loudspeaker arrays placed in a circular pattern around the subject. The loudspeakers in eight different azimuths consisted of Genelec 8020B professional studio monitors for accurate reproduction of the recorded spatial noise. The loudspeakers had a frequency response of 66 Hz to 20000 Hz (± 2.5 dB). Each of the eight tracts recorded in the restaurant through the microphone were fed to each of the eight loudspeakers to replicated the noise heard in the restaurant. Before the actual testing, calibration of the loud speakers was done using a Bruel and Kjaer sound level meter (type 2270) having a random incidence pre-polarized free-field ½" microphone (type 4189). The eight loudspeakers were positioned in a 360˚degree arc. The loudspeakers were placed 45˚ apart. The height of the loudspeaker was adjusted to be at the ear level of the participants.

The spatial restaurant noise and target speech stimuli were delivered to the loudspeakers via Lynx Aurora 16 sound card and Cubase, a computer controlled, multichannel, digital audio system. The speech stimuli were presented at 0˚ azimuth and the spatial restaurant noise was presented through loudspeakers placed at +45˚, -45˚, + 90˚, -90˚, 180˚, + 135˚, -135˚ and 0˚ azimuths, re-creating acoustic environment that typically occurs at a noisy restaurant. The participants were seated 60 cm (24 inches) in front of the 0˚ azimuth loudspeaker.

The speech identification in the presence of noise was tested at 0 dB SNR using the selected 200 words. The same 200 words were randomised thrice and presented in along with different noise conditions. The same 200 words were used to ensure that variations in the words did not affect the performance in noise. The listeners were instructed to repeat the words produced by the female talker in the presence of noise.

Procedure for testing speech perception in the presence continuous noise

The continuous speech-noise and target speech stimuli were presented through a loudspeaker placed at 0˚ azimuth. The noise and speech stimuli were delivered through the same digital audio system. The participants were seated in front of the 0˚ azimuth loudspeaker. The testing was carried out twice in the presence of continuous noise at 0 dB SNR, using the same 200 words. This SNR was selected based on a pilot study that was carried out on 5 children and 5 adults (Yathiraj & Hephzibha, 2017). The listeners were instructed to repeat the words produced. Adequate gaps were also provided to prevent fatigue as well as prevent the effect of word familiarity.

Scoring:

Every correctly identified word was given a score of one and an incorrectly identified word was given a score of zero. The scores for each child for each list was tabulated. The maximum obtainable word score was 200. To determine the errors in phoneme perception, initially percentages of the frequency of occurrence for all the phonemes were calculated. Later, using the formula given below the percentage of errors calculated. The responses were scored in a similar manner for both speech identification in the presence of spatial noise as well as continuous speech noise.

$$Percentage\ of\ error = \left(\frac{No\ of\ errors\ observed\ for\ particular\ phoneme}{Frequency\ occurrence\ of\ phoneme\ \times Total\ number\ of\ children}\right) \times 100$$

Statistical analyses

The data of the present study were tabulated and statistically analyzed using the Statistical Package for Social Sciences (SPSS, version 20.0) software. Descriptive and inferential statistics were carried out to estimate the mean and standard deviation of the test parameters. Shapiro-Wilks test of normality indicated that the word identification scores and phonetic scores of the children and adults were normally distributed. Hence, parametric tests were used. As the phoneme scores of the children and adults were not normally distributed, non-parametric tests were used.

RESULTS

The data obtained from the 100 participants, grouped into two age groups, were compared to determine the effect of spatial noise and continuous speech noise on speech identification. Analyses were done to compare scores obtained in the presence of spatial noise with scores in the presence of speech noise. This was done for children and adults separately for both word identification scores and phoneme error scores. In addition, the palace, manner and voicing errors were compared between the noise conditions (spatial noise & continuous speech noise) as well as between the 2 participant groups (children & adults). Prior to comparing the variables, Shapiro-Wilks test of normality was done to see if the scores of the two groups in each of the noise conditions were normally distributed. It was observed that the word identification scores and palace, manner and voicing errors scores were normally distributed. Hence, parametric statistics was used. The phoneme error scores were not normally distributed and hence, non-parametric statistics was used.

The results of the study are presented under the following headings:

1. **Comparison of *word identification scores* within and between children and adults**
    - 1.1. Comparison of word identification scores between noise conditions within children,
    - 1.2. Comparison of word identification scores between noise conditions within adults,
    - 1.3 Comparison of word identification scores between children and adults for each noise condition.
2. **Comparison of *place, manner and voicing errors* within and between children and adults**
    - 2.1. Comparison of place, manner and voicing errors between noise conditions within children
    - 2.2. Comparison of place, manner and voicing errors between noise conditions within adults
    - 2.3. Comparison of place, manner and voicing errors between children and adults for each noise condition,

3. **Comparison of *phoneme error scores* within as well as between children and adults for each noise condition**
    - 3.1. Comparison of phoneme error scores within children and within adults between noise conditions

3.2. Comparison of phoneme error scores between children and adults for each noise conditions

1. Comparison of word identification scores within and between children and adults

From the descriptive statistics (Table 4.1) it is evident that the word identification scores varied marginally across the test trials. This was seen for word identification scores presented in the presence of spatial noise as well as in the presence of speech noise. Further, the mean and median word identification scores were higher in the presence of speech noise compared to spatial noise. ANOVA was done to establish whether the difference in scores across trials were significantly different.

Table 4.1: *Mean, median and standard deviation of word identification scores*

Noise Type	Trials	Mean*			Median*			SD		
		Children	Adults	Avg	Children	Adults	Avg	Children	Adults	Avg
Spatial noise	1	160.7	166.8	163.8	160	166	163	6.2	7.5	7.5
	2	162.5	169.5	166.0	162	168	166.5	5.9	6.3	7.0
	3	162.8	169.9	166.4	163	169	166	5.7	6.3	6.9
Speech noise	4	178.2	182.3	180.2	178.5	184	180.2	6.9	5.4	6.5
	5	177.4	182.4	179.9	178	183	179.9	7.3	4.7	6.6

Note. * Maximum possible score = 200; Avg = Average scores of children & adults

1.1. Comparison of word identification scores between trials / noise conditions within children

To compare the word identification scores in children between noise conditions (3 trials with spatial noise & 2 trials with continuous speech noise), a one-way ANOVA was done. The results revealed that there was a statistically significant difference between the noise conditions among the children [$F(4,196) = 368.50$, $p < 0.001$, $\eta_p^2 = 0.88$].

As can be seen in the pair-wise comparisons shown in Table 4.2, within the spatial noise trials, a statistically significant difference occurred between the 1st and 2nd as well as the 1st and 3rd trials ($p < 0.05$). Likewise, the comparisons between spatial noise trials (trials 1, 2 & 3) and continuous speech noise (trials 4 & 5) were also observed to be significant ($p < 0.001$). However, the pair-wise comparison within the noise conditions indicated that there was no statistical significant difference between the 2nd and 3rd trials of spatial noise ($p > 0.05$) and between the 2 trials with continuous speech noise (trials 4 & 5).

Table 4.2: *Comparison of word identification scores between trials as well as types of noise in children*

Noise Type	Trials	1	2	3	4	5
Spatial noise	1	-	0.00*	0.00*	0.00*	0.00*
	2	-	-	0.99	0.00*	0.00*
	3	-	-	-	0.00*	0.00*
Speech noise	4	-	-	-	-	0.97
	5	-	-	-	-	-

Note. * = $p < 0.001$

1.2. Comparison of word identification scores between trials / noise types within adults

A one-way ANOVA was used to compare the word identification scores in adults within noise conditions (3 trials with spatial noise & 2 trials with continuous speech noise). The results revealed that there was a statistically significant difference between the noise types within the adults [$F(4, 196) = 254.33$, $p < 0.001$ $\eta_p{}^2 = 0.83$].

From Table 4.3 it can be seen that the pair-wise comparisons done within the noise conditions indicated no statistically significant difference between the scores obtained during the 2 trials with continuous speech noise ($p > 0.05$). However, for spatial noise there was a significant difference between the 1st and 2nd as well as the 1st and 3rd trials ($p < 0.001$), but not between the 2nd and 3rd trials ($p > 0.05$). The pair-wise comparison between continuous speech noise and spatial noise was observed to be significant ($p < 0.001$).

Table 4.3: *Comparison of word identification scores between trials as well as noise types in adults*

Noise Type	Trials	1	2	3	4	5
Spatial noise	1	-	0.00*	0.00*	0.00*	0.00*
	2	-	-	0.99	0.00*	0.00*
	3	-	-	-	0.00*	0.00*
Speech noise	4	-	-	-	-	1.00
	5	-	-	-	-	-

Note*. * indicates p < 0.05*

1.3. Comparison of word identification scores between children and adults for each trial / noise type

The comparison of word identification scores between children and adults was established using a mixed ANOVA (2 age groups x 5 noise trials). The results revealed that there was a significant main effect [$F(4, 392) = 613.86$, $p < 0.001$, $\eta_p^2 = 0.86$]. The interaction effect was observed to be significant [$F(4, 392) = 3.94$, $p < 0.05$, $\eta_p^2 = 0.39$]. The pair-wise comparison between the 2 groups for each noise trial, done using t-tests with Bonferroni correction, indicated that there was statistical significant difference between the 2 groups for both continuous speech noise and spatial noise in all the trials (Table 4.4).

Table 4.4: *Comparison of word identification scores for each trial between children and adults*

Noise used	**Trials**	**Children Vs Adults**
Spatial noise	1	$t(98) = -4.39$, $p < 0.00$, $d = 0.87$
	2	$t(98) = -5.70$, $p < 0.00$, $d = 1.14$
	3	$t(98) = -5.90$, $p < 0.00$, $d = 1.18$
Speech noise	4	$t(98) = -3.26$, $p < 0.00$, $d = 0.65$
	5	t(98) = -4.02, $p < 0.00$, $d = 0.80$

2. Comparison of place, manner and voicing error scores within and between children and adults

The mean, median and standard deviations for place, manner and voicing error scores are depicted in Table 4.5. The mean and median scores of the place errors were found to be higher than the manner and voicing error scores.

