Effect of Spectrally and Temporally Modulated Maskers on Speech Perception in Listeners with Auditory Dys-Synchrony, Cochlear Hearing Loss and Normal Hearing

[1]Merry Elizabeth Roy & [2]Animesh Barman

Abstract

The present study aimed at assessing the speech recognition performance in individuals with auditory dys-synchrony (AD), cochlear hearing loss and normal hearing in the presence of spectrally and temporally modulated maskers at 0 dB and 10 dB SNR and to observe which clinical group would take greater advantage of spectral and/or temporal dips to understand speech. Number of words correctly identified within each sentence was calculated in the presence of each of the modulated (spectrally modulated noise with 4 ERB gaps, spectrally modulated noise with 2 ERB gaps and temporally modulated noise) and unmodulated (speech shaped steady state noise) maskers at both SNRs in 10 individuals with AD, 13 individuals with cochlear hearing loss and 20 individuals with normal hearing sensitivity. All three groups performed poorer at 0 dB SNR than at 10 dB SNR and in the presence of unmodulated than modulated maskers. The AD group performed significantly poorer under temporally modulated noise at both the SNRs, while they showed better performance when masker was spectrally modulated. This could be attributed to the excessive masking in them due to smearing of the temporal waveform. The Cochlear hearing loss group did not benefit from 2 ERB gap spectral modulation and temporal modulation of noise. The AD group performed significantly poorer compared to the other two groups on all conditions due to their affected temporal resolution, while this group also showed significant release from masking for spectrally modulated maskers compared to the other groups.

Keywords: *Unmodulated masker, spectrally modulated masker, temporally modulated masker*

Introduction

Speech is considered to be a complex dynamic signal which fluctuates both in amplitude and frequency over time. To perceive these inherent fluctuations in the signal, the auditory system does a detailed spectral and temporal analysis of the signal. Normal perception is hence directly dependent on an intact peripheral and central auditory processing. But the perception of speech is intricate when distorted or attenuated in the presence of noise. This difficulty in perception seen even in normal hearing individuals is yet more unfavorable in those individuals with hearing impairment.

Studies (Festen & Plomp, 1990; Moore, 1996) have reported that listeners with normal hearing and those with hearing impairment have difficulty in the perception of speech in noisy and reverberant conditions. This is because noise reduces the redundancy that is available inherently within the signal. As the noise dominates, i.e., the speech to noise ratio (SNR) reduces, it becomes more difficult to understand speech. But if the noise or the background sound also fluctuates in time, there are moments or dips created where the speech is distinctive of noise. Individuals with normal hearing have the ability to recognize speech with much accuracy in such fluctuating backgrounds than in steady state or continuous noise (Festen & Plomp, 1990) unlike those with hearing impairment (Peters, Moore & Baer, 1998).

The modulated or fluctuating maskers are characterized by spectral and temporal dips. The temporal dips are instants when the overall level of the background noise is low during which the signal-to-noise ratio is high, which allows brief 'glimpses' to be obtained of the target speech. The spectral dips arise when the spectrum of the target speech signal over any short interval is different from that of the background noise. Although some parts of the target speech spectrum may be completely masked by the background, other portions of the signal during periods in which the masker reaches a dip is utilized to infer the complete target speech. This benefit received when listening to speech in the presence of fluctuating maskers than in the presence of steady state maskers is referred to as 'release of masking'.

However, studies have reported that individuals with cochlear hearing loss do not show this benefit, i.e., they perform almost similarly in presence of modulated and steady-state maskers (Middelweerd, Festen, & Plomp, 1990; Festen & Plomp, 1990).

Duquesnoy (1983) measured the speech recognition threshold (SRT) required to correctly identify 50% of the stimuli in presence of amplitude modulated noise and showed that a difference in SRT ranging from about 7dB to 15 dB exists between individuals with normal hearing and those with cochlear hearing loss. Peters et al. (1998) reported that, SRTs decreased by only 1 to 2 dB when the bandwidth of spectral dips of the masker was increased from two to four ERBNs in hearing impaired listeners, whereas SRTs decreased by 6 dB

[1]Email: merryroy88@yahoo.com,
[2]Reader in Audiology, Email: nishiprema@yahoo.com

for normal hearing listeners in comparison to a steady state masker. This reduced ability to take the benefit of spectral and temporal dips seen in these individuals with cochlear hearing loss could be attributed to the reduced temporal and spectral resolution (Wagener, Brand & Kollmeier, 2006; Peters, et al., 1998).

The potential to hear low-level speech segments and to resolve spectral dips is largely determined by the active mechanism in the cochlea, which depends on the functioning of outer hair cells (Moore, 2003). But in case of cochlear hearing loss, all the three factors important for release from masking: audibility, spectral resolution, and temporal resolution may be adversely affected (Moore, 2007).

Bernstein and Grant (2009) proposed that the magnitude of masking release also depends on the signal-to-noise ratio (SNR) at which performance is measured i.e., release from masking tends to be large when the SNR is low, and small or absent when the SNR is high. This means that it is important to compare the performances of hearing impaired and normal hearing listeners at different SNRs.

Analogous to those having cochlear hearing loss, individuals with Auditory Dys-synchrony (AD) have also shown to be having reduced spectral (Kraus et al., 2000) and temporal processing (Zeng, Kong, Michalewski & Starr, 2005). Rance, McKay and Grayden (2004) found significant correlation between reduced speech perception abilities and extremely poor temporal processing and frequency discrimination ability.

These deficits could be attributed to the reduced synchrony in neural firing which disrupts the timing cues and affects the listener's ability to cope with the dynamic nature of speech signals. It could impair not only the ability to use amplitude envelope cues in speech, but also to perceive rapidly changing spectra in the speech stimuli (Rance et al., 2004). Individuals with AD, are known to exhibit even greater difficulty for perceiving speech in the presence of noise. Kraus et al. (2000) have reported that individuals with AD, obtain significantly depressed scores in the presence of a multi talker speech babble, in spite of performing remarkably well in quiet.

Zeng and Liu (2006) reported that even at SNRs that show little or no effect on individuals with normal hearing (10 to 15 dB), these individuals show detrimental scores which is supported by psychophysical studies showing excessive masking effects in them (Zeng et al., 2005; Zeng, Oba & Starr, 2001; Kraus et al., 2000). The mechanisms underlying excessive noise effects in AD type hearing loss are unclear, although there is psychophysical evidence that auditory signals are more affected by simultaneous and non-simultaneous masking than normal listeners in these individuals with AD (Vinay & Moore, 2007; Zeng et al., 2005; Kraus et al., 2000).

Recent studies suggested that neural phase locking to the temporal fine structure of the target signal may be critical for listening in the background temporal dips (Moore, Glasberg & Hopkins, 2006; Leger, Moore & Lorenzi, 2012). It may thus be presumed that the reduced phase locking ability in these individuals with AD may hinder release from masking.

