EFFECT OF SPECTRALLY AND TEMPORALLY MODULATED MASKERS ON SPEECH PERCEPTION IN LISTENERS WITH AUDITORY DYS-SYNCHRONY, COCHLEAR HEARING LOSS AND NORMAL HEARING

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CERTIFICATE

This is to certify that this dissertation entitled **"Effect of Spectrally and Temporally Modulated Maskers on Speech Perception in listeners with Auditory Dys-synchrony, Cochlear Hearing Loss and Normal Hearing"** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No.: 10AUD021. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this dissertation entitled **"Effect of Spectrally and Temporally Modulated Maskers on Speech Perception in listeners with Auditory Dys-synchrony, Cochlear Hearing Loss and Normal Hearing"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this Master's dissertation entitled **"Effect of Spectrally and Temporally Modulated Maskers on Speech Perception in listeners with Auditory Dys-synchrony, Cochlear Hearing Loss and Normal Hearing"** is the result of my own study under the guidance of Dr. Animesh Barman, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

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CHAPTER 1

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 presence of noise. This difficulty in perception seen even in normal hearing individuals is yet more unfavorable in those individuals with hearing impairment.

Hearing impairment can be of different types based on the site of impairment and each of them differs in the way they impede speech perception. Conductive type of hearing loss is due to an external or middle ear problem which attenuates the sound reaching the inner ear, thus reducing the audibility. The speech perception can be restored if audibility is restored through amplification. Sensory type of hearing loss affects the primary organ of hearing called the cochlea. A cochlear hearing loss results in loss of audibility as well as distortion to the signal due to loss of ability of cochlea to analyze the signal into terms of its constituents, the frequency and amplitude. A third type of a hearing deficit is seen in individuals with auditory dys synchrony (AD) who exhibit problem in normal firing pattern of auditory nerve. These individuals may exhibit severe speech recognition problems which do not usually correspond to their signal detection abilities.

Studies (Moore, 1996, 1995) 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; Festen & Plomp, 1990).

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 presence of fluctuating maskers compared to 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 noises (Hygge, Ronnberg, Larsby & Arlinger, 1992; Bronkhorst & Plomp, 1990; Middelweerd, Festen, & Plomp, 1990).

Studies (Takahashi & Bacon, 1992; Duquesnoy, 1983) which measured the speech recognition threshold called the SRT required to correctly identify 50% of the stimuli in presence of amplitude modulated noise have shown 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 1-2 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 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 ability of glimpsing speech in spectral and temporal background dips requires low absolute thresholds (Desloge, Reed, Braida, Perez & Delhorne, 2010; George, Festen & Houtgast, 2006), and a certain degree of spectral (Peters et al., 1998; Baer & Moore, 1994; Baer & Moore, 1993; ter Keurs, Festen & Plomp, 1993) and temporal (George et al., 2006; Dubno, Horwitz & Ahlstrom, 2003) resolution. 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 the outer hair cells (Moore, 2003). But in case of cochlear hearing loss, all these three factors: 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 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 Auditory dys synchrony, are known to exhibit even greater difficulty for perceiving speech in presence of noise. Kraus et al. (2000) have reported that individuals with AD, obtain significantly depressed scores in presence of a multi talker speech babble, in spite of performing remarkably well in quiet.

Zeng and Liu (2006), reported that even at signal-to-noise ratios 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; Moore & Moore, 2003). It may thus be presumed that the reduced phase locking ability in these individuals with AD may hinder release from masking.

Need for the study

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 presence of fluctuating or modulated backgrounds is important. The literature reviewed has pointed out that there are studies which show that individuals with moderate to severe cochlear hearing loss may not be able to take advantage of spectral and temporal dips in the background noise as that of normal hearing individuals (Wagener, et al., 2006; Peters, et al., 1998). Also, as pointed out by Bernstein and Grant (2009), it is important to see if this masking release has been constrained by the SNR used. This attempt would give a better understanding of the effects of spectral and or temporal processing deficits in these individuals.

Studies (Rance, et al. 2007; Zeng & Liu, 2006; Kraus, et al. 2000) in auditory dys-synchrony have reported excessive masking effects seen in these individuals. Studies have not addressed the ability of masking release in presence of fluctuating maskers in these individuals with AD and thus it calls for a need to study the effect of such modulated maskers on speech perception. Because a temporal processing deficit is a hallmark of AD (Zeng, et al., 2005; Zeng, Oba, Garde, Sininger & Starr, 1999), it is essential to study if listeners with AD can take the benefit of modulations in the masker to understand speech. Thus a comprehensive knowledge about psychophysical findings reported in literature could be better corresponded with the speech perception difficulties. And henceforth, the present study was 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.

Aim of the study:

The current study aimed to

1. Assess speech recognition performance in groups of individuals with auditory dys-synchrony, cochlear hearing loss and normal hearing in presence of the following noises at 0 dB SNR and 10 dB SNR:
    i. Spectrally modulated noise
    ii. Temporally modulated noise
2. To observe which clinical group would take greater advantage of spectral and/or temporal dips to understand speech.

CHAPTER 2

REVIEW OF LITERATURE

Auditory perception of speech is a process by which listeners recognize speech sounds to understand spoken language. An intact speech perception is dependent on normal hearing and normal auditory processing. But, any adverse listening conditions like noise or reverberation may degrade the perception of speech, in spite of having normal hearing. This undesirable effect will be much more severe in individuals with hearing impairment.

Much research has been carried out with regard to the perceptual consequences of hearing impairment. Studies have shown that presence of noise makes perception of speech difficult for both listeners with normal hearing and those with hearing impairment (Moore, 1996, 1995). The effects on perception have also been studied with background noises of varying nature. It has been found that certain noise conditions can be advantageous for individuals with normal hearing, because the reception of speech may be improved when listening in temporally or spectrally fluctuating noise versus continuous noise of the same long-term root-mean-square (RMS) level. This benefit, referred to as 'masking release', arises from the use of improved speech to noise ratios during momentary dips in the level of the fluctuating noise and this effect is reduced in individuals with hearing deficit.

Masking release

The effect of masking release is most useful in daily or 'cocktail-party' situations where background sounds often fluctuate in frequency and time. Masking release can be of two types: that based on listening in temporal dips (temporal masking release) and that based on listening in spectral dips (spectral masking release).

Normal Hearing

Peters et al. (1998) assessed the speech recognition threshold (SRTs, the signal-to-noise ratio required for 50% intelligibility) in 10 normal hearing individuals in presence of speech spectrum shaped steady state noise and also the same noise having spectral and temporal modulations embedded on it. They reported that normal-hearing listeners have greater speech intelligibility when background maskers have spectral and/or temporal fluctuations than when un modulated. The spectral modulations were incorporated by filtering the speech spectrum shaped noise to have spectral dips in various frequency regions based on equivalent rectangular bandwidth (ERB_N). Temporal modulations were created by imposing the envelope of a female talker on the speech shaped noise. They found that individuals with normal hearing attained significantly better SRTs for sentences presented against the spectrally and temporally modulated maskers than a steady speech-shaped noise. It was suggested that normal hearing listeners have the ability to use ‘glimpses’ to identify speech in modulating backgrounds. Glimpses refer to specific spectro-temporal dips or valleys in noise where target speech energy exceeds the masker energy by a given amount (Cooke, 2006). Also when the masker is the speech from a competing single talker, speech intelligibility improves compared to when un modulated noise is used (Festen & Plomp, 1990; Carhart, Tillman & Greetis, 1969; Wilson & Carhart, 1969; Miller & Licklider, 1950), even if the modulated and un modulated noises have equal average powers. In such a condition, glimpsing of temporal and spectral dips could be allowed by the moments when the overall level of the competing speech is low, for example during brief pauses, during production of low-energy sounds such as consonants /m/, /n/, /k/, or /p/, or during formant transitions.

The ability to listen in spectro-temporal dips is highly dependent on audibility (Desloge et al., 2010; George et al., 2006) frequency selectivity (Peters et al., 1998; Baer & Moore, 1994,1993; ter Keurs et al.,1993) and fine temporal resolution (George et al., 2006; Dubno et al., 2003;). These effects are in turn dependent on the active mechanism by the cochlear amplifiers which contributes to better sensitivity and sharp tuning of the auditory filters in normal hearing. Intact temporal processing is also important for listening in dips because the finely tuned information from the cochlea is carried on to the nerve fibers which lock onto the phase of the signal and decides whether a signal in the dips of a background sound is produced by the target speech or is simply a part of the background sound (Moore & Glasberg, 1987).