Table 4.5: *Mean, median and standard deviation of place, manner and voicing error scores*

Noise used	Feature	Trials	Mean*			Median*			SD		
			Children	Adults	Avg	Children	Adults	Avg	Children	Adults	Avg
Spatial noise	Place	1	21.6	21.4	21.5	23.0	21.5	22.0	6.8	5.0	5.9
		2	19.7	18.5	19.1	19.5	18.0	18.0	5.4	4.7	5.1
		3	20.8	18.2	19.5	20.0	17.5	19.0	5.3	4.5	5.1
Speech noise		4	11.5	10.1	10.8	11.0	9.5	10.0	4.4	3.1	3.7
		5	11.6	10.3	10.9	11.0	10.0	10.5	4.0	2.7	3.3
Spatial noise	Manner	1	18.6	17.9	18.2	18.5	18.0	18.0	5.3	4.9	5.1
		2	15.8	15.9	15.6	16.0	15.0	15.5	4.3	3.7	4.0
		3	17.3	14.6	15.9	17.0	14.0	15.0	5.0	4.3	4.8
Speech noise		4	10.2	9.2	9.7	10.0	9.0	9.0	4.1	2.7	3.4
		5	10.0	9.0	9.5	10.0	9.0	9.0	3.6	2.6	3.1
Spatial noise	Voicing	1	12.9	12.2	12.5	14.0	12.0	12.5	3.7	4.3	4.0
		2	12.1	11.0	11.5	12.0	11.0	12.0	3.8	3.4	3.6
		3	12.5	10.7	11.6	13.0	10.0	11.0	4.1	3.3	3.8
Speech noise		4	6.6	6.3	6.4	6.0	6.0	6.0	3.9	2.3	3.1
		5	7.1	6.5	6.8	7.0	6.0	7.0	3.4	2.4	2.9

Note. Avg = Average scores of children & adults

2.1. Comparison of place, manner and voicing errors between noise conditions within children

The comparison of place, manner and voicing error scores in children within noise conditions was analysed using one-way ANOVA, separately for place, manner and voicing error scores. A significant main effect was observed for place [(*F*(4, 196)

= 112.78, $p < 0.001$, $\eta_p^2 = 0.69$)], manner [$F(4, 196) = 97.73$, $p > 0.05$, $\eta_p^2 = 0.66$], as well as for voicing errors [$F(4, 196) = 62.12$, $p > 0.05$, $\eta_p^2 = 0.55$].

The results of pair-wise comparison of *place and voicing errors* revealed that there was no statistical significant difference within the spatial noise trials (trials 1, 2, & 3) and within the continuous speech noise trials (trials 4 & 5) at the 0.05 level. However, a statistically significant difference was observed between the noise conditions ($p < 0.001$). This can be observed in Tables 4.6.

Table 4.6: *Comparison of place, manner and voicing errors within children between trials / noise types*

	Noise used	Trials	1	2	3	4	5
PLACE ERRORS	Spatial noise	1	-	0.23	1.00	0.00*	0.00*
		2	-	-	0.32	0.00*	0.00*
		3	-	-	-	0.00*	0.00*
	Speech noise	4	-	-	-	-	1.00
		5	-	-	-	-	-
	Noise used	Trials	1	2	3	4	5
MANNER ERRORS	Spatial noise	1	-	0.00*	0.27	0.00*	0.00*
		2	-	-	0.09	0.00*	0.00*
		3	-	-	-	0.00*	0.00*
	Speech noise	4	-	-	-	-	1.00
		5	-	-	-	-	-
	Noise used	Trials	1	2	3	4	5
VOCING ERRORS	Spatial noise	1	-	1.00	1.00	0.00*	0.00*
		2	-	-	1.00	0.00*	0.00*
		3	-	-	-	0.00*	0.00*
	Speech noise	4	-	-	-	-	1.00
		5	-	-	-	-	-

Note. * = $p < 0.001$

The pair-wise comparison of *manner errors* within the noise conditions indicated that there was no statistical significant difference observed for continuous speech noise (trials 4 & 5) and 1st and 3rd as well as the 2nd and 3rd trials of spatial noise ($p > 0.05$). On the other hand, there was a statistical significant difference noted between 1st and 2nd trials for spatial noise ($p < 0.05$) in children. Similarly, a statistical significant difference was observed between the scores obtained under the 2 types of noise (spatial noise & continuous speech noise) at the 0.05 level (Table 4.16).

2.2. Comparison of place, manner and voicing errors between noise conditions within adults

Using a one-way ANOVA, comparison of place, manner and voicing error scores in adults, within noise conditions was analysed. This was done separately for place, manner and voicing error scores. A significant main effect was observed for place [$F(4, 196) = 180.72$, $p < 0.001$, $\eta_p^2 = 0.78$], manner [$F(4, 196) = 122.66$, $p > 0.05$, $\eta_p^2 = 0.71$]. as well as for voicing errors [$F(4, 196) = 61.42$, $p > 0.05$, $\eta_p^2 = 0.55$].

The pair-wise comparison of *place and manner errors* within the noise conditions (Tables 4.7) indicated that there was no statistical significant difference for speech noise and for 2nd and 3rd trials of spatial noise ($p > 0.05$). However, there was a statistical significant difference noted between 1st and 2nd and 1st and 3rd ($p < 0.001$). A statistical significant difference was also observed between the noise conditions ($p < 0.05$).

Table 4.7: *Comparison of place, manner and voicing errors within adults between trials / types of noise*

	Noise used	Trials	1	2	3	4	5
PLACE ERRORS	Spatial noise	1	-	0.00*	0.00*	0.00*	0.00*
		2	-	-	1.00	0.00*	0.00*
		3	-	-	-	0.00*	0.00*
	Speech noise	4	-	-	-	-	1.00
		5	-	-	-	-	-
	Noise used	Trials	1	2	3	4	5
MANNER ERRORS	Spatial noise	1	-	0.01	0.00*	0.00*	0.00*
		2	-	-	0.30	0.00*	0.00*
		3	-	-	-	0.00*	0.00*
		4	-	-	-	-	1.00

	Speech noise	5	-	-	-	-	-
	Noise used	Trials	1	2	3	4	5
VOCING ERRORS	Spatial noise	1	-	0.19	0.12	0.00*	0.00*
		2	-	-	1.00	0.00*	0.00*
		3	-	-	-	0.00*	0.00*
	Speech noise	4	-	-	-	-	1.00
		5	-	-	-	-	-

Note. ** = p < 0.001*

Unlike what was observed for place and manner errors, the results of the pair-wise comparison of *voicing errors* revealed that there was no statistical significant difference the trials within both the noise types (p > 0.05). However, a statistically significant difference was observed between the noise types (p < 0.001). This can be observed in Table 4.7.

2.3. Comparison of place, manner and voicing errors between children and adults for each noise types

The comparison of place, manner and voicing error scores between children and adults was done using a repeated measure ANOVA (2 age groups x 5 noise trials). The results of the *place errors* revealed that there was a significant main effect [$F(4, 392) = 277.27$, $p < 0.001$, $\eta_p^2 = 0.73$]. However, there was no significant interaction effect observed [$F(4, 392) = 1.91$, $p > 0.05$, $\eta_p^2 = 0.01$]. The results of the *manner errors* revealed that there was a significant main effect [$F(4, 392) = 214.16$, $p < 0.001$, $\eta_p^2 = 0.68$]. The interaction effect between the noise trials and groups was also noted be significant [$F(4, 392) = 2.86$, $p < 0.05$, $\eta_p^2 = 0.28$]. For *voicing errors* there was a significant main effect [$F(4, 392) = 122.34$, $p < 0.001$, $\eta_p^2 = 0.55$]. On the other hand, there was no significant interaction effect observed [$F(4, 392) = 1.27$, $p > 0.05$, $\eta_p^2 = 0.01$].

Additionally, a comparison of place, manner, and voicing error scores between children and adults was done separately using a repeated measure ANOVA for spatial noise (2 age groups x 3 noise trials) and speech noise (2 age groups x 2 noise trials). This was done as difference in scores were observed between the 2 types of noise in the earlier evaluations. For the spatial noise and speech noise, no significant difference was present between the two groups for place, manner, and voicing error scores (Table 4.8).

Table 4.8: *Comparison of place, manner and voicing errors between children and adults, with test trials combined*

Type of Noise	Feature	Between group difference (ANOVA)
Spatial Noise	Place	$F(1, 98) = 1.93, p > .05, \eta_p^2 = 0.01$
	Manner	$F(1, 98) = 2.42, p > .05, \eta_p^2 = 0.02$
	Voicing	$F(1, 98) = 3.64, p > .05, \eta_p^2 = 0.03$
Speech Noise	Place	$F(1, 98) = 3.78, p > .05, \eta_p^2 = 0.03$
	Manner	$F(1, 98) = 2.47, p > .05, \eta_p^2 = 0.02$
	Voicing	$F(1, 98) = 0.62, p > .05, \eta_p^2 = 0.00$

3. Comparison of *phoneme error scores* within as well as between children and adults for each noise condition

The phoneme error scores within each participant group (children & adults) was analysed using Friedman’s test, followed by Wilcoxon sign ranked test. The between group comparison was established using Mann Whitney U test. Non-parametric statistics was used as the phoneme error data were not normally distributed, as mentioned earlier.

3.1. Comparison of phoneme error scores within children and within adults between noise conditions

The Friedman’s test done to compare the phoneme errors within the children and within the adults indicated a significant overall difference within children across noise trials [$\chi^2(59) = 912.57$, $p < 0.001$] as well as in adults [$\chi^2(59) = 912.57$, $p < 0.001$]. To confirm which of the noise trials differed within each participant group, Wilcoxon signed rank test was done. The results indicated that both the groups showed no statistical significant difference for all the phonemes within continuous speech noise except for /z/ and /r/ in children and /g/ in adults. Unlike the above finding, in there was a significant difference in phoneme errors in both groups within the spatial noise trials at a 0.05 level (1st & 2nd, 1st & 3rd, 2nd & 3rd trials) as well between the noise types (1st & 4th, 1st & 5th, 2nd & 4th, 2nd & 5th, 3rd & 4th, and 3rd & 5th trials). The phonemes which showed significant difference are listed in Table 4.15. Details of the findings of the Wilcoxon signed rank test are provided in Appendix 1.