Considering the natural conditions of speech perception in background noises that are temporally and spectrally varying, such as clattering dishes or background conversations, the investigation of speech perception in the presence of fluctuating or modulated backgrounds is important. Intact spectral and temporal resolution in individuals with normal hearing sensitivity allows them to utilize the spectral and temporal dips in noise. Psychophysical studies have pointed out that individuals with cochlear hearing loss and those with AD exhibit spectral and temporal resolution problems. Thus a comprehensive knowledge about psychophysical findings reported in literature could be better corresponded with the speech perception difficulties. The present study was hence undertaken to examine the effects of maskers which are modulated either spectrally or temporally on speech perception in individuals with normal hearing, cochlear hearing loss and auditory dys synchrony.

The study aimed to assess speech recognition performance in groups of individuals AD, cochlear hearing loss and normal hearing in presence of spectrally and temporally modulated noise at 0 dB SNR and 10 dB SNR. It also aimed to observe which clinical group would take greater advantage of spectral and/or temporal dips to understand speech.

Method

Participants

To accomplish the goal, a total of 43 participants participated in the study. They were categorized into 3 groups. Group I consisted of 10 individuals with AD in the age range 18 to 55 years having pure tone thresholds within 55 dB HL with either flat or gradually rising audiogram. Group II included 13 Individuals with cochlear hearing loss of age ranging from 18 to 55 years with pure-tone thresholds between 25 to 55 dB HL having a flat audiometric configuration. Group III consisted of 20 normal hearing listeners age matched with that of individuals in group I and II of age ranging from 18 to 55 years

The actual experiment was carried out in two phases.

Phase 1: Preparation of the Stimulus

Target speech stimuli: Seven lists of sentences were taken from standardized quick SIN test in Kannada developed by Methi, Avinash and Kumar, (2009) to assess the speech recognition ability in the participants from all the three groups. Each list contains 7 sentences and each sentence has 5 key words, making a total of 35 keywords in each list.

Maskers: Following are the ipsilateral maskers and the procedure to generate, used to determine the SIS:

Speech shaped steady state noise: A Speech shaped noise or SSN was generated from the whole set of sentences at a sampling frequency of 44.1-kHz by estimating the long-term power spectrum of recorded test sentences. This was done by randomizing the phase of the Fourier spectrum of concatenated words of original signals using MATLAB (version 2009). It had a spectrum which approximates the average long term spectrum of the target sentences spoken by an adult male with a secondary peak present around 100 Hz.

Speech shaped noise with spectral modulations: The speech shaped steady state noise was filtered so as to have spectral dips in several frequency regions. The filtering was done based on the equivalent-rectangular-bandwidth (ERB) scale derived from the auditory filter bandwidths for normally hearing participants (Glasberg & Moore, 1990). The relationship between the number of ERBs and frequency is,

ERB number = 21.4 $\log_{10}$ (4.37F+1).

Each ERB represents one auditory filter bandwidth.

The noise was filtered in 2 ways as shown in the Figure 1: first, with an alternating pattern of two ERBs present and two ERBs removed (spectrally modulated noise with 2 ERB gaps) and the second with an alternating pattern of four ERBs present and four ERBs removed (spectrally modulated noise with 4 ERB gaps)

Speech shaped noise with temporal modulations: Speech spectrum-shaped wide-band noise was modified to have envelope modulations or temporal fluctuations imposed on it. This was achieved by modulating the amplitude of speech shaped noise at the rate of 10 Hz using MATLAB software (version 2009). This noise was referred to as 'temporally modulated noise'.

The rms level of all these noises were adjusted according to the level of the target speech stimuli to achieve the desired SNR using MATLAB software (version 2009). The noises were mixed with the passages using MATLAB software at 2 different SNRs. A total of 7 conditions were prepared using 7 sentence lists to assess sentence perception at two SNRs. The conditions at both 0dB SNR and 10 dB SNR included the following noise types: speech shaped noise, spectrally modulated noise with 4 ERB gaps, spectrally modulated noise with 2 ERB gaps and temporally modulated noise. An

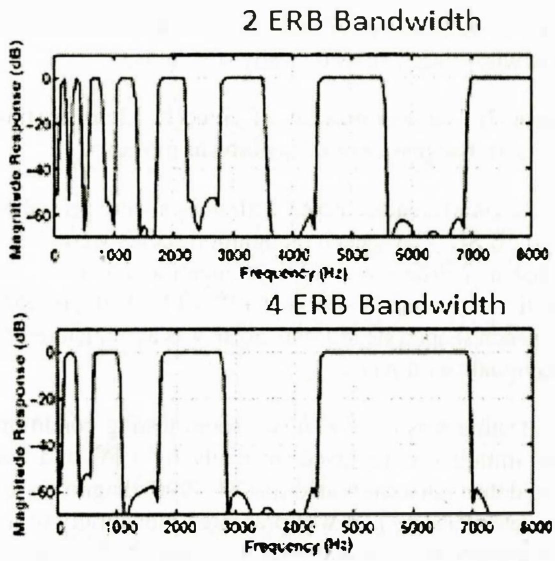

Figure 1: Characteristics of the digital filters used to produce the noises with multiple spectral notches

additional testing condition in the presence of Speech shaped noise at 10 dB SNR was prepared for group I: individuals with AD. This was done based on the results of a pilot study revealing very poor scores at 0dB SNR for all noise conditions. Hence to make a better comparison of modulated and unmodulated masker conditions, this additional condition was prepared. Randomly selected sentences from list 1 and list 2 were mixed with speech shaped steady state noise at 10dB SNR which served as an additional testing condition for individuals with AD.

All the 7 lists of sentences were used for each of the 7 conditions mentioned above. Thus a total of 49 lists were made. These 49 lists were randomly grouped into 7 sets of sentence lists, such that each set had all the 7 test conditions. Hence, each participant was tested with all seven lists having 7 different conditions, so as to avoid any effect of a particular list on the performance. These 7 testing conditions were administered in a randomized order across participants and also within each list, sentences were presented in random.

The Adobe audition software (Version 3) was used to normalize the stimuli to a level of -15dB. The order of presentation followed the manner such that always lists with sentences at 0 dB SNR was presented before the sentences presented at 10 dB SNR. These prepared stimuli were transferred digitally to a recordable compact disc for use in the experiment. The CD had a total of 9 tracks. Track 1 had a calibration tone of 1 kHz with a level identical to the normalized level of the stimuli. Using the 1-kHz calibration tone, VU meter on the audiometer was adjusted to read '0'. Tracks 2-8 had 7 sets of lists with different stimulus conditions as mentioned in the order earlier. Track 9 had the additional lists prepared to administer on individuals with AD at 10 dB SNR with speech shaped steady state noise.