Gnansia, Jourdes and Lorenzi (2008) measured consonant identification for normal hearing listeners using nonsense vowel-consonant-vowel (VCV) stimuli in a steady-state or temporally-fluctuating noise masker. VCVs and noise were either unprocessed or processed by degrading fine structure cues within 32 frequency bands. The temporal release from masking was significantly affected when fine structure cues were degraded, suggesting certain contribution of temporal fine structure cues to the masking release. Thus an intact spectral and temporal processing is an important prerequisite for taking the advantage of spectral and temporal dips in background noise.

Cochlear Hearing Loss

Cochlear hearing loss is caused due to the damage to the structures inside the cochlea and it results in a reduction in active mechanism, due to an impairment or absence of the cochlear amplifiers (Patuzzi, Yates & Johnstone, 1989; Pickles, 1988; Moore, 1995; van Tasell, 1993; Ruggero & Rich, 1991). Cochlear disorders results in a loss of hearing sensitivity that is essentially same for air conduction and bone conduction and it often involves a greater loss of hearing sensitivity at higher frequencies than at lower frequencies.

Mechanism

Cochlear hearing loss involves damage to the OHCs and IHCs, the stereocilia may be distorted or destroyed, or entire hair cells may die. The OHCs otherwise called the cochlear amplifiers are generally more vulnerable to damage than the IHCs. As a result, the sensitivity to weak sounds is reduced and the tuning curves on the basilar membrane become much more broadly tuned, less sharp with reduced sensitivity around the tip and all of the frequency-selective effects weaken or disappear altogether. Evans and Harrison (1976) reported that tuning in auditory nerve fibers also get affected by the loss of integrity of OHCs. Thus abnormal frequency analysis at the level of cochlea has serious consequences in further processing of speech (Evans, 1978; Scharf, 1978). Hence loss of frequency selectivity would affect speech perception ability in individuals with cochlear hearing loss.

Speech Perception in Quiet

Speech perception difficulties in cochlear hearing loss vary depending on the severity of the impairment. Individuals with mild or moderate degree of losses can usually understand speech reasonably well when they are in a quiet room with only one person talking. But they might have difficulty when more than one person is talking at once or when background noise or reverberation is present. While individuals with severe or profound losses usually have difficulty even when listening to a single talker in a quiet room and they have severe problems when background noise is present (Moore, 2008).

The reasons for these difficulties in understanding speech have been suggested to be arising primarily from reduced audibility, such that the amount by which speech is above threshold, and the proportion of the speech spectrum which is above threshold are both less in those with hearing loss than for normal listeners (Lee & Humes, 1993). Other researchers (Glasberg & Moore, 1989; Plomp, 1986, 1978; Dreschler & Plomp, 1985, 1980;) have argued that the difficulty in understanding speech arises at least partly from a reduced ability to discriminate sounds which are well above the threshold. Studies (Faulkner, Rosen, & Moore, 1990) have correlated reduced frequency selectivity with poor perception of words in isolation or within sentences.

In contrary, studies (Festen & Plomp, 1983; Dreschler & Plomp, 1980) have also reported that speech perception in quiet is not related to the tuning of the auditory filter. Frequency selectivity may be more important in reducing the effects of noise because, in quiet, the redundancy of speech compensates for poor frequency resolution. The presence of noise would reduce the effective SNR within each auditory filter resulting in reduced redundancy and poor perception (Stelmachowicz & Jesteadt, 1984). Rance et al. (2007) reported that loss of precision at the level of cochlea has greater consequences in presence of noise.

Speech Perception in Noise

Perception of speech in presence of noise has been found to one of the major consequences of cochlear hearing loss. Studies (Peters et al., 1998) have often quantified the speech perception in noise by estimating the speech-to-noise ratio (SNR) required to achieve a given level of intelligibility, such as 50%. The hearing impaired needs a higher SNR to achieve the same level of performance as individuals with normal hearing.

However, the difference in SRT for normal and hearing-impaired people varies depending on the nature of the background noise. When the background is a steady noise with the same long-term average spectrum as the speech (called speech-shaped noise), the difference is typically in the range 2–5 dB (Plomp, 1994; Glasberg & Moore, 1989). This denotes a considerable deficit, since intelligibility in this situation worsens by 11% to 19% for each 1dB decrease in speech-to-noise ratio (Nilsson, Soli & Sullivan, 1994; Moore, Lynch & Stone, 1992; Laurence, Moore & Glasberg, 1983; Plomp & Mimpen, 1979).

But when the background is a single competing talker (Moore, Glasberg & Vickers, 1995; Hygge et al., 1992; Duquesnoy, 1983; Carhart & Tillman, 1970), a time-reversed talker (Duquesnoy, 1983), or an amplitude-modulated noise (Eisenberg, Dirks & Bell, 1995; Takahashi & Bacon, 1992, Duquesnoy, 1983), the difference in SRT between normal and hearing-impaired individuals can be much larger, ranging from about 7 dB to 15 dB which indeed is a very large deficit. At signal-to noise ratios where normally hearing people would achieve almost 100% intelligibility, hearing-impaired people may understand almost nothing. Thus, the problems faced by hearing-impaired people, in comparison to normally hearing people, are much greater when the background sound is a fluctuating masker than when it is a steady speech shaped noise.

The relatively poor performance of hearing-impaired people when listening in a background of a fluctuating masker appears to arise from a failure to take advantage of 'dips' in the competing voice. This could be attributed to poor temporal and spectral resolution in these individuals (Moore, 1995; Festen, 1993; Glasberg & Moore, 1992, 1986; Festen & Plomp, 1990; Moore & Glasberg, 1988; Festen, 1987; Glasberg, Moore, & Bacon, 1987; Tyler, 1986).

Festen and Plomp (1990) measured SRTs for sentences for young normal hearing listeners (aged 16-36 years) and listeners with moderate hearing loss (aged 21- 77 years). The sentences were presented in the background of steady state noises, amplitude-modulated noises, and a single competing talker. For normal hearing listeners, the SRT obtained for sentences in modulated masker was 4-6 dB lower than for steady-state noise; and 6-8 dB lower for sentences masked by a competing speech. However, hearing impaired listeners showed no obvious release from masking. Similar results were also obtained by Gustafsson and Arlinger (1994).

Peters et al. (1998) observed that both young and elderly listeners with moderate hearing loss showed very limited ability to take advantage of two to four equivalent rectangular bandwidth, ERB_N - wide spectral dips. Moreover, for hearing impaired listeners, SRTs decreased by only 1-2 dB when the bandwidth of spectral dips was increased from two to four ERBNs, whereas SRTs decreased by 6 dB for normal hearing listeners.

Recently Leger, Moore and Lorenzi, (2012) reported that individuals with mild degree of hearing loss may show spectral and temporal release from masking similar to those having normal hearing. This would imply that the possible spectral and temporal processing deficits in these individuals may not affect listening in dips. They also suggest that the reported deficits in previous studies (Jin & Nelson, 2006) in listeners with hearing impairment could have been obtained due to the higher degree of hearing loss (moderate-severe) which demonstrates greater deficits affecting release from masking.

Psychophysical correlates

The reasons attributed for poor release from masking have been reduced audibility and poor spectral and temporal resolution in these individuals. Several studies have shown that the ability to understand speech in noise is highly correlated with measures of frequency resolution, although the effect of audibility also plays a crucial role (Glasberg & Moore, 1989; Dreschler & Plomp, 1985, 1980). The studies using the articulation index or speech intelligibility index (Smoorenburg, 1992; Pavlovic, Studebaker & Sherbecoe, 1986; Pavlovic, 1984; Dugal, Braida & Durlach, 1978) suggest that, while audibility is of major importance, it is not the only factor involved, at least for people with moderate to severe cochlear losses.