Table 4.9: *Comparison of phoneme error scores within and between noise types in children and in adults*

Noise Type	Trials	Phonemes significant in children	Phonemes significant in adults
Within Spatial noise	1st and 2nd	/k/, /f/, /v/, /r/, /h/	/k/, /d/, /s/, /f/, /v/, /th/ and /r/
	1st and 3rd	/k/ and /sh/	/b/, /s/, /f/, /v/, /n/, /w/ and /h/
	2nd and 3rd	/k/,/j/,/r/,/l/ and /h/	/m/, /n/ and /ch/
Within Speech noise	4th and 5th	/z/ and /r/	/g/
Spatial noise vs Speech noise	1st and 4th	/p/,/k/,/g/,/t/,/d/,/s/,/sh/,/z/,/v/, /th/,/ch/,/m/,/n/,/r/,/l/and /h/	/b/,/g/,/t/,/d/,/sh/,/v/,/th/,/j/,/m/, /n/,/r/ and /h/
	1st and 5th	/p/,/k/,/g/,/t/,/d/,/s/,/sh/,/v/, /th/,/ch/,/m/,/n/,/r/,/l/and /h/	/g/,/t/,/sh/,/j/,/m/,/n/,/r/ and /h/
	2nd and 4th	/p/,/b/,/k/,/g/,/t/,/d/,/s/,/z/,/f/, /v/,/th/,/ch/,/n/,/l/,/w/ and /h/	/p/,/b/,/k/,/g/,/t/,/d/,/s/,/z/,/f/,/v/ ,/th/,/ch/,/n/,/l/,/w/ and /h/
	2nd and 5th	/p/,/b/,/k/,/g/,/t/,/d/,/s/,/f/, /v/,/th/,/ch/, /j/,/n/, /r/, /l/ and /h/	/b/,/k/,/g/,/t/,/d/,/s/,/f/,/v/ ,/th/,/ch/,/n/,/r/,/l/ and /h/
	3rd and 4th	/p/,/k/,/g/,/t/,/d/,/s/,/z/,/th/,/ch/, /j/,/n/, /r/, /l/ and /h/	/p/,/b/,/k/,/g/,/t/,/d/,/s/,/f/,/v/ ,/th/,/ch/,/n/,/r/,/l/ and /h/
	3rd and 5th	/b/,/k/,/g/,/t/,/d/,/s/ ,/th/,/ch/,/j/,/m/,/n/,/r/,/l/ and /h/	/p/,/b/,/k/,/g/,/t/,/d/,/s/, /sh/,/f/,/v/,/th/,/j/,/n/,/r/,/l/ and /h/

3.2. Comparison of phoneme error scores between children and adults for each noise conditions

The comparison of phoneme scores between children and adults were carried out using Mann Whitney U test. The results revealed that 15 out of the 20 phonemes studied were statistically significant ($p < 0.05$) for spatial noise. However, only 8 out of the 20 phonemes showed statistical significant ($p < 0.05$) for speech noise. None of the phonemes errors were consistently different between the 2 participant groups across the 3 trials with spatial noise (trials 1, 2, &3) and the 2 trials with continuous speech noise (trials 4 & 5). Details of the significance of difference between the 2 participant groups for each of the 20 phonemes, in each trial is provided in Appendix 2.

DISCUSSION

The results of the current study that aimed to determine the influence of spatial noise on speech identification in children and adults are discussed below. The results are discussed under the following headings:

- Effect of spatial and speech noise on word identification scores
- Effect of spatial and speech noise on place, voicing, and manner of articulation scores
- Effect of spatial and speech noise on phoneme scores

Effect of spatial and speech noise on word identification scores

From, the findings of the study, it was noted that the word identification scores were different when evaluated in the presence of speech noise and spatial noise. The results indicated that word identification scores vary across trials when spatial noise was used but not when speech noise was used. There was difference observed between spatial and speech noise, in both the groups. Further, the scores were higher in continuous speech noise than spatial noise.

The poorer scores in the presence of spatial noise compared to continuous noise could be attributed to informational masking that may have occurred in the former condition. It has been observed by Carhart, Tillman, and Greetis (1969) and Freyman, Helfer, McCall, and Clifton (1999) that release from masking would enable individuals to get glimpses of the signal resulting in masking occurring due to information content (either phoneme or cognition) rather than energy masking (frequency or temporal). This informational masking has been noted to have a more adverse effect compared energy masking. Larsby and Arlinger (1994) also noted that the speech spectrum random noise had more masking effect than speech maskers. Sperry et al. (1997) reported that when the acoustic and linguistic features of the target signal and the competing signal become more similar, it becomes more difficult to differentiate between the target signal and the competing signal. In the current study, the spatial noise maskers consisting of speech of the patrons and the waiters was probably similar to the speech stimuli and hence had a more detrimental effect when compared to continuous speech noise.

In the present study, variations in speech identification scores occurred from one trial to another in the presence of spatial noise. This could be attributed to the varying acoustical parameters in the noise. The spatial noise, recorded in a typical quick-serving Indian restaurant, varied over time in terms as the acoustical signal constantly differed. The varying noise included people talking, kitchen noise, cutlery noise and traffic noise, as it was a roadside restaurant. This would have varying masking effects and could have influenced the speech identification scores from each test trial to another when session. Unlike the spatial noise, the speech noise was a constant noise that did not differ much over time. Thus, the masking effect of speech noise would have be constant resulting in the similar speech identification scores from one trial to another.

Effect of spatial and speech noise on place, voicing, and manner of articulation scores

Error analysis of the participants indicated that the mean place error scores were the highest followed by manner and voicing errors. Further, the error scores were higher in the presence of speech noise than spatial noise. Between the two types of noise (spatial noise & continuous speech noise), pair-wise comparisons revealed that all three feature errors (place, manner, & voicing) were significantly different with the errors being more in the presence of spatial noise. This difference in performance was seen both in children and adults. However, these feature scores were not significantly different between the children and adults.

The larger number of errors in the presence of spatial noise can be attributed to the ability of the participants to utilise segmental cues in the presence of a masking noise. In the presence of continuous speech noise, due to the masking effects of speech noise being similar over a period of time, the participants were probably able to carryout auditory closure more readily and predict the speech sounds. However, the varying masking effects of speech noise over time probably made it difficult for the participants to predict the way the speech segmental cues would be masked to be able to correctly identify them. This could have led to the phoneme errors being larger in the presence of spatial noise compared to continuous speech noise.

Within the two types of noises, the feature errors of children differed from that of adults across trials. In the children no significant difference was observed between trials for all three features, except for manner errors that varied between two of the trials in the presence of spatial noise (trials 1 & 2). In contrast, among the adults, place and manner error showed difference across trials, but such a difference was not seen in voicing errors.

The lack of variation in performance in children across trials can be ascribed to their immature phoneme development. It is known that speech sounds are masked differently in the presence of noise, depending on the frequency characteristics of noise (Larsby & Arlinger, 1994; Papso & Blood, 1989; Prosser et al., 1991). In the presence of varying noise conditions, the children perhaps could not predict speech sounds from the available segmental cues to perceive a variety of speech sounds unlike adults. The immature phoneme development in children probably hampered them from perceiving different speech sounds in the presence varying masking signals unlike adults. Unlike the children, the adults would have utilised the varying masked cues to perceive different speech sounds from one trial to the other.

In the adults the variations in phoneme errors was seen for place and manner features but not for voicing features. The availability of multiple segmental cues while perceiving voicing features in the presence of noise, would have led the participants to have lesser variations in errors from one trial to another. This reduced variability in voicing errors compared to place and manner is evident in Table 4.5. On the other hand, the reduced number of cues for the perception of place and manner cues would have made them more vulnerable to the varying effects of masking from one trial to another. This would have resulted in the adults, to utilise these limited cues differently from one trial to the other.

Effect of spatial and speech noise on phoneme scores

The findings of phoneme error scores revealed that across the types of noise the phoneme errors across trials were significantly more in the presence of spatial noise than in the presence of speech noise. Additionally, within each type of noise, the number of phoneme errors that were significantly different across trials were much larger in the presence of spatial noise than within trials in the presence of speech noise. Further, this was observed more in children than adults, both across the noise types as well as within the noise types (Table 4.9).

It was also noted that the phoneme error pattern varied more for spatial noise than for continuous speech noise. This could be attributed to variations in frequency, intensity and temporal characteristics of the spatial noise. The noise that was presented from each loudspeaker has different environmental sources of noise that varied in frequency, intensity and temporal characteristics over a period. As this noise varied from time-to-time, it is possible that the masking effect of the noise for standard speech stimuli would vary from one test session to another, in the absence of any other change. The noise that varies in these parameters is likely to result in varying speech perception scores in individuals with normal hearing. This variation could be co-variable affecting the findings of studies reporting of performance with different algorithms on listening devices. The findings of studies such as those done by Gifford and Revit (2010a) and Brockmeyer and Potts (2011), based on speech identification in the presence of R-SPACE^{TM} noise, reported of improving with the use of pre-processing strategies in cochlear implants. It can be inferred that in addition to the strategies manipulated in the cochlear implants (ADRO, ADRO+ASC, ADRO+ASC+BEAM), the spatial noise used by them could have also affected the speech identification scores reported by them. Similar results were observed by Potts and Kolb (2014), who reported of the advantage of using different noise reduction algorithms in cochlear implants when sentence recognition was evaluated in the presence of spatial noise. Likewise, Rakszawski et al. (2016) inferred about the influence of noise reduction algorithms based on their study using adaptive HINT sentences along with R-SPACE™ noise. From the findings of the current study it can be deduced that the results of the studies that used noise similar to spatial noise are highly likely to have been influenced by the inherent variations that occurs from one test trial to another. Thus, although spatial noise gives a better indication of speech perception in a real-life situation, the variations in scores seen across test trials could influence the findings of studies that evaluate the effect of various parameters.

CONCLUSIONS

The study indicated that when spatial noise was used, significant differences in word as well as phoneme scores occurred from one test trial to another. Such differences were not seen when continuous speech noise was used. These differences were seen for children as well as adults. Although word identification scores differed between children and adults, no such significant difference occurred for the feature errors when the 5 test trials were combined or when the test trials for each type of noise were combined. Across trials, the type of phoneme errors varied considerably when speech was presented in the presence of spatial noise but did not differ to the same extent when presented in the presence of continuous speech noise. The variations in frequency, intensity and duration of the signals in spatial noise would have led to large variations in phoneme errors from one test trial to another in the presence of spatial noise. The outcome of studies that have used spatial noise to study the influence of various noise reduction algorithms in hearing aids and cochlear implants are likely to have been contaminated by the varying nature of the noise used. Thus, when testing with spatial noise, test reliability is likely to be compromised due to the varying effects of the noise.