Phase 2: Determination of Speech Identification scores in the presence of ipsilateral maskers

The target sentences mixed with noises were presented at 40 dB SL. The speech recognition scores were determined in 7 different conditions mentioned earlier. An additional testing condition at +10 dB SNR in presence of speech shaped steady state noise was administered on individuals with AD.

The testing was done in a two room testing condition. The stimuli was replayed manually by a PC and was routed through a calibrated (ANSI, 1996) diagnostic audiometer (GSI-61). It was presented monaurally to the participants through TDH 50P headphones. Participants were told that they would hear sentences in quiet and in noisy background and they were instructed to repeat verbally or write down what they heard. Only one ear was considered for all the participants to avoid the practice effect. Preferably right ear was chosen, otherwise ear with better speech recognition scores was selected.

Scoring

Each testing condition had a list with 7 sentences having 5 keywords in each sentence. The speech identification for each condition was calculated by counting the number of words the participant correctly identified. Each of the correctly identified key word was awarded one point for a total possible score of 35 points per list for each condition. The number of correctly identified words obtained using speech shaped steady state noise at 0 dB SNR and 10 dB SNR provided a reference condition against which speech identification obtained in other types of noises with spectral and temporal dips were compared. And as a measure of release from masking, number of correctly identified words under unmodulated speech shaped noise was subtracted from the scores obtained for each of the modulated noise condition separately. This was done so as to compare the release obtained with each of the modulated noise condition at a specific SNR.

Results

The results obtained are presented under within and across group comparisons.

Within Group Comparisons

Individuals with AD

Mean and standard deviation of number of correctly identified words (WRS) obtained for various noise conditions in 10 individuals with AD was calculated and tabulated in the Table 1.

Table 1: Mean and SD of number of correctly identified words (WRS) obtained for various noise conditions in individuals with AD

Conditions		Mean (no. of words)	SD
10 dB SNR	SSN	25.40	6.68
	ERB2	27.90	4.81
	ERB4	30.60	5.46
	AM10	21.40	7.77
0 dB SNR	SSN	04.60	5.18
	ERB2	11.10	5.87
	ERB4	19.00	8.53
	AM0	11.60	8.47

The various noise conditions are expanded as follows.

10 dB SNR SSN: Speech shaped steady state noise (SSN) at 10 dB SNR

10 dB SNR ERB2: Spectrally modulated noise with 2 ERB gaps (ERB2) at 10 dB SNR

10 dB SNR ERB4: Spectrally modulated noise with 4 ERB gaps (ERB4) at 10 dB SNR

10 dB SNR AM10: Temporally modulated noise (AM10) at 10 dB SNR

0 dB SNR SSN: Speech shaped steady state noise (SSN) at 0 dB SNR

0 dB SNR ERB2: Spectrally modulated noise with 2 ERB gaps (ERB2) at 0 dB SNR

0 dB SNR ERB4: Spectrally modulated noise with 4 ERB gaps (ERB4) at 0 dB SNR

0 dB SNR AM0: Temporally modulated noise (AM0) at 0 dB SNR

Note: abbreviations are the same for the consecutive tables also.

From the table it can be noted that mean of number of correctly identified words (WRS) obtained at 10 dB SNR is higher than that obtained at 0 dB SNR. At both the SNRs, WRS obtained for modulated maskers are greater than that obtained for the un modulated masker.

Effect of various maskers on number of correctly identified words (WRS) at different SNRs: Repeated measure ANOVA was done to see the effect of various maskers at 2 different SNRs on number of correctly identified words (WRS) in individuals with AD. The results indicated a significant difference in the number of correctly identified words (WRS) across noise conditions [$F (3, 27) = 15.021$ $p < 0.001$] at 0 dB SNR. At 10 dB SNR also, there was a significant difference in number of correctly identified words obtained across noise conditions [$F (3, 27) = 6.360$, $p < 0.01$]. Bonferroni's pairwise comparison was done to see in which two condi-

Table 2: Results of Bonferroni's pairwise comparison of scores obtained between noises at 0 dB SNR in group with AD

0 dB SNR	ERB2	ERB4	AM0
SSN	Significant p<0.05	Significant, p<0.01	Not significant, p>0.05
ERB2		Significant, p<0.01	Not significant, p>0.05
ERB4			Significant, p<0.05

Table 3: Results of Bonferroni's pairwise comparison of scores obtained between noises at 10 dB SNR in group with AD

10 dB SNR	ERB2	ERB4	AM10
SSN	Not Significant, p>0.05	Not Significant, p>0.05	Not significant, p>0.05
ERB2		Significant, p<0.01	Not significant p>0.05
ERB4			Significant, p<0.05

Table 4: Mean and standard deviation of difference in WRS due to release from masking obtained in individuals with AD

Conditions	Modulated- Unmodulated	Mean (WRS difference)	SD
10 dB SNR	ERB2 - SSN	2.50	7.05
	ERB4 - SSN	5.20	7.89
	AM10 - SSN	-4.00	7.43
0 dB SNR	ERB2 - SSN	6.50	5.33
	ERB4 - SSN	14.40	8.35
	AM0 - SSN	7.00	9.38

tions, the number of correctly identified words (WRS) obtained differed significantly, both at 0 dB SNR and +10 dB SNR. Details of Bonferroni's test results are shown in Table 2 for 0 dB SNR and Table 3 for +10 dB SNR respectively.

Amount of release from masking obtained (improvement in number of correctly identified words) under various modulated maskers at 0 dB and 10 dB SNR: Release from masking was calculated by subtracting the number of correctly identified words (WRS) obtained in presence of unmodulated noises from modulated noises at 0 dB SNR and 10 dB SNR separately. Release from masking was measured by subtracting the number of words correctly identified in the fluctuating masker condition (3 conditions) by the number of words correctly identified in the steady speech shaped noise masker condition.

The mean and standard deviation for amount of release from masking in terms of improvement or reduction in number of correctly identified words (WRS) were calculated. The details are shown in Table 4.

The mean value shows a greater release from masking when the noise is spectrally modulated with 4 ERB gaps than with 2 ERB gaps at both the SNRs. It can also be noted that, at 10 dB SNR, temporally modulated noise did not show any benefit, compared to a steady state noise. To see whether these effects are significant or not, one way repeated measure ANOVA was done. The results revealed that the amount of release obtained with all 3 modulated noise conditions were different and was statistically significant at both 0 dB SNR [$F(2, 18) = 12.954$, $p < 0.001$] and 10 dB SNR [$F(2, 18) = 11.097$, $p < 0.001$]. On Bonferroni's pairwise comparison, the pattern of results obtained was same at both SNRs and details are as shown in the Table 5.

The Table 5 shows that there is a significant release from masking in terms of number of correctly identified words (WRS) in the presence of spectrally modulated noise with 4 ERB gaps, when compared to other modulated maskers at both the SNRs.

0.0.1 Individuals with cochlear hearing loss

The mean and standard deviation of number of correctly identified words (WRS) under the various types of noise was obtained for all 13 individuals with cochlear hearing loss and tabulated in Table 6.