The results of simulation experiments (Baer & Moore, 1994; ter Keurs, et al., 1993) on spectral smearing also suggest that reduced frequency selectivity contribute significantly to the difficulties experienced by people with cochlear hearing loss in understanding speech in the presence of background sounds. Moore and Glasberg (1986) reported that individuals with moderate cochlear hearing loss have broader than normal PTCs and studies (Leeuw & Dreschler, 1994; Leek & Summers, 1993; Sommers &

Humes, 1993; Peters & Moore, 1992; Stone, Glasberg & Moore, 1992; Glasberg & Moore, 1986) have also reported that auditory filters are broader than normal in hearing-impaired subjects and that the degree of broadening increases with increasing hearing loss. Therefore the reduced masking release reported for hearing impaired listeners could be caused by the broadening of auditory filters which leads to the internal smearing of background spectral dips, and thus to a reduced ability to glimpse speech in the background noise (Moore, 2003; Peters et al., 1998; Glasberg & Moore, 1986; Tyler, 1986).

Recent studies suggested that coding of temporal fine structure of the signal may also be critical for listening in the background temporal dips (Moore & Moore, 2003; Moore et al., 2006). For normally hearing listeners, the intelligibility of speech, based on envelope cues alone is very poor in the background of a single talker or an amplitude-modulated noise (Nelson, Jin, Carney & Nelson 2003; Stone & Moore, 2003; Qin & Oxenham, 2003) and the same would apply for hearing-impaired listeners.

Similar results were obtained by Nelson, et al (2003) and Qin and Oxenham (2006) with sentence material and gated noise or noise artificially-modulated by speech envelopes. Hopkins, Moore and Stone (2008) suggested that reduced ability to take advantage of fine structure information in speech may partially explain why listeners with cochlear hearing loss get less benefit from listening in a fluctuating background than normal hearing listeners. The normal auditory system decides whether a speech signal in the dips of a background sound is produced by the target speech or is simply part of the background sound by using information derived from neural phase locking to temporal fine structure. Thus a poor coding of fine structure cues may lead to poor release from masking.

In contrast, Bernstein and Grant (2009) pointed out that masking release is dependent on the baseline SNR (the magnitude of temporal masking release decreasing with increasing SNR for hearing impaired listeners) and suggested that differences between normal hearing and hearing impaired listeners found in previous studies could have been limited due to the differences in the SNR. Yet, some studies (Peters et al., 1998) showed reduced temporal release from masking even at favorable SNRs in hearing impaired listeners.

Thus the psychophysical studies show the importance of intact spectral and temporal resolution, along with favorable speech to noise ratio in order to perceive speech in presence of fluctuating backgrounds. These abilities are found to be degraded in individuals with cochlear hearing loss and hence any enhancement of spectral and temporal features in speech is expected to benefit them in perception of speech in varying backgrounds.

Techniques to improve speech perception

Many studies (Lyzenga, Festen & Houtgast, 2002; Franck, Sidonne, van Kreveld-Bos, Dreschler & Verschuure, 1999; Baer, Moore & Gatehouse, 1993; Simpson, Moore & Glasberg, 1990; Bustamante & Braida, 1986; Boers, 1980) have been carried out to see if enhancement of spectral or temporal features helps the speech perception in individuals with cochlear hearing loss. An investigation by Apoux, Tribut, Debruille and Lorenzi (2004) on individuals with cochlear hearing loss revealed a significant improvement in speech perception in background noise when the envelope enhancement scheme enhanced the consonantal portion of the signal while compressing the vowel portion.

Several recent studies have studied the enhancement of spectral peaks in speech to improve speech intelligibility for hearing-impaired listeners (Bustamante & Braida 1986; Summerfield, Foster, Tyler & Bailey, 1985; Boers, 1980). Summerfield et al. (1985) implemented spectral contrast by narrowing the bandwidths of the first five formants in CVC syllables and found that individuals with cochlear hearing loss took very limited benefit out of it compared to normal hearing listeners due to poor frequency selectivity. Boers (1980) applied spectral enhancements of natural sentences when the speech was filtered through 12 one third octave digital filters and the magnitude of each filter output was squared and scaled to increase the contrasts between the peaks and valleys. He found slight improvement in perception by 2 hearing impaired listeners. Baer and Moore (1994) studied a scheme using a mathematical optimization procedure to enhance spectral contrast in order to produce a normal excitation pattern in an impaired ear, but it failed to produce statistically significant improvements in intelligibility. The implication of such strategies in the hearing aid technology has yet not been realized completely.

Auditory Neuropathy/Dys-Synchrony (AN/AD)

Auditory neuropathy (AN/AD) is a form of hearing impairment in which cochlear outer hair cell function is preserved but afferent neural conduction in the auditory pathway is disordered (Berlin, Hood & Rose, 2001; Starr, Picton, Sininger, Hood & Berlin, 1996). The etiology of auditory neuropathy spectrum disorder (ANSD) is multifactorial and includes genetic, congenital, and acquired conditions.

In contrast to individuals with cochlear hearing loss, individuals with AN have speech perception difficulties that are often disproportionate to hearing threshold levels (Starr et al., 1996), and have significant difficulty hearing in noise (Rance et al., 2007; Kraus et al., 2000). The degree of hearing loss could range from normal to profound, and in some cases may be transient or degenerative in nature (Franck, Rainey, Montoya, & Gerdes, 2002; Madden, Rutter, Hilbert, Greinwald & Choo, 2002; Kraus et al, 2000; Deltenre et al., 1999; Starr et al., 1998).

Mechanisms

There are several potential sites of dysfunction for AN, which could be an isolated inner hair cell dysfunction (Gibson, 2002; Harrison, 1998) or a synaptic dysfunction between the nerve and hair cell or the nerve itself (Buchman et al., 2006; Rance, Cone-Wesson, Wunderlich & Dowell, 2002). The peripheral portion of auditory nerve could be demyelinating or have an axonal neuropathy.

ABR abnormality is thought to be the result of either a reduction of neural elements available to contribute to the volume conducted response as in axonal neuropathy, or a disruption of the synchrony or timing of neural activity in the auditory brainstem as in demyelinating neuropathy (Rance, 2005). This temporal inconsistency may be the primary deficit in patients with the AN/AD (Michalewski, Starr, Nguyen Kong & Zeng 2005; Kraus et al. 2000; Starr et al. 1991) which has a serious impact on speech perception.

Speech Perception in Quiet

Difficulty in speech understanding is a consistently reported consequence of AN/AD type hearing loss. In contrast to cochlear hearing loss, speech perception ability in adults diagnosed with auditory neuropathy/dys-synchrony type hearing loss has shown no correlation with the pure-tone audiogram (Zeng et al., 2001; Starr, Sininger, & Pratt, 2000), and has been significantly poorer than would be expected for cochlear losses of equivalent degree. Results in children also have shown limited capacity to understand speech despite having complete access to the normal speech spectrum (Rance et al., 2004).

A possible reason for this difficulty is that the neural timing disruption affects the listener's ability to cope with the dynamic nature of speech signals. Severe disruption of timing cues could impair not only the ability to use amplitude envelope cues in speech, but also to perceive rapidly changing spectral shapes in the flow of speech stimuli (Rance et al., 2004).

Speech Perception in Noise

Besides speech perception problems in favorable (quiet) listening conditions, extreme difficulties in background noise have been reported for both adults and children with AN/AD (Shallop 2002; Kraus et al. 2000; Starr et al. 1998). These studies have presented case examples showing excellent speech perception in quiet, but extremely poorer performance at signal-to-noise ratios of about +3 dB to +12 dB SNR.

Rance, et al (2007) evaluated speech perception in noise in children with AD, cochlear hearing loss, and those with normal hearing. Results showed that the perception of children with normal hearing and those with cochlear hearing loss was not altered significantly when the S/N ratio was -5 dB but the performance of the individuals with AD was significantly reduced. Kraus et al. (2000) studied speech perception in noise in an individual with auditory dys synchrony whose speech identification in quiet was 100%

but was abnormally reduced in the presence of a multitalker babble at a signal to noise ratio of -3 dB. Zeng and Liu (2006), studied the perception of 14 AN subjects and found consistent reductions in speech recognition ability, even at signal-to-noise ratios that show little or no effect on subjects with normal hearing (10 to 15 dB). Parallel findings were also reported by Shallop (2002). The mechanisms underlying these perceptual difficulties in noise are unclear.