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APPENDIX-1

Pair-wise comparison of phoneme /p/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=1.80	z=1.90	z=3.28	z=3.68	z=1.13	z=2.43	z=3.57	z=2.85	z=3.85	z=1.37
	p=0.07	p=0.36	p=0.00*	p=0.00*	p=0.25	p=0.01*	p=0.00*	p=0.04*	p=0.00*	p=0.16
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=1.50	z=1.03	z=1.55	z=0.59	z=0.86	z=3.36	z=2.75	z=3.23	z=2.05	z=1.05
	p=0.13	p=0.29	p=0.12	p=0.55	p=0.38	p=0.00*	p=0.06	p=0.00*	p=0.04*	p=0.29

Pair-wise comparison of phoneme /b/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=1.84	z=0.40	z=3.16	z=0.55	z=1.90	z=3.94	z=3.89	z=2.66	z=2.45	z=0.16
	p=0.06	p=0.68	p=0.09	p=0.09	p=0.05	p=0.00*	p=0.00*	p=0.08	p=0.01*	p=0.87
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=3.66	z=4.40	z=5.60	z=5.50	z=1.37	z=3.57	z=3.71	z=3.01	z=2.99	z=0.63
	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.17	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.52

Pair-wise comparison of phoneme /k/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=3.21	z=4.43	z=5.62	z=5.57	z=2.35	z=4.74	z=4.90	z=2.28	z=3.01	z=0.96
	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.01*	p=0.00*	p=0.00*	p=0.02*	p=0.00*	p=0.33
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=2.51	z=2.47	z=5.82	z=5.52	z=0.24	z=5.11	z=4.91	z=5.39	z=4.87	z=0.93
	p=0.01*	p=0.01*	p=0.00*	p=0.00*	p=0.81	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.34

Pair-wise comparison of phoneme /g/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=0.69	z=0.82	z=4.71	z=4.44	z=0.17	z=4.34	z=3.90	z=4.34	z=3.94	z=1.20
	p=0.43	p=0.40	p=0.00*	p=0.00*	p=0.85	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.22
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=0.06	z=0.46	z=3.59	z=4.60	z=0.36	z=3.70	z=4.79	z=3.52	z=4.97	z=2.98
	p=0.95	p=0.64	p=0.00*	p=0.00*	p=0.71	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.01*

Pair-wise comparison of phoneme /t/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=0.74	z=0.03	z=4.44	z=4.20	z=0.61	z=4.68	z=4.13	z=5.03	z=4.85	z=0.77
	p=0.45	p=0.97	p=0.00*	p=0.00*	p=0.53	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.43
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=0.06	z=0.05	z=3.63	z=2.40	z=0.18	z=4.13	z=3.00	z=4.71	z=2.96	z=1.73
	p=0.94	p=0.96	p=0.03*	p=0.01*	p=0.85	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.08

Pair-wise comparison of phoneme /d/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=0.22	z=0.03	z=3.36	z=3.81	z=0.20	z=3.30	z=4.24	z=3.21	z=3.76	z=0.22
	p=0.82	p=0.97	p=0.00*	p=0.00*	p=0.83	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.82
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=4.26	z=5.15	z=0.40	z=0.82	z=0.82	z=4.19	z=4.90	z=4.12	z=4.91	z=1.38
	p=0.00*	p=0.00*	p=0.68	p=0.40	p=0.40	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.16

Pair-wise comparison of phoneme /s/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=0.67	z=1.71	z=3.66	z=3.98	z=0.49	z=3.29	z=4.27	z=2.66	z=3.09	z=1.45
	p=0.49	p=0.08	p=0.00*	p=0.00*	p=0.62	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.14
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=3.96	z=3.55	z=4.10	z=4.80	z=0.25	z=1.68	z=2.59	z=2.13	z=4.15	z=1.29
	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.80	p=0.09	p=0.00*	p=0.03*	p=0.00*	p=0.19

Pair-wise comparison of phoneme /sh/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=1.18	z=2.44	z=2.28	z=2.90	z=1.66	z=1.89	z=2.32	z=0.25	z=0.77	z=1.34
	p=0.23	p=0.01*	p=0.02*	p=0.00*	p=0.09	p=0.58	p=0.20	p=0.79	p=0.44	p=0.18
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=2.32	z=0.84	z=2.00	z=3.00	z=1.50	z=0.37	z=1.34	z=1.18	z=2.12	z=1.63
	p=0.20	p=0.39	p=0.04*	p=0.00*	p=0.13	p=0.70	p=0.18	p=0.23	p=0.03*	p=0.10

Pair-wise comparison of phoneme /z/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=0.39	z=1.18	z=2.38	z=0.34	z=1.60	z=2.53	z=0.00	z=3.44	z=1.69	z=2.82
	p=0.69	p=0.23	p=0.01*	p=0.73	p=0.10	p=0.01*	p=1.00	p=0.00*	p=0.09	p=0.00*
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=1.00	z=0.57	z=1.41	z=0.00	z=0.44	z=2.00	z=0.81	z=1.73	z=1.41	z=1.41
	p=0.31	p=0.56	p=0.15	p=1.00	p=0.65	p=0.04*	p=0.41	p=0.08	p=0.65	p=0.15

Pair-wise comparison of phoneme /f/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=2.28	z=0.92	z=0.79	z=0.09	z=1.50	z=2.72	z=2.38	z=1.27	z=1.29	z=0.41
	p=0.02*	p=0.35	p=0.42	p=0.92	p=0.13	p=0.00*	p=0.01*	p=0.20	p=0.19	p=0.67
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=3.29	z=4.03	z=1.09	z=0.51	z=0.56	z=4.37	z=3.22	z=4.56	z=3.17	z=1.92
	p=0.00*	p=0.00*	p=2.72	p=0.60	p=0.57	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.05

Pair-wise comparison of phoneme /v/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=2.13	z=2.57	z=3.98	z=3.50	z=1.08	z=2.23	z=2.31	z=1.04	z=0.97	z=0.00
	p=0.03*	p=0.10	p=0.00*	p=0.00*	p=0.27	p=0.02*	p=0.02*	p=0.29	p=0.33	p=1.00
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=4.20	z=3.13	z=4.84	z=4.59	z=1.21	z=2.12	z=1.66	z=3.31	z=2.88	z=0.57
	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.22	p=0.03*	p=0.09	p=0.00*	p=0.04*	p=0.56

Pair-wise comparison of phoneme /th/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=1.04	z=0.05	z=3.41	z=3.31	z=0.61	z=3.83	z=3.79	z=3.66	z=3.66	z=0.00
	p=0.29	p=0.95	p=0.00*	p=0.00*	p=0.54	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=1.00
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=2.19	z=0.85	z=3.88	z=3.55	z=1.63	z=2.32	z=1.61	z=3.38	z=3.40	z=0.62
	p=0.02*	p=0.39	p=0.00*	p=0.00*	p=0.10	p=0.02*	p=0.10	p=0.00*	p=0.00*	p=0.53

Pair-wise comparison of phoneme /ch/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=1.75	z=0.27	z=2.23	z=3.00	z=1.56	z=3.21	z=3.75	z=2.40	z=2.98	z=0.70
	p=0.08	p=0.78	p=0.02*	p=0.00*	p=0.11	p=0.00*	p=0.00*	p=0.01*	p=0.00*	p=0.48
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=1.00	z=0.29	z=1.63	z=1.63	z=2.30	z=0.44	z=0.44	z=2.71	z=2.49	z=0.00
	p=0.31	p=0.19	p=0.10	p=0.10	p=0.02*	p=0.65	p=0.65	p=0.00*	p=0.01*	p=1.00

Pair-wise comparison of phoneme /j/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=1.04	z=0.68	z=1.13	z=2.99	z=2.02	z=0.89	z=2.15	z=2.32	z=3.25	z=1.27
	p=0.29	p=0.49	p=0.25	p=0.00*	p=0.04*	p=0.37	p=0.03*	p=0.02*	p=0.00*	p=0.20
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=3.69	z=3.51	z=4.02	z=4.47	z=0.30	z=1.00	z=1.00	z=1.02	z=2.45	z=1.34
	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.76	p=0.31	p=0.31	p=0.30	p=0.01*	p=0.18

Pair-wise comparison of phoneme /m/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=1.53	z=0.25	z=3.00	z=3.02	z=1.56	z=1.56	z=1.83	z=3.13	z=3.53	z=1.11
	p=0.12	p=0.80	p=0.00*	p=0.00*	p=0.11	p=0.11	p=0.06	p=0.00*	p=0.00*	p=0.26
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=0.51	z=0.92	z=2.43	z=2.22	z=2.11	z=2.99	z=3.15	z=1.58	z=1.69	z=0.16
	p=0.61	p=0.35	p=0.01*	p=0.02*	p=0.03*	p=0.00*	p=0.00*	p=0.11	p=0.09	p=0.72

Pair-wise comparison of phoneme /n/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=0.00	z=0.54	z=3.28	z=3.11	z=0.39	z=3.55	z=2.94	z=3.43	z=3.35	z=0.76
	p=1.00	p=0.58	p=0.00*	p=0.00*	p=0.69	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.44
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=0.35	z=0.79	z=2.72	z=2.18	z=0.90	z=3.78	z=2.93	z=3.49	z=3.35	z=0.00
	p=0.72	p=0.42	p=0.00*	p=0.02*	p=0.36	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=1.00

Pair-wise comparison of phoneme /r/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=3.18	z=0.72	z=4.48	z=5.18	z=2.52	z=1.88	z=3.45	z=4.79	z=5.32	z=2.48
	p=0.00*	p=0.46	p=0.00*	p=0.00*	p=0.01*	p=0.06	p=0.00*	p=0.00*	p=0.00*	p=0.01*
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=2.27	z=2.78	z=5.00	z=4.88	z=0.60	z=3.52	z=4.08	z=2.74	z=4.07	z=0.86
	p=0.02*	p=0.00*	p=0.00*	p=0.00*	p=0.54	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.38