The mean of number of correctly identified words (WRS) obtained for 10 dB SNR is higher than that obtained at 0 dB SNR. It was also noted that the number of correctly identified words (WRS) obtained in the presence of spectrally modulated noise having 4 ERB gaps, were almost equal at both the SNRs.

Effect of various maskers on number of correctly identified words (WRS) at different SNRs: One way repeated measure ANOVA was done to see the effect of various maskers at different SNRs on number of correctly identified words (WRS) in individuals with cochlear hearing loss. The results showed a significant difference across noise conditions [$F(3, 36) = 5.879$ $p < 0.01$] at 0 dB SNR. Bonferroni's pairwise analysis revealed a significant difference in 3 comparisons as shown in Table 7.

Table 5: Results of Bonferroni's pairwise comparison of differences in WRS obtained for modulated and unmodulated noises at both 0 dB SNR and 10 dB SNR in individuals with AD

Modulated - Unmodulated	ERB4-SSN	AM-SSN/AM10-SSN
ERB2-SSN	Significant, p<0.01	Not significant, p>0.05
ERB4-SSN		Significant, p<0.01

Table 6: Mean and SD of WRS obtained for various noise conditions in individuals with cochlear hearing loss

Conditions		Mean (WRS)	SD
10 dB SNR	ERB2	34.38	0.96
	ERB4	34.69	0.85
	AM10	34.00	1.91
0 dB SNR	SSN	27.76	4.53
	ERB2	29.15	5.45
	ERB4	32.53	3.43
	AM0	28.00	6.39

Table 7: Results of Bonferroni's pairwise comparison of differences in WRS obtained for modulated and unmodulated noises at both 0 dB SNR and 10 dB SNR in individuals with AD

0 dB SNR	ERB2	ERB4	AM0
SSN	Not Significant p>0.05	Significant, p<0.001	Not significant p>0.05
ERB2		Significant p<0.05	Not significant p>0.05
ERB4			Significant p<0.05

It is evident from the Table 7 that number of correctly identified words (WRS) in the presence of spectrally modulated masker with 4 ERB gaps was significantly more than any other conditions. However word identification did not differ significantly between un modulated masker and other types of modulated maskers. However, at 10 dB SNR, there was no significant difference across the noise conditions [F (2, 24) = 1.16, p >0.05].

Amount of release from masking obtained (improvement in number of correctly identified words) under various modulated maskers at 0 dB SNR: Amount of release from masking in terms of improvement in number of correctly identified words (WRS) was calculated by subtracting the WRS obtained in the presence of unmodulated noises from modulated noises at 0 dB SNR as done for the previous group. The amount of release was not obtained at 10 dB SNR, because in all conditions all the individuals obtained almost maximum WRS possible and a test condition of unmodulated masker at 10 dB SNR was not included in the experiment in this group for comparisons. Thus improvement in terms of number of correctly identified words (WRS) due to release from masking at 10 dB SNR could not be observed. Mean and standard deviation of improvement in correctly identified words (WRS) at 0 dB SNR are tabulated in Table 8.

The mean value shows a greater release from masking when the noise is spectrally modulated with 4 ERB gaps than with 2 ERB gaps. It was also noted that temporally modulated noise showed almost no release from masking. To see if these effects are statistically significant or not, one way repeated measure ANOVA was done to compare the release from masking with different noise conditions at 0 dB SNR. The results showed that all 3 modulated noise conditions are significantly different [F (2, 24) = 7.174, p< 0.01]. Bonferroni's pairwise comparison revealed significant differences between 2 comparisons as shown in the Table 9.

Table 8: Mean and standard deviation for amount of release obtained (improvement in number of correctly identified words) with modulated noises in comparison to unmodulated noise in individuals with cochlear hearing loss

Conditions	Modulated minus Unmodulated	Mean (WRS difference)	SD
0 dB SNR	ERB2 - SSN	1.38	5.73
	ERB4 - SSN	4.76	3.13
	AM0 - SSN	.23	5.01

Table 9: Results of Bonferroni's pairwise comparison of amount of release from masking obtained (improvement in number of correctly identified words) at 0 dB SNR in individuals with cochlear hearing loss

Modulated minus Unmodulated	ERB4-SSN	AM0-SSN
ERB2-SSN	Significant, p<0.05	Not significant, p>0.05
ERB4-SSN		Significant, p<0.01

The Table 9 shows that there is a significant release from masking in terms of improvement in number of correctly identified words (WRS) in presence of spectrally modulated noise with 4 ERB gaps over the other two modulated masker conditions at 0 dB SNR.

Individuals with normal hearing sensitivity

The mean and standard deviation of number of correctly identified words (WRS) obtained in 7 different conditions in 20 individuals with normal hearing sensitivity are given in the Table 10.

The mean of number of correctly identified words (WRS) obtained at 10 dB SNR showed a ceiling effect across all noise conditions, which restricted any further comparison across the conditions at 10 dB SNR.

Effect of various maskers on number of correctly identified words (WRS) at different SNRs: One way repeated

Table 10: Mean and SD of number of correctly identified words (WRS) obtained for various noise conditions in individuals with normal hearing sensitivity

Conditions		Mean (WRS)	SD
10 dB SNR	ERB2	35.00	0
	ERB4	35.00	0
	AM10	35.00	0
0 dB SNR	SSN	32.25	2.57
	ERB2	33.55	2.01
	ERB4	34.30	1.30
	AM0	33.75	2.07

measure ANOVA was done to see the effect of various maskers on number of correctly identified words at 0 dB SNR. The results revealed a significant difference across the noise conditions [F (3, 72) = 13.313 p< 0.001] at 0 dB SNR. Bonferrroni's pairwise analysis showed significant differences between 2 comparisons as seen in the Table 11.

Table 11: Results of Bonferroni's pairwise comparison of WRS between noises in individuals with normal hearing sensitivity

0 dB SNR	ERB2	ERB4	AM0
SSN	Significant, p<0.01	Significant, p<0.001	Significant, p<0.001
ERB2		Not Significant, p> 0.05	Not significant p>0.05
ERB4			Not significant p>0.05

The Table 11 revealed that individuals with normal hearing obtained significantly better WRS in presence of all types of modulated maskers when compared to the unmodulated masker.

Amount of release from masking obtained (improvement in number of correctly identified words) under various modulated maskers at 0 dB SNR: Amount of release from masking was calculated by subtracting the scores obtained in presence of unmodulated noises from modulated noises at 0 dB SNR. The amount of release was not obtained at 10 dB SNR, because in all conditions all the individuals obtained maximum WRS possible. Mean and standard deviation of improvement in number of correctly identified words (WRS) at 0 dB SNR are tabulated in Table 12.