Psychophysical correlates

Recent psychophysical studies have also shown excessive masking of pure tones in auditory neuropathy/ dys-synchrony subjects by simultaneous noise, as well as noise bursts presented before and after the test signal (Vinay & Moore 2007; Zeng et al. 2005; Kraus et al., 2000; Zeng et al., 2001). These abnormal or excessive masking effects could be attributed to the poor temporal and spectral processing in participants with AD (Zeng, et al., 2005; Rance et al., 2004; Starr et al., 2003; Zeng et al., 1999).

Significant temporal resolution deficits have been demonstrated in auditory neuropathy/ dys-synchrony subjects. Zeng et al. (2005) and Zeng et al. (1999), have reported that in adults and children with AN/AD type hearing loss, abnormal results were obtained on various temporal resolution measures, including gap detection and the temporal modulation transfer function. Starr et al. (1991) have also shown profoundly impaired use of temporal cues (gap detection, monaural stimulus separation) in an 11-year-old subject with progressive AN/AD. Abnormal masking level difference, have been a consistently reported finding in individuals with AN/AD (Hood, 1999; Starr et al., 1996; Starr et al., 1991). Subjects with auditory neuropathy/ dys-synchrony typically show no masking release, whereas subjects with normal hearing usually show a masking level difference of approximately 10 dB (Licklider, 1948).

Moreover Zeng et al. (2005), Zeng et al. (2001), and Kraus et al. (2000) have presented forward and backward masking data suggesting wider than normal temporal windows in adult auditory neuropathy/dys-synchrony subjects. These abnormal backward and/or forward masking patterns, also suggest impaired temporal resolution ability.

Studies have correlated severe speech perception difficulties in AN/AD subjects with abnormal temporal resolution (Zeng et al., 2005; Zeng et al., 2001; Zeng et al., 1999; Starr et al., 1991). Rance et al., (2004) reported that seven of the 14 AN/AD children showed normal or only mildly impaired modulation detection ability, and all these subjects demonstrated significant open-set speech discrimination (≥60%). In the other 7 subjects, the ability to perceive amplitude fluctuations even at relatively slow modulation rates was significantly depressed and they obtained little or no open-set speech perception scores.

Psychophysical investigation of frequency resolution in subjects with AD type hearing loss has shown mixed results. Cacace, Satya-Murti and Gimes (1983) plotted Psychophysical tuning curves in 2 subjects having Fredriech’s ataxia by using a simultaneous masking paradigm and found that tuning curves were sharply tuned and of normal morphology. Rance et al., (2004) tried to correlate the open-set speech perception performance with the auditory filter bandwidth obtained using notched noise masking technique in 14 children with AN/AD. They found similar results for both children with normal hearing and those with AN/AD.

In contrast, Kraus et al. (2000) reported abnormal frequency resolution in an adult AN/AD patient using similar masking paradigms as Rance et al., (2004). The participant with AN/AD performed significantly poorer when compared to normal hearing participants. They attributed this deficit to central coding deficit (assuming normal cochlear function from the presence of recordable otoacoustic emissions).

Severe difficulty with frequency discrimination has been reported in individuals with AN/AD. Starr et al. (1991) measured 'just noticeable differences' for pairs tone-burst stimuli at octave frequencies from 250 Hz to 8 kHz in an 11- year-old AN/AD subject. The results showed significantly depressed discrimination scores when compared to normal hearing children. Zeng et al (2005) also found impaired frequency discrimination ability in 12 subjects with auditory neuropathy/dys-synchrony. The subjects performed extremely poorer than normal hearing group especially in low to mid frequency range (≤2 kHz) and discrimination in the high-frequency range appeared to be less impaired, approaching the normal range at the 8-kHz. This might imply a disruption of the low-frequency temporal discrimination processes in individuals with AN/AD (Zeng et al., 2005).

Rance et al., (2004) also reported similar results in a group of 14 children with AD/AN. The results revealed the mean difference limen for 4-kHz pure tones was 4.5 times the normal value, whereas discrimination at 500 Hz averaged 11 times poorer than that of the normally hearing group. They also correlated frequency discrimination ability with speech understanding in subjects with auditory neuropathy/dys-synchrony and found a strong relationship between open set-word score and DLF.

Thus from the psychophysical experimental findings it is clear that individuals with AN/AD have a significantly disrupted temporal processing which has adverse effects on speech perception. These effects are unlike those individuals with cochlear hearing loss having a major deficit in frequency processing. And henceforth studies have implemented various temporal envelope enhancement techniques in individuals with AN/AD for compensating the effects of reduced temporal processing on speech perception.

Techniques to improve speech perception

Studies (Zeng et al., 2005; Kraus & Braida, 2004; Liu, Del Rio, Bradlow, & Zeng, 2004) have tried to expand temporal modulation or 'envelope expansion algorithms' because one of the features in clear speech is enhanced amplitude modulation. Narne and Vanaja (2009) reported that individuals with AD get benefitted from an envelope enhanced speech in both quiet and in presence of noise.

The use of frequency-transposition amplification strategies is another option that has been proposed to minimize the frequency discrimination difficulties that affect many AN/AD subjects (Zeng et al., 2005; Zeng et al., 2002). Either filtering out low-frequency sounds or transposing the acoustic speech signal into the high-frequency region may be beneficial in some cases.

Processing strategies that manipulate timing differences in the speech may also help in the perception of temporal cues in subjects with auditory neuropathy/dys-synchrony. Tallal et al. (1996) proposed a processing algorithm that combined a peak enhancement strategy with a temporal expansion algorithm that prolonged the duration of the speech signal by 50%. The resulting speech was considered to have maintained its spectral integrity and natural quality. The applicability of such programs to subjects with auditory AN/AD type hearing loss still needs to be investigated.

The literature review recognizes an impaired temporal and spectral processing in individuals with cochlear and AN/AD type hearing loss. But these processes need to be intact for taking advantage of any spectral or temporal dips in noise to understand speech. Thus it could be inferred that these clinical population may have a deficit in release from masking. A comparison of this ability across the groups having cochlear hearing loss and auditory dys synchrony would help us to weigh the importance of these processes in the respective clinical group and thus making a comprehensive correspondence of perceptual difficulties and psychophysical test findings.

CHAPTER 3

METHOD

The current study was carried out to assess speech recognition performance in groups of individuals with auditory dys-synchrony, cochlear hearing loss and normal hearing in the presence of spectrally modulated and temporally modulated noise. Also aimed to know which clinical group would take greater advantage of spectral and or temporal dips to understand speech at different SNRs.

Participants:

To accomplish the goal, a total of 43 participants participated in the study. They were categorized into 3 groups as follows:

Group I: Listeners with Auditory Dys-synchrony

This group included 10 individuals of age ranging from 18 to 55 years who were diagnosed as having Auditory Dys synchrony. They were selected based on the following criteria:

- Pure tone thresholds were within 55 dB HL with either flat or gradually rising audiogram configuration with a greater hearing loss at lower frequencies than at higher frequencies.
- Absent auditory brainstem response beyond that expected with the degree of pure tone hearing loss indicating neural involvement.
- Otoacoustic emissions and/or cochlear microphonics were preserved in them, suggestive of normal OHC function.
- Speech identification scores in quiet obtained at 40 dB SL were greater than 50% on routine speech audiometry. Since the experiment involved speech identification in

adverse listening condition, the minimum criterion of 50% scores in quiet was selected to accurately attribute the effects of various types of noise. However all of them had very poor or no speech identification scores at 0dB SNR.

- They had normal tympanometric findings with absent ipsilateral and contralateral acoustic reflexes.
- None of them reported to have any history of middle ear infection and also middle ear pathology, which was ruled out by an otological examination.
- The presence of any other neurological involvement was ruled out by a neurological evaluation.
- All of them were native and fluent speakers of Kannada

Group II: Listeners with cochlear hearing loss

This group consisted of 13 Individuals of age ranging from 18 to 55 years having cochlear hearing losses. They were selected based on the following criteria:

- Subjects with pure-tone thresholds between 25 to 55 dB HL having a flat audiometric configuration which indicates approximately equal hearing loss across frequencies or a gradually sloping configuration in which thresholds fell approximately 5 to 10 dB per octave.
- Speech identification scores were comparable to their degree of hearing loss as suggested by Nadol and McKenna, (1993).
- Normal tympanometric findings with acoustic reflexes present, elevated or absent.
- They had absent DPOAEs indicating cochlear damage.
- Auditory brainstem responses (ABR) were proportional to the degree of hearing loss indicating absence of retrococlear pathology.