Pair-wise comparison of phoneme /l/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=0.37	z=1.30	z=3.37	z=3.22	z=2.10	z=4.20	z=4.49	z=2.41	z=2.59	z=0.10
	p=0.70	p=0.19	p=0.00*	p=0.00*	p=0.03*	p=0.00*	p=0.00*	p=0.01*	p=0.01*	p=0.91
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=0.57	z=1.06	z=1.51	z=1.92	z=0.61	z=3.04	z=3.13	z=3.24	z=3.24	z=0.00
	p=0.56	p=0.28	p=0.13	p=0.05	p=0.53	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=1.00

Pair-wise comparison of phoneme /w/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=1.60	z=1.80	z=0.64	z=0.57	z=0.20	z=2.30	z=1.39	z=2.50	z=1.33	z=1.50
	p=0.10	p=0.07	p=0.51	p=0.56	p=0.84	p=0.02*	p=0.16	p=0.01*	p=0.18	p=0.13
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=1.38	z=2.16	z=0.71	z=1.24	z=0.40	z=0.80	z=0.34	z=1.50	z=0.85	z=0.68
	p=0.16	p=0.03*	p=0.47	p=0.21	p=0.68	p=0.42	p=0.73	p=0.13	p=0.39	p=0.49

Pair-wise comparison of phoneme /h/ between noise conditions

Children	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=3.14	z=1.05	z=2.78	z=2.83	z=2.12	z=5.34	z=5.08	z=4.41	z=3.82	z=0.97
	p=0.00*	p=0.29	p=0.00*	p=0.00*	p=0.03*	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.33
Adults	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
	z=0.28	z=2.57	z=3.40	z=4.14	z=3.36	z=3.50	z=4.45	z=5.09	z=5.57	z=0.33
	p=0.77	p=0.01*	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.00*	p=0.73

APPENDIX –2

Significance of difference between the 2 participant groups (children & adults) for each phoneme across 5 trials

Noise	Phoneme	*z*	*p*
Spatial noise	*/p/1*	1.43	0.15
	/p/2	1.89	0.05
	/p/3	0.55	0.57
Speech noise	*/p/1*	1.30	0.19
	/p/2	3.25	0.00*
Spatial noise	*/b/1*	5.16	0.00*
	/b/2	0.00	1.00
	/b/3	1.09	0.27
Speech noise	*/b/1*	1.68	0.09
	/b/2	1.58	0.11
Spatial noise	*/k/1*	3.09	0.00*
	/k/2	2.37	0.01*
	/k/3	0.00	1.00
Speech noise	*/k/1*	3.86	0.00*
	/k/2	1.73	0.08
Spatial noise	*/g/1*	0.57	0.56
	/g/2	0.33	0.74
	/g/3	0.40	0.68
Speech noise	*/g/1*	0.93	0.35
	/g/2	2.38	0.01*
Spatial noise	*/t/1*	2.11	0.03*
	/t/2	1.30	0.30
	/t/3	2.47	0.01*
Speech noise	*/t/1*	0.16	0.87
	/t/2	0.17	0.86
Spatial noise	*/d/1*	0.93	0.35
	/d/2	1.11	0.26
	/d/3	0.90	0.36
Speech noise	*/d/1*	0.04	0.96
	/d/2	1.29	0.19
Spatial noise	*/s/1*	0.41	0.67
	/s/2	3.20	0.00*
	/s/3	3.37	0.00*

Speech noise	*/s/1*	2.01	0.04*
	/s/1	1.38	0.16
Spatial noise	*/sh/1*	0.81	0.41
	/sh/2	1.97	0.04*
	/sh/3	0.39	0.69
Speech noise	*/sh/1*	0.31	0.75
	/sh/2	1.01	0.31
Spatial noise	*/z/1*	2.45	0.01*
	/z/2	1.50	0.13
	/z/3	3.48	0.00*
Speech noise	*/z/1*	1.42	0.15
	/z/2	2.44	0.01*
Spatial noise	*/f/1*	4.08	0.00*
	/f/2	2.78	0.00*
	/f/3	1.49	0.13
Speech noise	*/f/1*	4.79	0.00*
	/f/2	3.77	0.00*
Spatial noise	*/v/1*	0.62	0.53
	/v/2	1.52	0.12
	/v/3	1.65	0.09
Speech noise	*/v/1*	1.37	0.17
	/v/2	0.47	0.63
Spatial noise	*/th/1*	0.31	0.75
	/th/2	3.15	0.00*
	/th/3	0.81	0.41
Speech noise	*/th/1*	0.00	0.99
	/th/2	1.24	0.21
Spatial noise	*/ch/1*	2.30	0.02*
	/ch/2	4.38	0.00*
	/ch/3	1.36	0.17
Speech noise	*/ch/1*	1.67	0.09
	/ch/2	1.01	1.01
Spatial noise	*/j/1*	1.83	0.06
	/j/2	1.61	0.10
	/j/3	2.40	0.01*
Speech noise	*/j/1*	1.00	0.31
	/j/2	1.46	0.14

Spatial noise	*/m/1*	1.03	0.30
	/m/2	2.13	0.00*
	/m/3	0.28	0.77
Speech noise	*/m/1*	2.13	0.33
	/m/2	3.22	0.00*
Spatial noise	*/n/1*	0.04	0.96
	/n/2	0.54	0.58
	/n/3	1.35	0.17
Speech noise	*/n/1*	1.94	0.05
	/n/2	1.32	0.18
Spatial noise	*/r/1*	1.04	0.29
	/r/2	1.01	0.31
	/r/3	3.04	0.00*
Speech noise	*/r/1*	2.55	0.01*
	/r/2	0.64	0.51
Spatial noise	*/l/1*	1.92	0.05
	/l/2	2.03	0.04*
	/l/3	0.06	0.94
Speech noise	*/l/1*	0.59	0.55
	/l/2	0.73	0.46
Spatial noise	*/w/1*	2.37	0.01*
	/w/2	1.62	0.10
	/w/3	2.15	0.03*
Speech noise	*/w/1*	3.01	0.00*
	/w/2	2.26	0.02*
Spatial noise	*/h/1*	2.09	0.03*
	/h/2	1.33	0.18
	/h/3	3.25	0.00*
Speech noise	*/h/1*	1.29	0.19
	/h/2	0.98	0.32

Note. * = $p < 0.05$

APPENDIX-3

Article presented at the 3rd International conference on Audiological Sciences

EFFECT OF CONTINUOUS NOISE ON SPEECH IDENTIFICATION IN VARIOUS SIGNAL TO NOISE RATIO (SNR)

Asha Yathiraj & Tina Hephzibha

Paper presented during the 3rd International conference on Audiological Sciences organized by the Department of Audiology & Speech Language Pathology, Kasturba Medical College, Manipal University, Mangaluru from 21st- 23rd September, 2017.

INTRODUCTION

Speech is the most important auditory stimuli in everyday situation, the audiological tests involving speech stimuli are more essential in hearing assessment. The recognition of speech in the presence of competing noise will provide an idea on which ear is most suitable for amplification. The word recognition tests also provide insight about communicative effectiveness and social adequacy. The addition of background noise to the test stimuli is to make the test representative of real life listening. Evaluating speech in quiet will not provide a realistic index of communicative difficulty. Speech in noise may be used to identify communicative difficulties and increases the sensitivity of the test. Testing in noise under various signal to noise ratio (SNR) provides information about communicative difficulties, and the resultant counselling of the patient and/or family can be the most important aspect of the hearing aid evaluation.

Studies have reported that testing in the presence of various signal to noise ratios affects speech recognition monotonically, were the increase in SNR will lead to better (increase) speech recognition performance. Beattie (1989) investigated word recognition function in the presence of multitalker noise in adults with normal hearing and hearing impairment. The stimuli were varied in SNR from 0, 6, 12, 18 and 24 dB and the subjects were tested with fixed intensity at 45 dB and 65 dB HL. The scores of normal hearing listeners were 20% higher than the listeners with hearing impairment. The 50%-word recognition scores were obtained at approximately 6 dB and 11 dB for normal hearing and hearing-impaired listeners, respectively. Thus, suggesting that listeners with hearing impairment need more favourable SNR than normal hearing listeners to achieve a word recognition score of 50%.

Beattie, Barr and Roup (1997) studied the effects of noise on word recognition scores in normal-hearing and hearing-impaired adult individuals. The participants were tested using multitalker noise in three different signals to noise ratio, 5, 10, and 15 dB. The results revealed that the percentage of scores increased with increase in SNR from 5 to 15 dB. The percentage scores of individuals with hearing impairment was lower than normal hearing individuals. The findings indicated that, the individuals with hearing impairment require more favourable SNR than normal hearing individuals to achieve comparable word recognition scores. Studebaker and Sherbecoe (1999) studied monosyllabic word recognition at higher-than-normal speech and noise levels in seventy-two normal hearing adults and thirty-two hearing impaired children. The SNR was varied from 28 to -4 dB and speech levels ranged from 64 to 99 dB SPL. The results of this study revealed, speech intelligibility in noise decrease when the levels of speech exceed 69 dB SPL and the SNR remains constant. The authors concluded that the effects of speech and noise levels are synergistic and both normal-hearing and hearing-impaired subjects are affected similarly by increased signal level when differences in speech audibility are considered.

Similarly, Finitzo-Hieber and Tillman (1978) reported that word recognition performance decreased across SNR of +12, +6 and 0 dB for children with normal hearing. In another study, Yacullo and Hawkins (1987) examined the effects of noise on monaural speech recognition in normal hearing school children, using varying SNR +2 and +6 dB. The results revealed that, the speech recognition performance decreased when the SNR decreased from +6 to +2 dB. Papso and Blood (1989) evaluated word recognition performance of thirty children (4 to 6 years) and 30 adults (19 to 28 years) on the Word intelligibility by picture identification (WIPI) in the presence of quiet and in background of multitalker noise and pink noise. WIPI list in quiet and in noise were presented through a loudspeaker at 0-degree azimuth. The mean word recognition scores for children were 77.9% and 67.6% in pink noise and multitalker noise, respectively. For adults, the score was 97.6% and 94.9% in pink noise and multitalker babble respectively. The multitalker babble have adverse effect on word recognition in children than in non-speech like noise.

The present study was carried out to know in which signal to noise ratio 70% of speech identification scores are achieved in the presence of continuous noise. Thus, the aim of the study is to determine the effect of continuous noise on speech identification in various signal to noise ratios. The specific objectives of the study are to assess speech identification in various signal to noise ratios (SNR), 0, +5 and +10 dB and to check at which SNR 70% speech identification scores are achieved.