Table 12: Mean and standard deviation of amount of release obtained (improvement in number of correctly identified words) with modulated noises at 0dBSNR in individuals with normal hearing sensitivity

Modulated- Unmodulated	Mean(WRS difference)	SD
ERB2 - SSN	1.30	1.94
ERB4 - SSN	2.05	1.98
AM0 - SSN	1.50	1.98

The mean value shows almost similar amount of release across all types of noises. One way repeated measure ANOVA was done to compare the release from

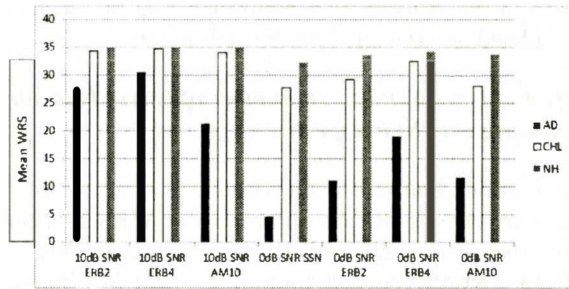

Figure 2: Mean of number of correctly identified words (WRS) obtained by three groups of participants across the various masking conditions.

masking with different noise conditions, at 0 dB SNR. The release obtained with all 3 modulated noise conditions were not different significantly [F (2, 38) = 2.048, p>0.05].

Between Group Comparisons

Effects of different types of noise, group and SNR on number of correctly identified words (WRS)

Mean and standard deviation of number of correctly identified words (WRS) obtained for all the noise conditions at both SNRs in all three groups of participants are shown in the Figure 2.

From the figure, we can observe that all the three groups perform comparatively poorer at 0 dB SNR than at 10 dB SNR. Group with AD scored the least scores across all conditions compared to the other two groups. Individuals with normal hearing as well as those with cochlear hearing loss perform almost similarly at 10 dB SNR. All the groups scored poorer in unmodulated noise than compared to modulated noises. The amount of improvement in WRS for the modulated noise differed across the groups. Maximum scores were obtained in the condition where noise is spectrally modulated with 4 ERB gaps across all the groups at both SNRs.

Mixed ANOVA was done to see the main effects of groups, SNR and noises (3x2x3) (excluding the speech shaped steady state noise). The speech shaped steady state noise was excluded from overall comparison, because a masking condition with this noise at 10 dB SNR was not performed in groups with normal hearing sensitivity and cochlear hearing loss. The main effect of groups was highly significant [F (2, 40) = 69.061, p< 0.001]. The main effect of types of noises [F (2, 80) = 62.950, p< 0.001] and SNRs [F (1, 40) = 178.744, p < 0.001] were also highly significant. It was also found that there was a significant interaction between all the 3 variables: SNRs and groups [F (2, 40) = 54.317, p < 0.001]; noise and groups [F (4, 80) = 24.019, p< 0.001]; SNRs and noises [F (2, 80) = 6.341, p<0.01] and SNRs, noises and groups [F (4, 80) = 4.050, p<

0.01]. This indicates that performance in presence of modulated noises varied across groups.

Effect of types of noise on number of correctly identified words (WRS) irrespective of groups

Bonferroni's pairwise comparison was done to see if there are any significant differences in WRS between the noises, irrespective of the groups at each SNR, as Mixed ANOVA showed significant effect of different types of noise on word identification. At both SNRs, results followed a similar pattern which is shown in Table 13.

Table 13: Results of Bonferroni's pairwise comparison of WRS between types of noise at 0 dB and 10 dB SNR

0 dB SNR/10 dB SNR	ERB4	AM
ERB2	Significant p<0.001	Significant p<0.01
ERB4		Significant p<0.001

It was found that the 3 noises differed significantly from each other at 0 dB SNR and 10 dB SNR.

Effect of groups on WRS across noises at 0 dB SNR and 10 dB SNR:

To compare the scores obtained for four different noise conditions across the 3 groups at 0 dB SNR and 10 dB SNR, MANOVA was carried out. It was found that there was a highly significant ($p < 0.001$) difference between the groups across all the four noise conditions. Details are given in Table 14.

Table 14: F- values obtained across three groups at 0 dB SNR and 10 dB SNR for each of the noise conditions

Conditions		F values at p < 0.001
0 dB SNR	SSN	F (2, 40) = 172.518
	ERB2	F (2, 40) = 92.455
	ERB4	F (2, 40) = 40.068
	AM0	F (2, 40) = 54.099
10 dB SNR	ERB2	F (2, 40) = 33.084
	ERB4	F (2, 40) = 10.192
	AM10	F (2, 40) = 45.761

Duncan's post hoc test was done to see if the groups differed from each other for every noise condition at 0 dB SNR and 10 dB SNR. Duncan's post-hoc test ranked this difference in three homogeneous subsets for SSN, ERB2 and AM0 at 0 dB SNR. The results showed that at all conditions, group with AD differed significantly from the other two groups.

Amount of release from masking obtained (improvement in number of correctly identified words) across the groups at 0 dB SNR

Improvement in word identification due to release from masking in different groups was considered only at 0 dB SNR. It was not considered at 10 dB SNR, as groups having normal hearing group and cochlear hearing loss obtained maximum possible scores for all the conditions. The mean and SD values obtained at 0 dB SNR are shown in Table 15.

Table 15: Mean and standard deviation of amount of release obtained (improvement in terms of number of correctly identified words) in 3 groups of participants at 0 dB SNR

0 dB SNR	ERB2 - SSN	ERB4 - SSN	AM10 - SSN
AD	6.50 (5.33)	14.40 (8.35)	7.00 (9.38)
Cochlear HL	1.38 (5.73)	4.76 (3.13)	0.23 (5.01)
Normal Hearing	1.30 (1.94)	2.05 (1.98)	1.50 (1.98)

It can be observed that all groups showed a greater amount of release for spectrally modulated noise with 4 ERB gaps compared to other modulations in the noise. Groups with cochlear hearing loss and normal hearing sensitivity do not show much difference between them.

Mixed ANOVA was also done to see the overall effects of release from masking obtained with the three modulated noise conditions and to see the interaction between the release from masking and groups at 0 dB SNR. It was found that there was a significant main effect of amount of release from masking, across the modulated noises [$F (2, 80) = 31.033$, $p < 0.001$]; across the groups [$F (2, 40) = 12.075$, $p < 0.001$] and also a significant interaction between the amount of release and the groups was found [$F (4, 80) = 8.193$, $p < 0.01$]. These results imply that the release may be different across different groups. Bonferroni's pairwise comparison was done to see if any significant difference exists between the amount of release obtained for each modulated noise, irrespective of the groups. The results are shown in Table 16.

Table 16: Bonferroni's pair wise comparisons for release obtained with modulated noises in comparison to unmodulated noise irrespective of groups

Noises at 0 dB SNR	ERB4-SSN	AM0-SSN
ERB2-SSN	Significant p<0.001	Not Significant p>0.05
ERB4-SSN		Significant p<0.001

The results revealed significant difference in amount of release obtained under spectrally modulated noise with 4 ERB gaps compared to other types of modulated noises irrespective of the groups.

