EFFECT OF SPECTRAL BANDWIDTH AND SPECTRAL INTEGRATION ON SPEECH PERCEPTION IN LISTENERS WITH NORMAL HEARING, COCHLEAR HEARING LOSS AND AUDITORY DYS-SYNCHRONY

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DEDICATED TO…….

ABBA, AMMA,

CHECHI, ANISH CHETTAN,

PONNOOTY

& OUR LITTLE STAR YET TO COME…….

CERTIFICATE

This is to certify that this dissertation entitled **"Effect of spectral bandwidth and spectral integration on speech perception in listeners with normal hearing, cochlear hearing loss and auditory dys-synchrony"** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No: 10AUD030. 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 spectral bandwidth and spectral integration on speech perception in listeners with normal hearing, cochlear hearing loss and auditory dys-synchrony"** 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 spectral bandwidth and spectral integration on speech perception in listeners with normal hearing, cochlear hearing loss and auditory dys-synchrony"** 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.

Mysore　　　　Register No.10AUD030

May, 2012

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CHAPTER 1

INTRODUCTION

Speech is a complex signal. The components of speech vary in terms of frequency and intensity over time. Approximately 95% of the frequency components in speech lie between 300 Hz and 3000 Hz (Hamernik & Davis, 1988). To perceive and understand speech one need to have normal hearing sensitivity within this frequency range. Hearing loss at any frequency within this frequency range will affect speech perception. The impact of hearing loss on speech perception is based on both type and configuration of hearing loss.

It is well established that different speech sounds have predominantly different energies across frequencies. For example nasals are predominantly lower in frequency, whereas fricatives are more of high frequency speech sounds. Thus, individual with low frequency hearing loss will have difficulty perceiving nasals and individuals with high frequency hearing loss will not be able to get the important features which are necessary to perceive fricatives. Hence, all these individuals would fail to comprehend speech.

Similarly type of hearing loss has also different perceptual consequences (Zeng & Liu, 2006). A conductive type of hearing loss which is thought to attenuate the acoustic signal reaching to the cochlea is likely to have less impact on speech perception, where as cochlear hearing loss would show deterioration in speech perception with the increase in severity of hearing loss. This is probably due to the loss of OHC's in the cochlea, which is responsible for fine discrimination. As the fundamental frequency, formant frequency and frequency transition are important features to understand speech, perception of these features will be affected due to lack of sharper tuning as a result of OHC damage. People with cochlear hearing loss usually have auditory filters that are broader than normal (Glasberg & Moore, 1986; Tyler, 1986). This means that their ability to determine the spectral shape of speech sounds and to separate components of speech from background noise is reduced. Impaired frequency resolution has been identified as the main reason for speech perception deficits in cochlear hearing loss with greater than moderate degree of hearing loss (Thornton & Abbas, 1980; Glasberg & Moore, 1989).

Another reason for impaired speech perception can be, reduced phase locking in these individuals. This may be due to fact that the propagation time of the travelling wave along the basilar membrane can be affected by the cochlear damage and this may disrupt the processing of temporal information by central mechanisms (Leob & White, 1983).

People with cochlear hearing impairment often complain that their greatest problem is understanding speech when background noise is present. The hearing impaired needs a higher signal-to noise ratio (SNR) to achieve the same level of performance (Glasberg & Moore, 1989; Plomp, 1994). This increase in signal to noise ratio ranged from 2.5 dB for mild hearing loss to 7 dB for moderate to severe hearing loss. An even larger SNR is required when the noise is fluctuating (Plomp, 1994).

Auditory neuropathy is another hearing disorder that has unique pathologies and perceptual consequences (Starr, Picton, Sininger, Hood & Berlin, 1996). It is a disorder characterized by abnormal or absent auditory brainstem responses (ABRs) and the presence of otoacoustic emissions (OAEs) and/or cochlear microphonics (CMs), indicating normal functioning of the outer hair cells (OHCs) (Starr et al., 1996).