- No history of middle ear infection and middle ear pathology which was ruled out by an otologist based on an ear examination
- None of them showed any symptoms of neural involvement.
- All of them were native and fluent speakers of Kannada

Group III: Normal hearing listeners

This group consisted of 20 age matched individuals with that of individuals in group I and II of age ranging from 18 to 55 years having hearing sensitivity within normal limits. They were selected based on the following criteria:

- Pure tone hearing thresholds did not exceed 15 dB HL at octave frequencies between 250 to 8000 Hz for air conduction and between 250 to 4000Hz for bone conduction.
- All of them had A type tympanogram with presence of acoustic reflexes.
- All of them had speech identification scores of above 90% with SPIN scores greater than 60% at 0dB SNR.
- They had no history of otological problems, which was verified by an otological examination.
- They had no history of any relevant neurological problems.
- All of them were native and fluent speakers of Kannada

Equipment:

Several equipments were used in the study. Some of the equipments were used for routine audiological evaluation required for the selection of subjects and some were used for the experimental purpose. The following equipments were used for the routine audiological evaluation to select the candidates for the study:

Pure Tone Audiometer

A two channel diagnostic audiometer GSI 61 coupled to impedance matched TDH 50P earphones with MX-41/ AR ear cushions and a bone vibrator (Radio ear B-71) was used. It was used to obtain air conduction and bone conduction pure tone thresholds at different frequencies and also to obtain Speech identification scores in quiet and in the presence of ipsilateral maskers.

Immittance meter

A calibrated immittance meter Grason Staddler Inc. Tympstar (GSI-TS) was used for Immittance testing. Each ear of the subject was tested for the type of tympanogram and presence or absence of ipsilateral and contralateral acoustic reflexes.

Otoacoustic emission Analyser

To check the Outer hair cell functioning, Madsen Capella OAE analyzer was used. To examine cochlear dysfunction, DPOAE (DP gram) was obtained.

Auditory Brainstem Responses:

Biologic Navigator Pro (Bio-logic, Mundelein, IL) AEP system with SINCER 008 earphones (used with Bio-logic Navigator Pro AEP) was used. It was used for threshold estimation and also for site of lesion testing.

All the above mentioned equipments were calibrated prior to use. They were calibrated as per standards specified by the manufacturer.

Test Environment

All the audiological evaluations were carried out in a sound treated room. The ambient noise of the test rooms were within the permissible limits as recommended by ANSI S-3.1 (1999).

Test Procedure

All the subjects underwent pure tone audiometry, immittance audiometry, OAEs and ABR testing. Based on the audiological test results, the selected subjects were grouped as per the criteria mentioned earlier.

Pure tone audiometry

To estimate the hearing sensitivity, pure tone audiometry was carried out for all the groups. The behavioral thresholds in octave frequencies from 250 to 8000 Hz and inter octave frequencies of 1500, 3000 and 6000 Hz for air conduction and in octave frequencies from 250 to 4000 Hz for bone conduction were obtained. Thresholds were tracked using modified Hughson and Westlake method (Carhart & Jerger, 1959).

Speech Audiometry

Speech recognition thresholds for spondees and speech identification scores for phonetically balanced monosyllabic words were calculated in quiet for all the subjects. Speech identification scores were also calculated at 0 dB SNR to help in deciding the candidacy in different groups. Speech identification scores were obtained for 25 phonetically balanced bisyllabic words developed by Yathiraj and Vijayalakshmi (2005) at 40 dB SL w.r.t. SRT.

Tympanometry

To rule out middle ear pathology, immittance test was carried out using 226 Hz probe tone by sweeping the pressure from +200 to -400 dapa. In reflexometry, both ipsilateral and contralateral acoustic reflex thresholds were measured for 500 Hz, 1000 Hz, 2000 Hz, and 4000Hz pure tone at the peak pressure. The minimum intensity required to elicit the acoustic reflexes was noted. The change of admittance value by

0.03ml after the onset of the reflex eliciting signal was considered as presence of acoustic reflex.

Oto acoustic Emissions

To check the cochlear function DPOAE gram was obtained. DPOAEs were recorded using tone with an f2/f1 ratio of 1.2 presented at 65/55dB SPL, having f2 frequencies of 500Hz to 8000Hz in octaves.

Auditory Brainstem Responses

ABR was recorded for click stimulus presented at a rate of 90.1/sec and 11.1/sec to rule out any retrocochlear dysfunction. A vertical electrode montage was used with Fz-non-inverting, M1/M2 - inverting; M2/M1 - ground electrodes. Also, in the evidence of normal cochlear function in individuals with AD, the cochlear microphonics was measured from auditory brain stem responses averaged to separate presentations of condensation and rarefaction clicks.

The actual experiment was carried out in two phases.

- Preparation of the stimulus
- Determination of speech identification scores in presence of ipsilateral maskers with spectral and temporal dips at 0 dB and 10 dB SNR.

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 all participants from three groups. Each list contains 7 sentences and each sentence has

5 key words making a total of 35 keywords in each list. Sentences were high probability items for which the key words are somewhat predictable from context.

The sentences spoken by a male native speaker of Kannada and was digitally recorded in an acoustically treated room using a unidirectional microphone kept at a distance of 10 cm from the speaker's mouth. A PC having Adobe audition software (Version 3) was used to record the stimuli. The recorded signal was normalized so that all the words had the equal intensity.

Maskers

Speech Identification Scores were calculated for target sentences in presence of 3 different types of maskers. Following are the ipsi lateral maskers and procedure to generate, used to determine the SIS:

1) **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 software (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.
2) **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 subjects (Glasberg

& Moore, 1990). The relationship between number of ERBs and frequency is, **ERB number = 21.4 $\log_{10}$ (4.37*F*+1).** Each ERB represents one auditory filter bandwidth.

The noise was filtered in 2 ways:

(i) with an alternating pattern of two ERBs present and two ERBs removed (spectrally modulated noise with 2 ERB gaps)

(ii) with an alternating pattern of four ERBs present and four ERBs removed (spectrally modulated noise with 4 ERB gaps)

The characteristics of the digital filters are illustrated in Figure 3.1

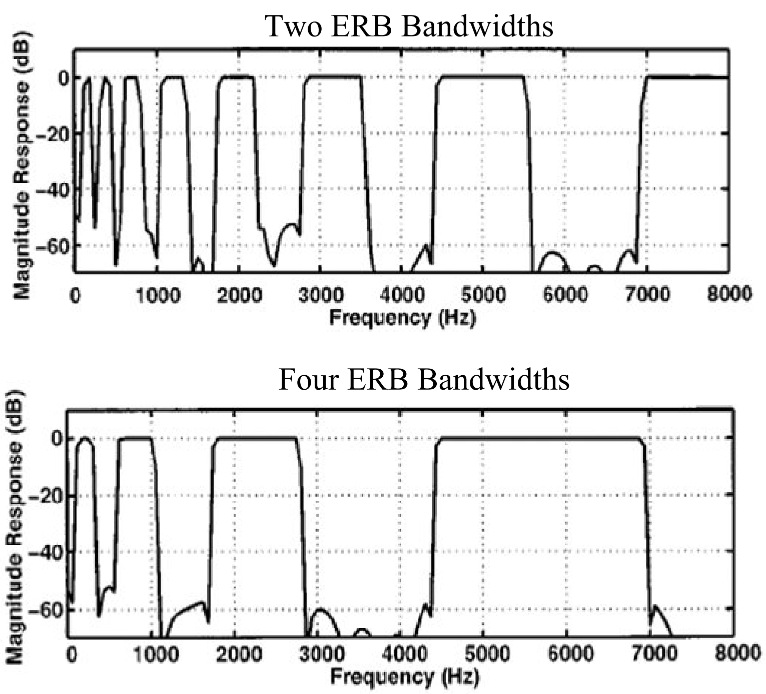

Figure 3.1 Characteristics of the digital filters used to produce the noises with multiple spectral notches

3) **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 in presence of following noise conditions at two SNRs.