To compare the amount of release obtained for 3 modulated noise conditions across the 3 groups at 0 dB SNR, MANOVA was carried out. It was found that there was a highly significant difference between the groups across all the comparisons as seen in Table 17.

Duncans post hoc test was done to see if the groups differed from each other in terms for amount of release from masking obtained with modulated maskers at 0 dB

Table 17: F values obtained across three groups at 0 dB SNR for 3 modulated noises

Conditions		F value
0 dB SNR	ERB2- SSN	F (2, 40) = 5.663, p<0.01
	ERB4 - SSN	F (2, 40) = 25.181, p<0.001
	AM0 - SSN	F (2, 40) = 4.943, p<0.01

SNR. It was found that group with auditory dys synchrony was significantly different from the other two groups in terms of release of masking obtained with modulated noises.

Discussion

The results obtained from various groups across various maskers at different SNRs on speech identification ability have been discussed below.

Individuals with AD

The results revealed that individuals with Auditory Dyssynchrony have significantly poorer speech identification scores in presence of speech shaped steady state noise (un modulated noise) and at 0dB SNR. This could be due to excessive masking effects in individuals with AD as reported by many authors (Zeng et al., 2005; Rance et al., 2004; Starr et al., 2003; Zeng et al., 1999). Zeng and Liu (2006) reported significantly poorer speech identification in presence of speech spectrum shaped noise at 0 dB SNR in 13 individuals with AD when compared to individuals having normal hearing and cochlear hearing impairment. Zeng et al. (1999) reported that impaired ability to follow temporal fluctuations in the signal is likely the underlying cause for the poor speech recognition in individuals with AD. A demyelinating neuropathy would lead to less faithful temporal representation of the signal due to loss of neural synchrony because; dys synchronous firing of neural impulses would reduce the number of neural spikes within each bin. Buss, Hall and Grose (2004) stated that individuals with AD are impaired in extracting both envelope and fine structure cues from speech signal and hence adding noise to the signal would exaggerate this difficulty. Physiologically, these excessive masking effects could be due to inner hair cell loss or loss of synchronous firing due to damaged nerve fibers (Harrison, 1998; Starr et al., 1996).

Demyelinated fibers may also display emphatic transmission (cross-talk) between fibers, with one active fiber cutting off discharges in adjacent fibers (Starr, Picton & Kim, 2001). This cross talk of fibers may lead to broader than normal neural tuning curves and this might lead to severe distortion in the coding of complex sounds like speech.

The current results pointed out that no significant differences in the speech identification was obtained in presence of speech shaped steady state noise and temporally modulated noise at 0 dB SNR as well as at 10 dB SNR. This indicates that these individuals with AD do not have the ability to take the advantage of temporal dips or modulations in noise, which could also be attributed to the poor temporal processing in these individuals (Zeng et al. 2005; Zeng et al. 1999). Eggermont (1997) stressed on the importance of neural synchrony across populations of neurons in the signaling of differences between a dynamic and a steady state signal. Hence the dys-synchronous neural discharge would have prevented these individuals with AD from detecting the temporal modulations in the signal. Figure 3 depicts the phenomenological model of auditory dys synchrony given by Zeng et al. (1999) to explain the temporal processing deficits in individuals with AD which could have led to poorer gap detection ability.

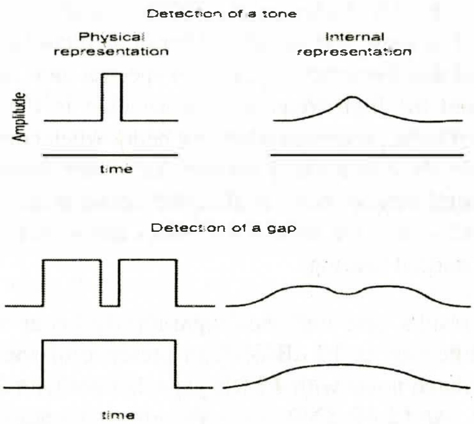

Figure 3: A phenomenological model of AD (Zeng et al., 1999). Desynchronous neural activity results in a smeared internal representation of a physical stimulus. Smearing of the temporal envelope does not affect the detection of a tone (top panel) because this task requires all or none decision. However, smearing causes greater problem in gap detection (bottom panel) as the task requires finer discrimination of two wave forms.

This abnormal smearing of the temporal waveform due to the dys-synchronous neural firing would fill in the temporal gaps in noise, thereby making the gaps unavailable for them to access glimpses of target speech. The persistence of effects of noise in the gaps could also be validated with the findings reporting excessive forward and backward masking in these individuals (Zeng et al., 2005), preventing them to separate out successive signals. The cross talk of nerve fibers which leads to broader neural tuning could also result in temporal smearing and hence poor detection of gaps in noise to perceive speech. Thus the average neural response to speech in presence of a temporally modulated background would be similar to the one in presence of un modulated signal.

In spite of these excessive masking effects, the current study found that individuals with AD are able to take the benefit of spectral modulations imposed on to the steady state speech spectrum shaped noise at 0 dB SNR which was statistically significant. This benefit was observed for both spectral modulations at 0 dB SNR, i.e. with 2 ERB gaps as well as with 4 ERB gaps. However, temporal modulation in noise also showed improvement in WRS, but was not significantly different from that obtained in presence of steady state noise. This implicated relatively intact spectral processing in individuals with AD enabling them to detect spectral gaps in noise. Psychophysical tuning curves in individuals with AD have shown sharper tips indicating normal OHC function (Vinay & Moore, 2007).

Near normal frequency discrimination ability at higher frequencies (Zeng et al., 2005) and normal auditory filter bandwidth (Rance et al., 2004) have also been reported in these individuals. Therefore it could be assumed that the intact detection of spectral gaps in noise allowed the high frequency information in the target speech to be perceived relatively better when compared to a steady state noise. However due to their underlying temporal deficit (Zeng et al. 2005; Zeng et al. 1999), overall scores are less, when compared to individuals with normal hearing.

The results also indicated significantly better speech identification at 10 dB SNR in presence of spectrally modulated noise with 4 ERB gaps, but not with 2 ERB gaps. At 10 dB SNR, since the effects of noise were already lesser, the additional advantage of the release from masking due to fluctuations in the masker may have resulted in improved scores for spectral modulations with 4 ERB gaps, but not with 2 ERB gaps. Even then, these individuals did not show any benefit from temporal modulations in noise at 10 dB SNR. This would imply that even at favorable noise conditions like 10 dB SNR, these individuals exhibit poorer temporal processing.