It is difficult to localize the exact cause for auditory neuropathy. There may be multiple underlying causes (Rance, 2005). Auditory neuropathy (AN) may result from a loss of inner hair cells (IHC), dysfunction of the IHC-nerve synapses, neural demyelination, axonal loss or a possible combination of multiple sites. These pathologies may be present with the traditional cochlear loss involving outer hair cells and/or central processing disorders involving the brainstem and cortex, complicating the classification of auditory neuropathy (Rapin & Gravel, 2003).

One major characteristic of AN is an impaired capacity for temporal processing and difficulty in speech understanding, particularly in noise, that is disproportionate to the degree of hearing loss measured by pure-tone thresholds (Rance, Cone- Wesson, Wunderlich & Dowell, 2002; Rance, McKay & Grayden, 2004, Zeng, Kong, Michalewski & Starr, 2005). Zeng and Liu (2006) said that these individuals have poor pitch processing at low frequencies, excessive masking in noise, and inability to process interaural timing information. Most of the individuals with auditory dys-synchrony has a raising pattern of hearing loss indicating a low frequency hearing loss. This is mainly due to the auditory nerve fibers which are getting affected in them since the low frequency fibers are the longest ones they have more chances of getting involved and this results in poor pitch processing at low frequencies. Zeng , Oba, Garde, Sininger and Starr (1999) studied the frequency discrimination abilities of these individuals across frequencies and found that they have very poor discrimination at low frequencies. Even at signal to noise ratios of 10-15 dB individuals with auditory dys-synchrony found difficult to perceive speech which is due to the excessive masking.

Several studies have tried to explain the reasons for poor speech perception abilities, especially in the presence of noise in the individuals with auditory neuropathy. Psychophysical studies have demonstrated poor temporal and spectral processing in participants with auditory neuropathy and they attributed this as the reason for poor speech perception (Rance et al., 2004; Starr et al., 2003; Zeng et al., 1999).

Vinay and Moore (2007) reported that their subjects with auditory neuropathy had poor frequency resolution when compared to individuals with normal hearing. Kumar and Jayaram (2010) reported that the poor speech perception abilities are predominantly due to temporal processing deficit. They also saw a poor correlation between pure tone thresholds and speech perception abilities and concluded that audibility is not a major factor that causes impaired speech perception in individuals with auditory neuropathy.

Need for the study

Most of the studies in the literature aimed at relating the impaired speech perception to the deficits in phase locking, frequency resolution and temporal processing. A few other studies have seen the speech perception scores in the presence of noise. There are only a few studies which compared the ability to combine speech information from different frequency regions in individuals with hearing loss.

The ability to perceive speech on the basis of sparse cues that are separated in frequency could be important for speech understanding in noisy backgrounds. For example, when the signal to noise ratio is very low, a listener may not have access to the entire spectrum of a speech target and good performance may depend upon the ability to integrate speech fragments that are separated in frequency (Miller & Licklider, 1950; Assmann & Summerfield, 2004)

Mlot, Buss and Hall (2010) studied the development of the ability to combine speech information from different frequency regions. They also studied bandwidth required to achieve a low criterion level of speech identification for two frequency bands.

They found that children required more bandwidth to identify the stimulus but their ability to integrate the information was similar to that of adults.

Grant, Tufts and Greenberg (2007) examined the intelligibility of speech filtered into relatively narrow spectral bands for both normal-hearing listeners and listeners with sensorineural hearing impairment. They found that ability to integrate the information across the bands was reduced in listeners with sensorineural hearing impairment compared to normals.

Hall, Buss and Grose (2008) found that individuals with mild-moderate hearing loss have no difficulty in integrating the information across frequencies. Their scores were comparable to that of the normal hearing group.