1. Speech shaped noise at 0 dB SNR
2. Spectrally modulated noise with 4 ERB gaps at 0 dB SNR
3. Spectrally modulated noise with 4 ERB gaps at 10 dB SNR
4. Spectrally modulated noise with 2 ERB gaps at 0 dB SNR
5. Spectrally modulated noise with 2 ERB gaps at 10 dB SNR
6. Temporally modulated noise at 0 dB SNR
7. Temporally modulated noise at 10 dB SNR

An additional testing condition in 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 group I 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 subject 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 subjects 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.

Determination of Speech Identification scores in presence of ipsi lateral maskers.

The target sentences mixed with noises were presented at 40 dB SL. The speech recognition scores were determined in 7 different conditions as follows:

1. Sentences in the presence of speech shaped steady state noise at 0dB SNR (to serve as baseline for comparison)
2. Sentences in noise at 0dB SNR (with following ipsilateral maskers)
    i. Spectrally modulated noise with two ERB gaps
    ii. Spectrally modulated noise with four ERB gaps

iii. Temporally modulated noise

3. Sentences in noise at +10dB SNR (with following ipsilateral maskers)

i. Spectrally modulated noise with two ERB gaps

ii. Spectrally modulated noise with four ERB gaps

iii. Temporally modulated noise

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 played manually by a PC and was routed through a calibrated (ANSI, 1996) diagnostic audiometer (GSI-61). It was presented monaurally to the subjects through TDH 50P headphones. Subjects 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 subjects 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 were calculated by counting the number of words the subject 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.

CHAPTER 4

RESULTS

The current study aimed at comparing the speech recognition performance of three groups namely those with auditory dys synchrony, cochlear hearing loss and normal hearing sensitivity across 4 different noise conditions at 2 different SNRs. The noises included both un modulated masker (steady state noise) and modulated maskers (spectrally and temporally modulated noise). The data from 43 participants were analyzed of which, 10 had auditory dys synchrony, 13 had cochlear hearing loss and 20 had normal hearing. The obtained scores were analyzed using statistical package for social sciences (SPSS) software version 16.

The following analyses were done between and within the groups:

1. Descriptive statistics for all the parameters tested
2. Mixed ANOVA was done to see the overall main effects of type of noises, groups and SNRs. Mixed ANOVA was also done to compare the amount of release from masking in terms of improvement of speech identification obtained across modulated noise conditions, and across groups.
3. Bonferroni's multiple comparison was done to test pair wise differences if results of Mixed ANOVA were significant.
4. MANOVA was done to compare the number of correctly identified words (WRS) under three different modulated noise conditions across the 3 groups at 0 dB SNR and 10 dB SNR. It was also done to compare the amount of release from masking obtained in terms of improvement in number of correctly identified words across three groups at 0 dB SNR.

5. Duncans post hoc test was done to see the differences between groups in terms of the number of correctly identified words across different noise conditions and also in terms of release from masking.
6. Repeated Measure ANOVA was done to compare across the noise conditions at each SNR within each group. It was also done to compare the amount of release from masking obtained (improvement in speech identification scores) across the modulated noises at each SNR within the group.
7. Bonferroni's multiple comparison was done to test pair wise differences if results of Repeated Measure ANOVA were significant.

The results obtained are discussed under the following headings:

I. Within group comparisons

1. *Individuals with auditory dys synchrony*
   a. Descriptive statistics of all parameters tested
   b. Effect of various maskers on number of correctly identified words (WRS) at different SNRs
   c. Amount of release from masking obtained (improvement in number of correctly identified words) under various modulated maskers at different SNRs
2. I*ndividuals with cochlear hearing loss*
   a. Descriptive statistics of all parameters tested
   b. Effect of various maskers on number of correctly identified words (WRS) at different SNRs

c. Amount of release from masking obtained (improvement in number of correctly identified words) under various modulated maskers at 0 dB SNR

3. *Individuals with normal hearing sensitivity*

a. Descriptive statistics of all parameters tested

b. Effect of various maskers on number of correctly identified words (WRS) at different SNRs

c. Amount of release from masking obtained (improvement in number of correctly identified words) under various modulated maskers at 0 dB SNR

II. Between group comparisons

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

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

c. Effect of groups on number of correctly identified words across noises at 0 dB SNR and 10 dB SNR

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

I. Within group comparisons

1. *Individuals with auditory dys synchrony*

a. Descriptive statistics of all parameters tested

A total of ten individuals with auditory dys synchrony comprised one of the clinical groups. Number of correctly identified words (WRS) was obtained in these individuals under various experimental noise conditions at both 10 dB SNR and 0 dB

SNR. Mean and standard deviation was calculated and tabulated for this data, which is provided in the table 4.1.

Table 4.1

Mean and SD of number of correctly identified words (WRS) obtained for various noise conditions in individuals with auditory dys synchrony

Conditions		Mean	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	4.60	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 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.

b. 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 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 conditions, 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 4.2 for 0 dB SNR and table 4.3 for +10 dB SNR respectively.

Table 4.2

Results of Bonferroni's pairwise comparison of scores obtained between noises at 0 dB SNR in group with auditory dys synchrony

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 4.3

Results of Bonferroni's pairwise comparison of scores obtained between noises at 10 dB SNR in group with auditory dys synchrony

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

c. 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 un modulated noises from modulated noises at 0 dB SNR and 10 dB SNR separately. Improvement or reduction in word identification due to presence or absence of release from masking, were calculated for the following conditions.

a. Number of correctly identified words (WRS) in the presence of spectrally modulated noise with 2 ERB gaps – Number of correctly identified words (WRS) in the presence of speech shaped steady state noise (ERB2- SSN)

b. Number of correctly identified words (WRS) in the presence of spectrally modulated noise with 4 ERB gaps – Number of correctly identified words (WRS) in the presence of speech shaped steady state noise (ERB4- SSN)

c. Number of correctly identified words (WRS) in the presence of temporally modulated noise - Number of correctly identified words (WRS) in the presence of speech shaped steady state noise (AM0- SSN/AM10 - SSN)

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 4.4.

Table 4.4

Mean and standard deviation of difference in WRS due to release from masking obtained in individuals with auditory dys synchrony

	Modulated– Unmodulated	Mean	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

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 Bonferrroni's pairwise comparison, the pattern of results obtained was same at both SNRs and details are as shown in the table 4.5.

Table 4.5

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 auditory dys synchrony

Modulated– Un modulated	ERB4-SSN	AM-SSN/AM10-SSN
ERB2-SSN	Significant, $p<0.01$	Not significant, $p>0.05$
ERB4-SSN		Significant, $p<0.01$

The table 4.5 shows that there is a significant release from masking in terms of number of correctly identified words (WRS) in presence of spectrally modulated noise with 4 ERB gaps, when compared to other modulated maskers at both the SNRs.

2. Individuals with cochlear hearing loss

a. Descriptive statistics of all parameters tested

A total of 13 individuals with cochlear hearing loss were included in the group. The number of correctly identified words (WRS) was obtained for all these individuals under the various types of noise at 0 dB SNR and 10 dB SNR. The mean and standard deviation of WRS obtained for each noise condition is tabulated in table 4.6.

Table 4.6

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

Conditions		Mean	SD
10 dB SNR	ERB2	34.38	.96
	ERB4	34.69	.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

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 presence of spectrally modulated noise having 4 ERB gaps, were almost equal at both the SNRs.

b. 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. Bonferrroni's pairwise analysis revealed a significant difference in 3 comparisons as shown in table 4.7.

Table 4.7

Results of Bonferroni's pairwise comparison of number of correctly identified words (WRS) under various maskers at 0 dB SNR in group with cochlear hearing loss

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 4.7 that number of correctly identified words (WRS) in 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].

c. 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 presence of un modulated 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 un modulated 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 4.8.

Table 4.8

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

	Modulated – Unmodulated	Mean	SD
0 dB SNR	ERB2 - SSN	1.38	5.73
	ERB4 - SSN	4.76	3.13
	AM0 - SSN	.23	5.01

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 [$F(2, 24) = 7.174$, $p < 0.01$]. Bonferrroni's pairwise comparison revealed significant differences between 2 comparisons as shown in the table 4.9.