The results on amount of release from masking obtained for each of the modulated noise conditions also revealed that there is maximum release from masking with a spectrally modulated noise with 4 ERB gaps followed by the spectrally modulated noise with 2 ERB gaps at both 0 dB SNR and 10 dB SNR. There is minimal or no release from masking obtained for temporally modulated noise. The cross talk between the nerve fibers would probably have caused smearing of adjacent frequencies and hence the narrow spectral gaps (ERB 2), could have been masked relatively more by the smearing when compared to 4 ERB spectral gaps with far off frequencies. Therefore speech identification under noise with 4 ERB spectral modulations showed maximum release from masking.

Minimal or no release from masking obtained for temporal modulations in noise could also be attributed to the underlying temporal deficit caused by the dys-synchronous firing of neural impulses.

Individuals with Cochlear Hearing Loss

The individuals with cochlear hearing loss also showed maximum masking for unmodulated masker at 0 dB SNR as also reported by Leger et al. (2012). Investigators have reported that when the masker is modulated either periodically or by the speech of a single talker, speech intelligibility improves compared to when unmodulated noise is used , even if the modulated and un modulated noises have equal average powers (Festen & Plomp, 1990). The results also indicated that there was no significant difference between the speech identification under un modulated noise and spectrally modulated noise with 2 ERB gaps, i.e. these individuals could not take benefit of noise with spectral modulations with narrow 2 ERB gaps. Peters et al. (1998) reported that individuals with cochlear hearing loss perform significantly poorer in speech identification in presence of spectrally modulated noise.

This would indicate that reduced spectral resolution due to broader auditory filters in individuals with cochlear hearing loss (Glasberg & Moore, 1986) do not allow them to take benefit of narrow spectral gaps (ERB 2).

But the results also indicated that when the noise had broader spectral modulations with 4 ERB gaps, the individuals with cochlear hearing loss attained significantly better identification than under un modulated noise. It could be because the noise with 4 ERB gaps gives broader spectral gaps; to help these individuals also take benefit of release from masking. But these results of the present study are contradicting with the findings reported by Peters et al. (1998). They reported that individuals with cochlear hearing loss do not show much benefit in terms of SNR required to achieve 50% speech identification scores even when the bandwidth of spectral modulations were increased from two to four ERBNs.

Another finding of the present study was that the temporal modulations in noise showed no significant benefit when compared to steady state noise at 0 dB SNR. The reduced release from masking in presence of temporally modulated noise could be attributed to reduced frequency selectivity in such individuals (Peters et al, 1998). The broader auditory filter bandwidths in such individuals could cause reduced ability to use fine structure information and hence affect neural coding of temporal information (Glasberg & Moore, 1986) reported that a reduced release from temporal dips in noise could be due to deficit in coding the temporal fine structure cues in the signal due to poor phase locking ability of the nerve fibers. This would imply that some amount of temporal processing deficits is also exhibited by the individuals with cochlear hearing loss.

The comparison of modulated and unmodulated maskers did not show any significant differences at 10 dB SNR. This could be because, at this condition, the level of noise is inadequate to mask the high level of speech in individuals with cochlear hearing loss. At 10 dB SNR, maximum scores could be obtained even in presence of unmodulated noise condition.

The comparison of amount of release from masking obtained from various modulated maskers at 0 dB SNR also revealed that individuals with cochlear hearing loss demonstrated a significant amount of release only for the noise with 4 ERB spectral modulations. This could also be reasoned with the reduced spectral and temporal resolution in such individuals.

Individuals with Normal Hearing Sensitivity

Individuals with normal hearing sensitivity showed significantly better speech identification scores in presence of spectrally modulated noises and temporally modulated noise than when compared to the unmodulated masker. This indicates that individuals with normal hearing sensitivity have the ability to take advantage of spectral and temporal dips in the noise to understand the target speech signal (Peters et al, 1998; Festen & Plomp, 1990). The intact spectral and temporal resolution in these individuals facilitated to utilize the spectral and temporal fluctuations in the masker (Leger et al., 2012; Peters, et al., 1998).

The results also indicated that individuals with normal hearing benefited from spectral modulations with 2 ERB gaps as comparable to masker modulations of 4 ERB gaps, since the speech identification obtained under those two noise conditions were not statistically significant. This indicates that these individuals could take the advantage effectively even for narrow ERB gaps (2 ERB gaps). Thus there was no significant difference between the speech identification obtained under noises with 2 ERB and 4 ERB modulations.

When the amount of release obtained for each of the modulated masker was compared, no significant differences between the modulated noises were obtained. This implicated that individuals with normal hearing sensitivity utilized both spectral and temporal modulations in the masker to the same extend. Peters et al., (1998) and Duquesnoy, (1983) reported that normally hearing listeners can obtain very large advantage of listening in spectral and temporal dips.

Comparison of effect of various maskers across the groups

Results revealed that individuals with AD performed worst under all conditions of noise than normal hearing listeners or those with cochlear hearing loss. At 0 dB SNR, except for the spectrally modulated noise with 4 ERB gaps, under all other types of noise (modulated and un modulated), the speech identification was greatest in individuals with normal hearing sensitivity followed by those with cochlear hearing loss and then by those with AD. These results are in line with the findings reporting excessive masking effects observed in individuals with AD followed by cochlear hearing loss. Rance et al. (2007) reported that children with AD have significant perception problems in noise than when compared to peers having cochlear hearing loss.

Spectrally modulated noise with 4 ERB gaps gave the maximum speech identification scores across all three groups of individuals. This indicates that it was the easiest of all the noise conditions. Duquesnoy, (1983) reported that as the width of the spectral dips increases, the speech identification performance increases.

In the presence of spectrally modulated noise with 4 ERB gaps condition at 0dB SNR, individuals with cochlear hearing loss and those with normal hearing had similar scores. This implies that individuals with cochlear hearing loss could take the benefit of spectral modulations with 4 ERB gaps as normal hearing listeners.

Also when the amount of release from masking was compared across the 3 groups, it was found that individuals with AD differed significantly from other 2 groups. These results indicated that there was little or no amount of release obtained with temporally modulated noise in individuals with AD when compared to the other groups. Also, individuals with AD show significant release from masking in presence of spectrally modulated noise when compared to individuals with cochlear hearing loss. This also points out to the poor temporal processing in these individuals when compared to those with normal hearing (Liu et al., 2004) and cochlear hearing loss (Payton, Uchanski & Braida, 1994). A direct comparison with individuals with normal hearing cannot be made because individuals with normal hearing obtained relatively good speech identification scores even for the unmodulated noise. Hence the improvement in scores noticed with spectral modulations with 4 ERB gaps was the maximum in individuals with AD.