METHODS

The current study aimed to determine the influence of continuous noise on word identification scores at different signal to noise ratio (SNR), the study was carried out in following phases:

Phase 1: Procedure for selection of participants

Phase 2: Familiarity test of words

Phase 3: Testing in sound field situation with a loudspeaker on children and adults.

Participants

Two groups of participants were recruited for the study, with varying age range.

Table 1: Details of participants

Group	***No. of participants***	***Age range***	***Mean age and SD***
I	5	6 to 7 years	6.7 and 0.35
II	5	18 to 25 years	23.4 and 1.35

The children were selected from regular schools where they had been educated in English, as the medium of instruction for at least 3 years. All the schools were in Mysore city. The young adults who were fluent speakers of Indian-English were selected for the study.

All the participants had thresholds less than 25 dB HL from 250 to 8000 Hz, normal middle ear functioning as determined by immittance evaluation, presence of TEOAEs, speech identification score greater than 75% in quiet, no report of otological or neurological problem, no history of speech and language problems. Additionally, none of them were found to have symptoms of auditory processing disorder (APD) on a screening checklist. All the above participants were non-native speakers of English language, but are exposed to English from childhood.

Instrumentation

The below mentioned equipment's were used to carry out the study:

- A calibrated dual channel diagnostic audiometer, MA 52 with TDH-39 headphones routed to recorded audio signals through an auxiliary input, was used to select the participants with normal hearing sensitivity.
- A calibrated immittance meter, GSI-Tympstar was used to rule out the presence of middle ear pathology.
- An otoacoustic emission analyser, ILO V6 was employed to confirm the status of hearing.
- A personal computer, Hewlett Packard, with Intel core processor 5 was utilised to develop speech noise and normalize the word material.
- Adobe Audition version 3.0, audio workstation
  Canton CD 220 speaker

All the equipment's that required calibration were calibrated prior to the data collection. The calibration of audiometer was done as per the guidelines of ANSI S3.6 (2004) and the calibration of loud speakers were done according to the sound field reference levels

Test environment

All audiological evaluations were carried out in an air-conditioned acoustically treated double room that met the specifications of ANSI S3.1 (1999). The testing of speech identification in speech noise was carried out in a quiet room with a loud speaker, free from visual disturbances.

Material

The materials mentioned below are employed for the study. Test materials were developed as a part of the study, kin the absence of the standard material.

- Screening Checklist for Auditory processing (SCAP) developed by Yathiraj and Mascarrenhas (2003) was used to rule out auditory processing disorder.
- Speech identification was tested using the "Phonetically balanced speech identification test in Indian-English" (Yathiraj & Muthuselvi, 2009) consisted of 5 lists with 25 words each.
- Binaural fusion test in English for children developed by Shivaprasad and Yathiraj (2006) consisted of 92 words were used

Test procedure

The audiological evaluations were carried out to select the participants for the study to ensure that they met the inclusion criteria. Those who meet the inclusion criteria were screened with Screening Checklist for Auditory processing (SCAP) to rule out auditory processing disorder. The details of the procedure used to select the participants are described below.

Phase 1: Procedure for selection of the participants

To ensure that all the participants met the inclusion criteria of the study, relevant information was obtained from them or family members or from teachers as well as they were subjected to various tests. The information obtained and tests administered on the participants are described in the below sections.

A case history was taken to know any relevant information related to their hearing. The information regarding the presence of hearing loss, family history of hearing loss, history of ear infections/ surgery and any other history positive related to hearing was obtained. The individuals who had no positive history were subjected to further investigation for the inclusion into the study.

A pure tone audiometry with both air conduction and bone conduction testing was carried out using modified Hughson- Westlake procedure (Carhart & Jerger, 1959). The air conduction and bone conduction testing were established for frequencies between 250 to 8000 Hz and 250 to 4000 Hz, respectively. The individuals with pure-tone thresholds $\leq$ 25 dB HL between 250 to 8000 Hz were included for further evaluation.

Speech identification scores (SIS) were measured using the phonemically balanced word identification test in English (Yathiraj and Muthuselvi, 2009). The recorded words were presented at 40 dB SL with reference to the Speech reception threshold (SRT). The total percentage of words correctly identified, was considered as the SIS. The individuals with scores greater than 75% in quiet were selected for the study.

Immittance Audiometry was carried out to determine the middle ear function using a calibrated immittance meter. A tympanogram was obtained with 226 Hz probe tone for adults and children. Ipsilateral and Contralateral reflex thresholds were measured for 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. The individuals indicating normal middle ear function were selected for the study.

Transient otoacoustic emissions (TOAEs) were measured to ensure the absence of any cochlear pathology. The click stimuli were presented at 85 dB SPL. TOAEs were considered present when the amplitude of the response was 3 dB above the noise floor. The individuals with presence of TOAEs were included in the study.

Five children with an age range of 6 to 7 years and Five adults with an age range of 18 to 25 years, who met the above inclusion criteria were selected for the testing of speech identification in the presence of speech noise.

Phase 2: Familiarity test of words

A familiarity test was carried out in children between 6 and 7 years and for adults between 18 to 25 years. The selected participants were comfortably seated on a wooden chair which was two metre away from the loudspeaker producing the stimuli. The participants were instructed to listen to the word stimulus and were asked give oral response of what they hear. The response of the participants was noted on a sheet. The words least familiar to the participants were taken out. A total of two hundred words were finalized based on the familiarity test results.

Phase 3: Testing in sound field situation with a loudspeaker on children and adults

All the participants who met the selection criteria were tested in a sound field situation. The speech noise and the word stimuli were presented through the canton CD 220 loudspeaker placed at 0˚ azimuth.

Before the actual testing, the loudspeaker was calibrated by presenting a 1000 Hz calibration tone. The Bruel and Kjaer loudspeaker type 2270, class 0 with random incidence microphone was used to calibrate the loudspeakers. The 1000 Hz tone was calibrated to 60 dB SPL, with respect to the RETSPL value of 0˚ azimuth (Dirks, Stream & Wilson, 1972; Stream & Dirks, 1974). The speech noise and target speech stimuli were delivered to the loudspeakers via a calibrated dual channel diagnostic audiometer, MA 52 in free field condition, which was routed to the loud speaker at 0˚ azimuth.

Speech identification testing was carried out using a list of two hundred monosyllabic words. The speech noise and the word stimuli were presented through loudspeaker placed at 0˚ azimuth. For the testing, the participants were seated comfortably in the centre, with the loudspeaker placed at 24 inches (60 cm) from the subject’s head. The loudspeaker was at a height of 45 inches, to be ear level for a seated participant. All these testing was carried out in a double-walled sound treated booth, which met the ambient noise level with permissible limits (ANSI s3.1, 1999)

The speech identification in the presence of speech noise was tested at 0 dB, +5 dB and +10 dB SNR using all the words available in the list. Each individual was tested one’s in each SNR in the presence of speech noise. The listener’s task was to repeat the words produced by the female talker in the presence of speech noise presented at a fixed level of 60 dB SPL bilaterally. A total of 200 words were presented at each SNR level to each participant. The scores were calculated as percent correct word score. The words were randomized to prevent the effect of word familiarity. Adequate gaps were also provided to prevent fatigue as well as prevent the effect of word familiarity.

Statistical Analyses

The data of the present study was tabulated and statistically analyzed using the Statistical Package for Social Sciences (SPSS, version 20.0) software. Descriptive statistics was used to estimate the mean, median and standard deviation across SNR for children and adult. The speech identification scores across SNR was analyzed using Mann Whitney U test and Wilcoxon signed rank test.

RESULTS

The aim of the present study was to determine the influence of speech noise on word identification scores at different signal to noise ratio (SNR). The data was statistically analysed using Statistical Package for Social Sciences (SPSS, version 20.0). the comparison between children and adult scores was carried out using non-parametric tests. The results of all the measures are presented under the following headings:

- Comparison of speech identification scores between children and adults for different signal to noise ratio (SNR)
- Comparison of speech identification scores within children for different signal to noise ratio (SNR)
- Comparison of speech identification scores within adults for different signal to noise ratio (SNR)

Comparison of speech identification scores between children and adults for different signal to noise ratio (SNR)

The scores of children and adults were combined and the between group comparison analysis was carried out using Mann Whitney U test for all three signal to noise ratios (SNR). The results revealed statistically significant difference for all three SNRs between groups.

Table 2: Z value between children and adult across SNR

SNR	|Z|	Significance
0 dB	2.63	0.008*
+5 dB	2.67	0.007*
+10 dB	2.65	0.008*

*Note: * indicates p<0.05*

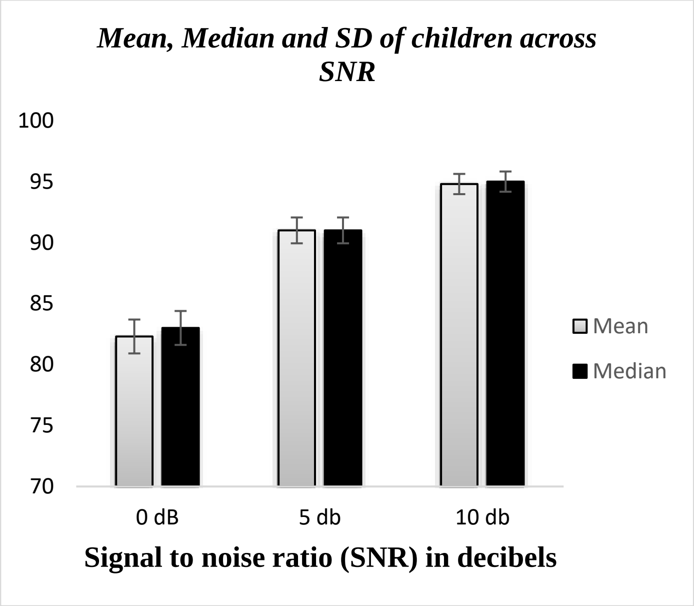
It is evident from the above table that there is statistically significant difference ($p<0.05$) between groups in all three SNR conditions. Thus, the data was further analysed to find out whether there is any statistically significant difference within groups across SNRs.

Comparison of speech identification scores within children for different signal to noise ratio (SNR)

Mean, Median and standard deviation of children across signal to noise ratios (SNR)

The mean and median values across SNRs in children with standard deviation is shown in the figure below.