Table 4.9

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 – Un modulated	ERB4-SSN	AM0-SSN
ERB2-SSN	Significant, p<0.05	Not significant, p>0.05
ERB4-SSN		Significant, p<0.01

The table 4.9 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.

3. *Individuals with normal hearing sensitivity*

   a. **Descriptive statistics of all parameters tested**

A total of 20 individuals with normal hearing sensitivity participated in the study. The number of correctly identified words (WRS) was obtained for various types of noises at both 0 dB SNR and 10 dB SNR. The mean and standard deviation of number of correctly identified words (WRS) obtained in 7 different conditions are given in the table 4.10.

Table 4.10

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

Conditions		Mean	SD
10 dB SNR	ERB2	35	0
	ERB4	35	0
	AM10	35	0
0 dB SNR	SSN	32.25	2.57
	ERB2	33.55	2.01
	ERB4	34.30	1.30
	AM0	33.75	2.07

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.

b. 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 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 4.11.

Table 4.11

Results of Bonferroni's pairwise comparison of WRS between noises at 0 dB SNR 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 4.11 revealed that individuals with normal hearing obtained significantly better WRS in presence of all types of modulated maskers when compared to the un modulated masker.

c. 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 un modulated 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 4.12.

Table 4.12

Mean and standard deviation of amount of release obtained (improvement in number of correctly identified words) with modulated noises in individuals with normal hearing sensitivity

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

II. **Between group comparisons**:

a. **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 4.1.

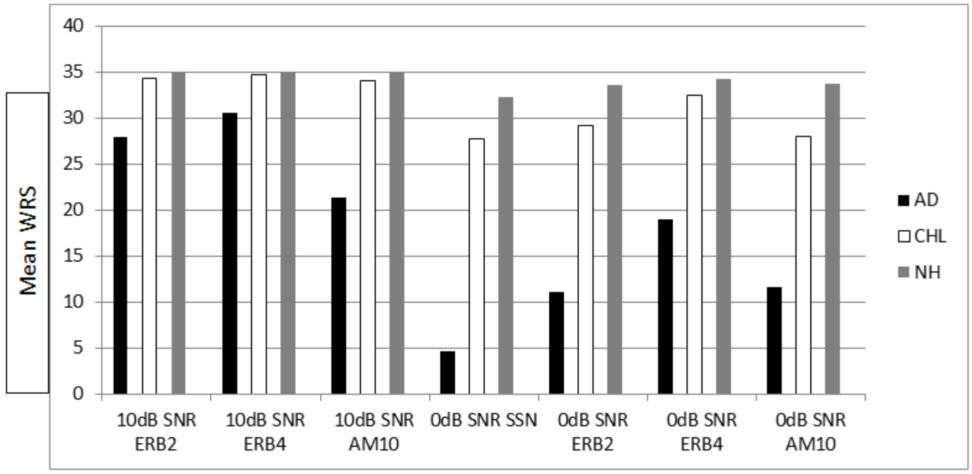

Figure 4.1 Mean of number of correctly identified words (WRS) obtained by three groups of participants across the various masking conditions.

The figure showed 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.

b. 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 4.13.

Table 4.13

Results of Bonferroni's pairwise comparison of WRS between noises 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.

c. 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 4.14.

Table 4.14

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	$F (2, 40) = 45.761$

Duncans 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 and results are shown in table 4.15.

Table 4.15

Results of Duncans post hoc test across the three groups at each noise condition.

Duncans post hoc	AD – CHL – NH (3 subsets)	AD – CHL/NH (2 subsets)
0 dB SNR SSN	***	
0 dB SNR ERB2	***	
0 dB SNR ERB4		***
0 dB SNR AM0	***	
10 dB SNR ERB2		***
10 dB SNR ERB4		***
10 dB SNR AM10		***

***Significance, $p<0.05$

The acronyms are expanded as follows:

AD – CHL – NH: Auditory dys synchrony – Cochlear Hearing Loss – Normal Hearing

Note: Abbreviation is same for the consecutive tables also.

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 other two groups.

d. 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 4. 16.

Table 4.16

Mean and standard deviation of amount of release obtained (improvement in 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
Auditory Dys synchrony	6.50 (5.33)	14.40 (8.35)	7.00 (9.38)
Cochlear HL	1.38 (5.73)	4.76 (3.13)	.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 4.17.

Table 4.17

Bonferroni's pair wise comparisons for release obtained with modulated noises in comparison to un modulated 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 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 the table below.

Table 4.18

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

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 SNR.

Table 4.19

Results of Duncans post hoc test across the three groups for each condition of release from masking (improvement in number of correctly identified words).

Duncans Post Hoc	AD – CHL/NH (2 subsets)
0 dB SNR ERB2 - SSN	***
0 dB SNR ERB4 - SSN	***
0 dB SNR AM0 - SSN	***

*** Significance, p<0.05

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.

The results obtained across groups in different noise conditions and different SNRs can be summarized as follows:

a) Individuals with AD

- Showed poorer word identification at 0 dB SNR than at 10 dB SNR
- Spectrally modulated noises showed significantly higher word recognition value, compared to the un modulated noise at 0 dB SNR

- Scores obtained under temporally modulated noise showed no significant difference between the scores obtained under un modulated noise
- Spectrally modulated noise with 4 ERB gaps showed significantly higher word recognition value, compared to other modulated noise conditions at 10 dB SNR
- Improvement in word recognition due to release from masking is significantly higher in presence of spectrally modulated noise with 4 ERB gaps than compared to other modulated noise conditions
- There was no release from masking obtained for temporally modulated noise.

b) Individuals with cochlear hearing loss

- Showed poorer word identification at 0 dB SNR than at 10 dB SNR
- Spectrally modulated noise with 4 ERB gaps showed significantly higher word recognition value, compared to the un modulated and other modulated noise conditions at 0 dB SNR
- No differences in word identification was obtained in presence of spectrally modulated masker with 2 ERB gaps and temporally modulated noise when compared to steady state masker
- No differences in word identification between any of the noise conditions were obtained at 10 dB SNR
- Improvement in word recognition due to release from masking is significantly higher in presence of spectrally modulated noise with 4 ERB gaps than compared to other modulated noise conditions at 0 dB SNR

c) Individuals with normal hearing sensitivity

- Showed poorer word identification at 0 dB SNR than at 10 dB SNR

- All modulated noises (spectral and temporal modulations) showed significantly higher word recognition value, compared to the un modulated noise condition at 0 dB SNR
- All modulated conditions showed similar improvement in WRS and were not significantly different from each other.

d) Between the groups comparisons revealed that AD group performed significantly poorer compared to other 2 groups in terms of word identification under all the noise conditions. Amount of release obtained from masking in terms of improvement in WRS was greatest in individuals with AD than those with normal hearing and cochlear hearing loss in presence of spectrally modulated noises.

CHAPTER 5

DISCUSSION

The current study investigated the effects of various modulated and un modulated maskers on speech identification in listeners with auditory dys synchrony, cochlear hearing loss and normal hearing. The results obtained from various groups across various maskers at different SNRs on speech identification ability have been discussed below.

Individuals with Auditory Dys synchrony

The results revealed that individuals with AD 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; Hood, 1999; Starr et al., 1996; Starr et al., 1991). 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 dyssynchronous neural discharge would have prevented these individuals with AD from detecting the temporal modulations in the signal. Figure 5.1 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.