Conclusions

The major findings of the study indicated that individuals with Auditory dys-synchrony can extract the target speech signal when the background noise has larger spectral dips. Due to their underlying temporal processing problem they could not differentiate the temporal gaps in noise and hence perception was poorer in presence of noise. Any noise reduction strategies should incorporate large spectral dips in continuous noise to enhance the speech perception by allowing glimpses of signal. The individuals with cochlear hearing loss also performed significantly better in the presence of noise with 4 ERB spectral gaps, but the improvement noted was lesser compared to those individuals having AD. This could be attributed to the broader auditory filter bandwidths in these individuals which may have disallowed glimpses of speech when the spectral dips were narrow. It was also found that individuals with normal hearing sensitivity could utilize even smaller glimpses present in the noise. Thus, the use of a fluctuating noise in assessing speech recognition may provide us with a sensitive way of evaluating the effects of signal processing in hearing devices such as frequency-selective amplification and compression.

References

American National Standards Institute. (1996). *Specifications for Audiometers* (ANSI S3.6-1996). New York, NY.

Bernstein, J. G. W., & Grant, K. W. (2009). Auditory and auditory-visual intelligibility of speech in fluctuating maskers for normal-hearing and hearing-impaired listeners. *Journal of the Acoustical Society of America, 125*, 3358-3372.

Buss, E., Hall III, J. W., and Grose, J. H. (2004) "Temporal fine-structure cues to speech and pure tone modulation in patients with sensorineural hearing loss," *Ear and Hearing, 25*(3), 242-50.

Duquesnoy, A. J. (1983). Effect of a single interfering noise or speech source on the binaural sentence intelligibility of aged persons. *Journal of the Acoustical Society of America, 74*, 739-743.

Eggermont, J. (1997). Firing rate and firing synchrony distinguish dynamic from steady state sound. *Neuroreport, 8*, 2709-2713.

Festen, J. M., & Plomp, R. (1990). Effects of fluctuating noise and interfering speech on the speech-reception threshold for impaired and normal hearing. *Journal of the Acoustical Society of America, 88*, 1725-1736.

Glasberg, B. R., & Moore, B. C. J. (1986). Auditory filter shapes in participants with unilateral and bilateral cochlear impairments. *Journal of the Acoustical Society of America, 79*, 1020-1033.

Glasberg, B. R., & Moore, B. C. J. (1990). Derivation of auditory filter shapes from notched-noise data. *Hearing Research, 47*, 103-138.

Harrison, R. (1998) An animal model of auditory neuropathy. *Ear and Hearing, 19*, 355-361

Kraus, N., Bradlow, M. A., Cheatham, M. A., Cunningham, C. J., King, C. D., Koch, D. B., et al. (2000). Consequences of neural asynchrony: a case of auditory neuropathy. *Journal of the Association Research in Otolaryngology, 1*, 33-45.

Leger, A., Moore, B. C. J., & Lorenzi, C. (2012). Temporal and spectral masking release in the low- and mid-frequency range for normal-hearing and hearing-impaired listeners.*Journal of the Acoustical Society of America, 131*, 1502-1514.

Liu, S., Del Rio, E., Bradlow, A. R., & Zeng, F. G. (2004). Clear speech perception in acoustic and electric hearing. *Journal of the Acoustical Society of America, 116*, 2374-2383.

Methi, R., Avinash, & Kumar, U. A. (2009). Development of sentence material for Quick Speech in Noise test (Quick SIN) in Kannada. *Journal of Indian speech and Hearing Association, 23*(1), 59-65.

Middelweerd, M. J., Festen, J. M., & Plomp, R. (1990). Difficulties with speech intelligibility in noise in spite of a normal pure-tone audiogram. *Audiology, 29*(1), 1-7.

Moore, B. C. J. (1996). Perceptual consequences of cochlear hearing loss and their implications for the design of hearing aids. *Ear and Hearing, 11*, 133-160.

Moore, B. C. J. (2003). *An introduction to the psychology of hearing* (5th ed.). Academic Press: London.

Moore, B. C. J., Glasberg, B. R., & Hopkins, K. (2006). Frequency discrimination of complex tones by hearing-impaired participants: Evidence for loss of ability to use temporal fine structure information. *Hearing Research, 222*, 16-27.

Moore, B. C. J. (2007). *Cochlear Hearing Loss: Physiological, Psychological and Technical Issues.* Wiley-Interscience: Chichester, England.

Payton, K. L., Uchanski, R. M., and Braida, L. D. (1994). Intelligibility of conversational and clear speech in noise and reverberation for listeners with normal and impaired hearing, *Journal of the Acoustic Society of America, 95*(3),1581-1592.

Peters, R. W., Moore, B. C. J., & Baer, T. (1998). Speech reception thresholds in noise with and without spectral and temporal dips for hearing-impaired and normally hearing people. *Journal of the Acoustical Society of America, 103*, 577-587.

Rance, G., Mc Kay, C., & Grayden D. (2004). Perceptual characterization of children with auditory neuropathy. *Ear and Hearing, 21*, 34-46.

Rance, G., Barker, E., Mok, M., Dowell, R., Rincon, A. & Garratt, R. (2007). Speech perception in noise for children with auditory neuropathy/dys-synchrony type hearing loss. *Ear and Hearing, 28*, 351-360.

Starr, A., Picton, T., Hood, L. J., & Berlin, C. (1996). Auditory neuropathy. *Brain, 119*, 741-753.

Starr, A., Picton, T. W., & Kim, R. (2001). Pathophysiology of auditory neuropathy. In Y. S. Sininger & A. Starr (Eds.), Auditory neuropathy (pp. 67-82). San Diego, CA: Singular.

Starr, A., Michalewski, H.J., Zeng, F.G., Brooks, S.F., Linthicum, F. Kim, et al. (2003). Pathology and physiology of auditory neuropathy with a novel mutation in the MPZ gene. *Brain, 126*, 1604-1619.

Vinay, S. N. & Moore, B. C. J. (2007). Ten(HL)-test results and psychophysical tuning curves for participants with auditory neuropathy. *International Journal of Audiology, 46*, 39-46.

Wagener K., Brand T. & Kollmeier B. (2006). The role of silent intervals for sentence intelligibility in fluctuating noise in hearing-impaired listeners. *International Journal of Audiology* , *45*(1), 26 - 33.

Zeng, F. G., Oba, S., Garde, S., Sininger, Y.,& Starr, A. (1999). Temporal and speech processing deficits in auditory neuropathy. *Neurology Report, 10*, 3429-3435.

Zeng, F. G., Oba, S., & Starr, A. (2001). Supra threshold processing deficits due to desynchronous neural activities in auditory neuropathy. In D.J Breebaart, A.J.M Houstma, A. Kohlrausch, et al. (Eds.), *Physiological and Psychophysical Bases of Auditory Function* (pp.365-372). Maastricht, Netherlands: Shaker Publishing BV.

Zeng, F. G., Kong, Y. Y., Michalewski, H. J. & Starr, A. (2005). Perceptual consequences of disrupted auditory nerve activity. *Journal of Neurophysiology, 93*, 3050-3063.

Zeng, F. G., & Liu, S. (2006). Speech perception in individuals with auditory neuropathy. *Journal of Speech, Language and Hearing Research, 49*, 367-380.