Figure 1: Mean, Median and SD of children across SNR



It can be noted that the mean and the median values are lower at 0 dB SNR with the value of 82.3 and 83, respectively than the other two SNRs with the mean value of 91 and 94.8 and median values of 91 and 95, for +5 and +10 dB, respectively. The speech identification scores increased with increase in SNR. Thus, to know the statistically significant difference between SNRs, the scores were further analysed.

For statistical analysis of speech identification scores across SNR, the Friedmans test was carried out, as there were three variables. This was followed by Wilcoxon signed rank test. The results of Friedman’s test across SNR are given below. The results revealed statistically significant difference across SNR with $p < 0.05$.

Table 3: Friedman test results across SNR in children

	N	**$\chi 2$ (2)**	**Significance**
Children	5	10	0.007*

*Note: * indicates p<0.05*

Further, Wilcoxon signed rank test was done to carry out pair-wise comparison of speech identification scores across SNR in children as shown below,

Table 4: Wilcoxon signed rank test results across SNR in children

SNR	**|Z|**	**Significance**
+5 to 0 dB	2.03	0.042*
+10 to 0 dB	2.03	0.042*
+10 to +5 dB	2.03	0.042*

*Note: * indicates p<0.05*

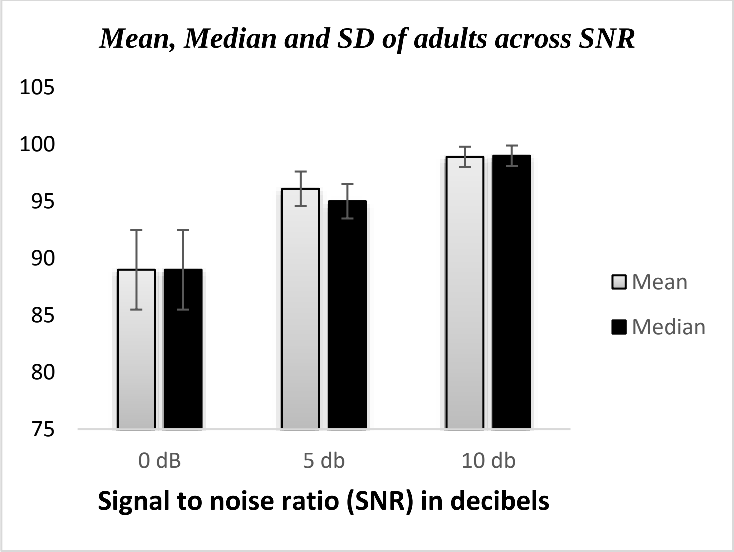
The results of Wilcoxon signed rank test for speech identification across SNR was significantly different from each other.

Comparison of speech identification scores within adults for different signal to noise ratio (SNR)

Mean, Median and standard deviation of adults across signal to noise ratios (SNR)

The mean and median values across SNRs in adult with standard deviation is shown in Figure 2.

Figure 2: Mean, Median and SD of adults across SNR



It can be noted that the mean and median values are lower at 0 dB SNR with the value of 89, than the other two SNRs with the mean value of 96.1 and 98.9 and median value of 95 and 99, for +5 and +10 dB, respectively. Thus, to know whether it is statistically significant, the scores were further analysed.

For statistical analysis of speech identification scores across SNR, the Friedmans test was carried out, as there were three variables. This was followed by Wilcoxon signed rank test.The results of Friedman's test across SNR are given below. The results revealed statistically significant difference across SNR with $p < 0.05$.

Table 5: Friedman test results across SNR in adults

	N	**$\chi2$ (2)**	**Significance**
Adults	5	10	0.007*

*Note: * indicates p<0.05*

Further, Wilcoxon signed rank test was donw to carry out pair-wise comparison of speech identification scores across SNR in adults as shown below,

Table 6: Wilcoxon signed rank test results across SNR in children

SNR	|Z|	Significance
+5 to 0 dB	2.03	0.042*
+10 to 0 dB	2.03	0.042*
+10 to +5 dB	2.02	0.043*

*Note: * indicates p<0.05*

The results of Wilcoxon signed rank test for speech identification across SNR was significantly different from each other.

Thus, the speech identification scores of three different SNRs showed statistically significant difference from each other, in all the above mentioned statistical analyses.

DISCUSSION

The present study aimed to know the signal to noise ratio required to achieve 70% speech identification scores. The participants were tested with speech noise in 0, +5 and + 10 dB SNR. Two-hundred monosyllabic words in English were used for the testing. The results revealed that both children and adult achieved 70% speech identification scores in all three SNRs and the mean and median speech identification scores increased as the SNR increased.

There was significant difference between children and adult speech identification scores. The Mann Whitney U test showed significant difference between groups and Wilcoxon signed rank test showed significant difference within group. The participants could obtain 70% speech identification scores even at 0 dB SNR. Neuman (2010) studied the combined effects of noise and reverberation on speech recognition of normal hearing children and adults. The SNR required for 50% performance and for 95% performance were determined for groups of children and young adults with normal hearing. The SNR of +21 dB to -6 dB were assessed in babble noise. The results revealed that 5 to 7 dB SNR would results approximately 50% performance for the youngest children and adults would be expected to obtain maximal performance at these SNRs. The authors also concluded that, improving the SNR will increase the performance, and significant increase in SNR is required for children than adults because the performance intensity function is shallower for children than adults.

Corbin, Bonino, Buss and Leibold (2015) measured the threshold for 50% correct recognition of open-set recognition of monosyllabic words with two-talker speech and speech shaped noise in normal hearing children and adults. The results revealed that both the children and adults perform more poorly in two talker speech than the speech shaped noise masker. It was also found that, the performance of children improved until about 10 years of age. In two talker conditions, the thresholds improved between 5 and 13 years. The authors concluded that, younger children require more SNR than older children and adults to achieve 50% correct word recognition in both the masker conditions.

Hall, Grose, Buss and Dev (2002) examined spondee recognition in both continuous and gated maskers in adults and children using a speech shaped noise and a two-talker masker. The results of the study revealed that, masking for continuous masker is greater in children aged 5 to 10 years than in adults. The effect of gated masker was smaller in children and/or absent in adults. The study also suggests that, children have greater effect than adults in real-life environments where the target stimuli must be separated from background noise. Many researchers also recommend that children require a more advantageous signal-to-noise ratio (SNR) than adults to achieve similar performance for speech recognition in the presence of relatively steady-state noise (Elliott et al. 1979; Nittrouer & Boothroyd 1990; Hall et al. 2002; Wightman & Kistler 2005; Nishi et al. 2010).

The study also highlights the native and non-native language results. The testing was carried out in English language which is not the native language of the participants. On comparing the above results with western literature, where English is the native language of the participants, the results of the present study indicates that, both children and adult significantly differ in their speech identification scores in a language that it not native to them.

CONCLUSIONS

The study concludes that the even with the lowest SNR, children and adults could obtain 70% speech recognition scores despite of testing in non-native language and in the presence of continuous speech noise. The study suggests that children’s speech perception in noise is usually assessed using relatively steady-state backgrounds. However, the performance obtained in noise maskers may not be realistic predictor of the challenges faced by children in real-world environments. Therefore, in future, a large-scale study can be done, to know the effect of real-world noise on speech recognition in children and adult and validating the use of that noise in hearing aid evaluation and rehabilitation procedures.

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APPENDIX-4

Article presented at the 50th ISHACON 2018

Effect of spatial noise and continuous noise on speech identification in children and adults

Asha Yathiraj & Tina Hephzibah

Effect of spatial noise and continuous noise on speech identification in children and adults. Presented at 50th ISHACON 2018 held at Mysuru between 5-7 January 2018.

Introduction

Despite notable improvements in speech recognition in quiet environments, understanding speech in the presence of background noise is a challenge for most individuals. Perception of speech has been found to vary depending on the type of background noise. It has been reported that speech perception scores vary depending on the type of noise of noise used[1, 2, 3, 4]. Prosser, Turrini, and Arslan [1] reported that competing continuous discourse had a more detrimental effect on speech discrimination than speech noise. Larsby and Arlinger [2] observed that the masking effect of speech was less than random noise maskers. However, unlike Larsby and Arlinger [2], Papso and Blood [3] reported that multi-talker noise had a greater masking effect than non-speech noise. Parikh and Loizou [4] also noted that the identification scores of vowels and consonants were lower with multi-talker babble compared to speech-shaped noise. Thus, the authors noted that noise with different acoustic characteristics had varying effects on speech perception scores.

To determine the listening difficulties faced by individuals with hearing impairment using listening devices, continuous noise or speech babble is typically used [5, 6, 7, 8]. However, such continues noise do not represent noise heard in a real-world listening situation. Thus, to study the effect of noise, a popular form of noise used in research studies is 'R-SPACE™ noise'. The noise is claimed to accurately simulate real-world acoustic environments, without compromising on of efficiency, control, and repeatability of noise used only in laboratories [9]. This noise has been used to establish the efficiency of different noise reduction algorithms incorporated within listening devices such as hearing aids, assistive devices, computer voice recognition systems, noise-cancelling listening systems, cellular telephones, and other communication systems. It has also been used to determine the effect of various noise reduction algorithms in cochlear implants [10, 11]. As described by the authors [10, 11], the noise is presented through eight different loudspeakers in a sound field situation. The noise presented from each loudspeaker has different environmental sources of noise that vary in terms of frequency, intensity and temporal characteristics over a period.

Based on the review of literature [1, 2, 3, 4], it is speculated that noise that is fluctuating over time would mask speech stimuli differently from one test session to another, in the absence of any other change. This would occur as it is known that speech perception scores vary depending on the frequency, intensity or temporal characteristics of noise. The varying acoustical parameters of R-SPACE^{TM} noise could contaminate the findings of studies that have used it to determine the effect of specific algorithms in listening devices. Thus, the reliability could be compromised due to the varying effect of the noise source. This variation could be a co-variable affecting the findings of studies reporting of performance with different noise reduction algorithms incorporated within listening devices. The extent of this variable needs to be investigated to determine how valid it is to utilise noise similar to R-SPACE^{TM} noise. Thus, the current study aimed to determine the effect of spatial noise (similar to R-SPACE^{TM} noise) speech identification in children and adults. The study also aimed to compare speech identification scores obtained in the presence of spatial noise with scores obtained with continuous noise.