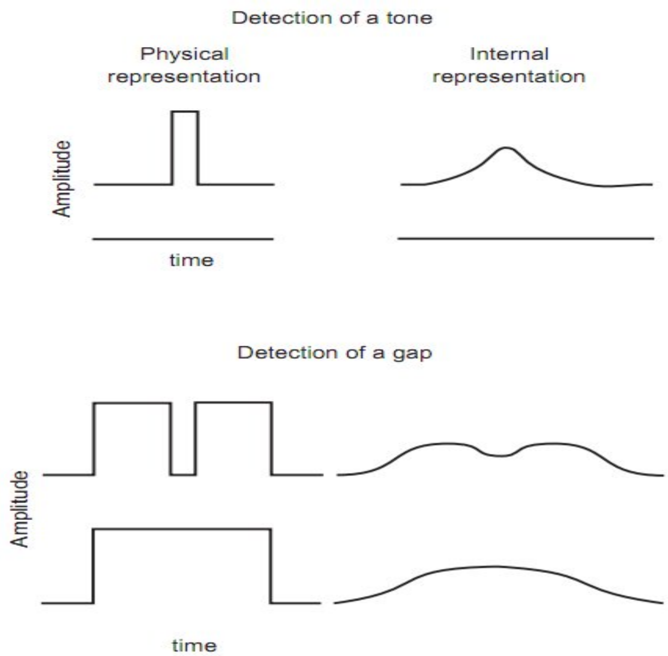

Figure 5.1 A phenomenological model of auditory dys synchrony (Zeng et al, 1999). Desynchronous neural activity results in a smeared internal representation of a physical stimulus. Smearing of the temporal envelope does not affect the detection of a tone (top panel) because this task requires all or 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; Hood, 1999; Starr et al., 1996; Starr et al. ,1991), 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 are 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 un modulated 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 un modulated noise is used , even if the modulated and un modulated noises have equal average powers (Festen

& Plomp, 1990; Carhart et al., 1969; Wilson & Carhart, 1969; Miller & Licklider, 1950). But Berry and Nerbonne (1972) and Horii, House and Hughes (1970) reported contradicting results mentioning that speech modulated by a single talker, masks speech more than un modulated noise does. These discrepancies may be due to failure to compensate for differences in average masker power.

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; Liberman & Kiang, 1978) do not allow them to take benefit of narrow spectral gaps (ERB 2). Studies (Carney & Nelson, 1983; Zwicker & Schorn, 1978) have reported that individuals with cochlear hearing loss have broader than normal PTCs which are in agreement with the finding that they have reduced frequency selectivity.

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; Liberman & Kiang, 1978). Other investigators (Gnansia *et al.*, 2008; Hopkins *et al.*, 2008; Qin & Oxenham, 2006) 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 un modulated 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 un modulated 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 un modulated 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; Gustafsson & Arlinger, 1994; Festen & Plomp ,1990; Duquesnoy, 1983). 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, etal, 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, etal, (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

A comparison of number of correctly identified words across groups 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 auditory dys synchrony. These results are in line with the findings reporting excessive masking effects observed in individuals with auditory dys synchrony 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 un modulated noise. Hence the improvement in scores noticed with spectral modulations with 4 ERB gaps was maximum in individuals with AD.

The major findings of the present study indicate that individuals with AD can extract the target speech signal when the background noise has larger spectral dips. Hence noise reduction strategies should be incorporated wherein a continuous noise can be imposed with large spectral dips and thus enhancing speech input. The same finding was obtained in individuals with cochlear hearing loss, but the improvement noted was lesser compared to those individuals having AD. It was also found that individuals with normal hearing sensitivity could utilize even smaller glimpses present in the noise.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Speech perception is a process in which the input speech is analyzed at various levels of auditory system to decode the spectral and temporal variations in speech. The perception of speech gets impaired in presence of background noises even in individuals with normal hearing sensitivity and normal auditory processing. This adverse effect of noise is more deleterious in individuals with any kind of hearing deficit. But if the interfering background noise fluctuates either in frequency or in time, there are moments created wherein the target signal dominates over the noise. These moments of release from masking allows better speech recognition than compared to steady background noise in normal hearing individuals. But studies have reported that individuals with cochlear hearing loss do not have access to the glimpses of speech from the dips in noise (Peters et al., 1998; Festen & Plomp, 1990). The reasons for poor release from masking were attributed to poor spectral and temporal processing in those individuals. Auditory dys synchrony is a hearing disorder characterized by extreme difficulty in speech perception in noise irrespective of hearing thresholds being normal or not. A need to study the effect of fluctuating maskers on speech perception in individuals with auditory dys synchrony, cochlear hearing loss and normal hearing was realized, because in natural daily listening situations we are exposed to various fluctuating backgrounds. Based on the deficit involved in each hearing disorder, the effect of these fluctuating maskers on speech perception would also differ. Hence the present study was taken up with the aim of assessing the speech recognition performance in groups of individuals with auditory dys-synchrony, cochlear hearing loss and normal hearing in presence of spectrally and temporally modulated noise at 0 dB SNR and 10 dB SNR and to observe which clinical group would take greater advantage of spectral and/or temporal dips to understand speech.

The study included 10 individuals with AD, 13 individuals with cochlear hearing loss and 20 individuals with normal hearing sensitivity in the age ranging between 18yrs to 55yrs. To assess the speech recognition in noise, number of words correctly identified within each sentence was calculated for each of the noise condition at 0 dB SNR and 10 dB SNR. The experimental noise conditions included speech shaped steady state noise, spectrally modulated noise with 4 ERB gaps, spectrally modulated noise with 2 ERB gaps and temporally modulated noise (modulated at 10 Hz). Noises were generated and mixed with the target sentences using MATLAB software (version 2009). Statistical analyses were done for within group and across group comparisons of word identification scores obtained under each noise condition. It was found that all three groups performed poorer at 0 dB SNR than at 10 dB SNR and in presence of un modulated masker than modulated maskers.

Individuals with AD

Individuals with AD performed significantly better for spectrally modulated noises unlike temporally modulated noise at both the SNRs. This was attributed to the poorer temporal representation of the waveform due to the dys synchronous neural firing in individuals with AD. That is, the temporal dips in the noise gets masked due to smearing of the response and hence they showed excessive masking effects as similarly exhibited in presence of steady state noise. The release from masking was found to be significantly greater in presence of noise with 4 ERB spectral modulations. This could be because the broader neural tuning due to dys synchronous firing might still allow spectral dips when the frequencies are far apart as in noise with 4 ERB gaps.

Individuals with cochlear hearing loss

Individuals with cochlear hearing loss showed significantly higher word recognition value in presence of 4 ERB spectral modulations when compared to the un modulated and other modulated noise condition at 0 dB SNR. But they did not show benefit of spectrally modulated noise with 2 ERB gaps and temporally modulated noise over the un modulated noise at 0 dB SNR. This could probably be due to the broader auditory filter bandwidths in these individuals which did not allow them to perceive the narrow spectral gaps available in noise with 2 ERB gaps. The broader filter bandwidths might have caused a reduced fine structure coding of the signal thereby reducing the perception of temporal dips in the signal. At 10 dB SNR, these individuals performed equally well under all the noise conditions which indicate that at favorable noise conditions, they have minimal masking effect.

Individuals with normal hearing sensitivity

Performed equally well under all the modulated noise conditions at 0 dB SNR indicating intact temporal and spectral processing in these individuals allowed significant and equivalent amount of release from masking.

Comparison between the groups

Between the groups comparisons revealed that AD group performed significantly poorer compared to other 2 groups in terms of word identification under all the noise conditions. This reduced speech identification ability in individuals with AD could be attributed to the excessive masking in them due to poorer ability to separate signal and noise in time. The amount of release obtained from masking was significantly better in individuals with AD compared to other two groups in presence of spectrally modulated noises but they did not show any statistically significant amount of release in presence of temporally modulated noise compared to other groups.

Conclusion:

The major findings of the study indicated that individuals with AD 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 this noise. Any noise reduction strategies should be incorporated wherein a continuous noise can be imposed with large spectral dips to enhance the speech perception through allowing glimpses of signal. The individuals with cochlear hearing loss also performed significantly better in 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 did not allow 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.

Implications:

- The present study allowed differentiating the effects of fluctuating maskers on individuals with cochlear hearing loss vs AD. This could be used as an index in evaluating the perceptual difficulties underlying these hearing deficits.
- The perception under various fluctuating maskers could be used for hearing aid selection in individuals with hearing deficits.

- The use of a fluctuating noise in assessing speech recognition may provide us with a sensitive way of evaluating the effects of signal processing such as frequency-selective amplification and compression.
- Conventional hearing aids provide no or minimal benefits to alleviate the unique perceptual difficulties associated with AD and is thus important to investigate other signal processing strategies that may improve speech perception in AD.
- Noise reduction strategies could incorporate larger spectral dips in the continuous noise which might allow more natural perception.

CHAPTER 7

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