Methods

Participants

The study included 100 participants comprising of 50 children aged 6 to 7 years and 50 adults aged 18 to 25 years. The children were selected from regular schools where the language of instruction was Indian-English. The children had been educated in the language for at least 3 years. It was ensured that the young adults selected for the study were fluent speakers of Indian-English. All the participants had thresholds less than 25 dB HL from 250 to 8000 Hz; normal middle ear functioning, as determined by immittance evaluation; presence of TEOAEs; speech identification score greater than 75% in quiet; no report of otological or neurological problem; and no history of speech and language problems. Additionally, none of them had any symptoms of an auditory processing disorder, when assessed using the 'Screening checklist for auditory processing' developed by (Yathiraj & Mascarenhas, 2004) [12].

Material

Spatial noise was constructed by recording restaurant noise on eight tracts using Adobe Audition (Version-3). The recording was done during peak lunch time in a typical quick-service Indian restaurant using directional free field microphones (Sennheiser ME 66). The recording was done at a strategic point in the restaurant at eight different azimuths (+45˚, -45˚, +90˚, -90˚, 180˚, +135˚, -135˚, & 0˚). Each microphone had a radius of one meter. The noise included people talking, clutter of vessels, mixie noise, and street noise. The noise picked-up from each microphone varied depending on the direction it faced. *Speech noise* was recorded from an audiometer. The speech noise generated from the audiometer was routed from the line-output of the instrument and saved as an audio file in a computer. Two-hundred *monosyllabic words* were used to evaluate speech identification. These words were selected from a corpus of words that had been earlier established to be familiar by children aged 6 years and above who had studied in English medium schools for at least 3 years. The words were digitally audio recorded by a female who spoke Indian-English with a neutral accent. The same 200 words were randomized thrice to form three equivalent word lists.

Procedure

Each individual was tested thrice in the presence of spatial noise and twice in the presence of speech noise. The speech stimuli were delivered to a loudspeaker placed at 0^{o} azimuth while the spatial noise was presented through the eight loudspeakers placed at different azimuths (+45˚, -45˚, +90˚, -90˚, 180˚, +135˚, -135˚, & 0˚). The stimuli and the noise were presented using a Lynx audio mixer and Cubase audio workstation. However, the continuous speech-noise and target speech stimuli were presented through a loudspeaker placed at 0˚ azimuth. The participants were seated 60 cm in front of the 0˚ azimuth loudspeaker. The height of the loudspeaker was adjusted to be at the ear level of the participants. All tests were carried out in a sound treated room, having standard ambient noise levels (ANSI S3.1, 1999 (R2008) [13]. The listeners were instructed to repeat the words heard in the presence of noise. Each correct response was given a score of 1 and an incorrect response was scored 0.

Descriptive and inferential statistics were carried out using SPSS (version 20.0). Shapiro-Wilks test of normality indicated that the word identification scores between children and adults were normally distributed. Hence, parametric tests were used.

Results

The data were analysed to compare speech identification scores in the presence of spatial noise with scores obtained with continuous speech noise. This was done separately for children and adults. Additionally, the speech identification scores obtained in each noise condition was compared between the two age groups.

Comparison of word identification scores across different noise conditions in children

The mean word identification scores in children (Table 1) was found to vary across depending on the type of masking noise that was used. These scores were observed to be higher in the presence of speech noise compared to spatial noise.

Table 1: *Mean, and standard deviation of word identification scores*

Noise used	**Trials**	**Mean***			**SD**		
		C	**A**	**Avg**	**C**	**A**	**Avg**
Spatial noise	1	160.7	166.8	163.8	6.2	7.5	7.5
	2	162.5	169.5	166.0	5.9	6.3	7.0
	3	162.8	169.9	166.4	5.7	6.3	6.9
Speech noise	4	178.2	182.3	180.2	6.9	5.4	6.5
	5	177.4	182.4	179.9	7.3	4.7	6.6

Note. Maximum possible score = 200; C = Children, A = Adults, Avg = Average

To confirm whether there was a statistical difference between the word identification scores in children across the noise conditions (3 trials with spatial noise & 2 trials with continuous speech noise), one-way ANOVA was done. The results revealed that there was a statistically significant difference between the noise conditions within the children [(F (4,196) = 368.50, $p < 0.001$, partial $\eta^2 = 0.88$)].

Pair-wise comparisons with Bonferroni correction of the 3 trials of spatial noise showed that a statistically significant difference occurred between the 1st and 2nd as well as the 1st and 3rd trials ($p < 0.05$) in children. Likewise, the comparisons between spatial noise (trials 1, 2 & 3) and continuous speech noise (trials 4 & 5) were also observed to be significant ($p < 0.001$). However, the pair-wise comparison within the noise conditions indicated that there was no statistical significant difference between the 2nd and 3rd trials of spatial noise and between the 2 trials with continuous speech noise (trials 4 & 5)($p > 0.05$), as can be seen in Table 2.

Table 2: *Comparison of word identification scores in children between noise conditions*

Type of Noise	Trials	1	2	3	4	5
Spatial noise	1	-	0.00*	0.00*	0.00*	0.00*
	2	-	-	0.99	0.00*	0.00*
	3	-	-	-	0.00*	0.00*
Speech noise	4	-	-	-	-	0.97
	5	-	-	-	-	-

Note. * = $p < 0.001$

Comparison of word identification scores across different noise conditions in adults

Similar to what was seen in the children, the mean word identification scores in adults also varied depending on the type of masking noise used, with it being higher in the presence of speech noise compared to spatial noise (Table 1). One-way ANOVA (3 trials with spatial noise & 2 trials with continuous speech noise) was done to confirm whether this difference was statistically different. It was observed that there was a statistically significant difference between the noise conditions within the adults [(F (4, 196) = 254.33, $p < 0.001$ partial $\eta^2 = 0.83$)].

The pair-wise comparison with Bonferroni correction, carried out within the noise conditions, indicated that there was no statistical significant difference between the scores obtained during the 2 trials with continuous speech noise ($p > 0.05$) in the adult group. However, for spatial noise, there was a significant difference between the 1st and 2nd as well as the 1st and 3rd trials ($p < 0.001$), but not between the 2nd and 3rd trials ($p > 0.05$), within the group. The pair-wise comparison between continuous speech noise and spatial noise was observed to be significant ($p < 0.001$). The above information is evident in Table 3.

Table 3: *Comparison of word identification scores within adults between noise conditions*

Noise used	**Trials**	**1**	**2**	**3**	**4**	**5**
Spatial noise	1	-	0.00*	0.00*	0.00*	0.00*
	2	-	-	0.99	0.00*	0.00*
	3	-	-	-	0.00*	0.00*
Speech noise	4	-	-	-	-	1.00
	5	-	-	-	-	-

Note. * = $p < 0.05$

Comparison of word identification scores between children and adults in each noise condition

The mean scores provided in Table 1 indicates that the adults obtained higher scores than the children. This was seen irrespective of the type of noise. The comparison of word identification scores between children and adults was accomplished using a mixed ANOVA (2 age groups x 5 noise trials). The results revealed that there was a significant main effect [(F (4, 392) = 613.86, $p < 0.001$, partial $\eta^2 = 0.86$)], with a significant interaction between age and noise trials [(F (4, 392) = 3.94, $p < 0.05$, partial $\eta^2 = 0.39$)]. The pair-wise comparison between the 2 groups for each noise trial, done using t-tests, indicated that there was statistical significant difference between the 2 groups for both continuous speech noise and spatial noise in all the trials.

Table 4: *Comparison of word identification scores for each trial between children and adults*

Noise used	Trials	Children Vs Adults
Spatial noise	1	t(98) = -4.39, p = 0.00, d = 0.87
	2	t(98) = -5.70, p = 0.00, d = 1.14
	3	t(98) = -5.90, p = 0.00, d = 1.18
Speech noise	4	t(98) = -3.26, p = 0.00, d = 0.65
	5	t(98) = -4.02, p = 0.00, d = 0.80

Discussion

From, the findings of the study, it was noted that the word identification scores are different for speech noise and spatial noise. The results indicated that word identification scores varied across trails when spatial noise was used but not when continuous speech noise was used. Further, the scores were consistently higher in the presence of speech noise when compared to spatial noise. These findings were observed both in adults as well as children.

The variations in scores from one trial to another while being tested with spatial noise could be attributed to the varying acoustical parameters each time an individual was tested. The spatial noise varied from one point of time to another, as the noise generated from different sources varied continuously, as is typically seen in any quick-service restaurant. This variation occurred constantly from all 8 sources that were recorded. Thus, it is to be expected that the masking effect of the noise on speech stimuli would have varied depending on the frequency and intensity of the noise at a point of time. Hence, speech sounds that were intelligible and could be identified during one trial could have been masked during another trial, making it unintelligible. Such variation in masking would not have occurred in the presence of the constant speech masker. The variations in the noise would have influenced the word identification score.

Further, in the current study, it was observed that the speech identification scores were poorer with the spatial noise compared to the constant speech noise. Larsby and Arlinger (1994) [2] also noted that the speech spectrum random noise had more masking effect than speech maskers. It is possible that the constant variations in the noise distracted the listeners more than the constant speech noise.

Thus, from the findings of the study it can be construed that when testing with any noise similar to spatial noise, test reliability is likely to be compromised due to the varying effects of the noise. The findings of studies that have used noise similar to the spatial are highly likely to be influenced by the varying masking effect of the noise. Thus, the findings of studies such as those done by (Brockmeyer & Potts, 2011; Gifford & Revit, 2010b) [10, 11] that used noise similar to spatial noise are questionable. It can be inferred that in addition to the strategies manipulated in the cochlear implants studied by them, (ADRO, ADRO+ASC, ADRO+ASC+BEAM), the varying masking effect of spatial noise used by them could have also affected the speech identification scores obtained by them. Thus, the results of studies that have used spatial noise need to be viewed skeptically.

Conclusion

Literature indicates that perception of speech varies depending on the frequency, intensity and temporal properties of the noise. From the present study, it can be concluded that due to the varying physical attributes of spatial noise, speech perception scores may vary. This could be a covariable when studying the effect of any noise reduction algorithm within a listening device. Hence, the results of studies that have used spatial noise to depict real-world conditions should be viewed with caution.

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