As it is evident from the literature that there are only a few studies (Grant et al., 2007; Hall et al., 2008; Mlot et al., 2010) which examined the ability of the individuals to spectrally integrate information's across frequencies. These studies have considered only individuals with cochlear hearing loss, and such experiments were not carried out in individuals with auditory dys-synchrony. It is evident from literature that individuals with auditory dys-synchrony also have poor speech perception abilities (Zeng et al., 1999; Rance et al., 2004) and also difficulty hearing in noise. So it is all the more important to study how the hearing impaired population combine the different spectral information to understand speech, even in noise.

Most of the studies (Hall et al., 2008; Mlot et al., 2010) have used sentences as stimuli which is more redundant. It would be better to use words which are less redundant in speech perception studies. The present study has used filtered words which makes it more difficult to get the redundant information. It is also seen that there is variability among the results of these studies. Hall et al. (2008) said that individuals with cochlear hearing loss has no difficulty in integrating information across frequencies whereas Grant et al. (2007) found that individuals with cochlear hearing loss has difficulty in integrating information across frequencies. Thus there is a need to study spectral integration abilities in individuals with cochlear hearing loss and also in individuals with auditory dys -synchrony.

Aims of the study

The present study aimed at:

1) Finding a criterion speech bandwidth which is necessary to get a minimum (15 to 25%) speech identification score separately for two center frequencies (500 Hz and 2500 Hz) in individuals with normal hearing, cochlear hearing loss and also auditory dys-synchrony,
2) To measure the spectral integration abilities ie finding the improvement in speech identification ability that resulted when both bands were presented simultaneously in all the three groups,
3) To identify how the criterion speech bandwidth varies across the three groups,
4) To know how the spectral integration abilities differs across the three groups,
5) To see the relation between the spectral integration abilities and the speech identification scores in quiet without any modification to the speech stimulus, across the groups

CHAPTER 2

REVIEW OF LITERATURE

Speech signal has amplitude and frequency components which vary over time. Perception of speech signals involves a chain of events and is the function of the auditory system. Inner ear plays a major role in conversion of sensory stimulus in to neural action potentials. This is done by sensory hair cells in the cochlea. Cochlea analyses frequency and amplitude components in the speech signal. Basilar membrane in the cochlea has the major role in frequency analysis of speech sounds. Basilar membrane has got different filters each with different center frequencies spanning the range from 50 to 15,000 Hz (Fletcher, 1940; Moore, Glasberg & Baer, 1997). The output of each filter is like a bandpass filtered version of the sound, which contains two forms of information: fluctuations in the envelope (the relatively slow variations in amplitude over time) and fluctuations in the temporal fine structure (the rapid oscillations with rate close to the center frequency of the band). It is commonly believed that envelope cues are represented in the auditory system as fluctuations in the short-term rate of firing in auditory neurons, while temporal fine structure cues are represented with phase locking by the auditory neurons ie., synchronization of nerve spikes to a specific phase of the carrier (Rose, Brugge, Anderson & Hind ,1967 ; Joris & Yin, 1992) .

In order to perceive a speech signal both temporal and envelope cues are to be perceived. But the perception of these cues gets affected in individuals with hearing loss. The degree to which these cues get affected depends on the type and the degree of hearing loss. Each type of hearing loss has different perceptual consequences (Zeng & Liu, 2006). In the present study cochlear hearing loss and auditory dys-synchrony are considered. Both cochlear hearing loss and auditory dys-synchory has different anatomical changes that occur in the auditory system. These anatomical changes also have physiological consequences which would in turn affect the perception of speech signal.

Anatomical and physiological changes individuals with cochlear hearing loss

Cochlear loss originates in the cochlea and has far more serious consequences for speech communication. The problem lies primarily in the outer hair cells (OHCs), which can be permanently damaged (Bohne & Harding, 2000; Mac Mohan & Patuzzi, 2002). Cochlear hearing loss may induce changes in the physiology of central auditory structures and this also may reflect in auditory perception skills.

Damage to the cochlea and particularly to the outer hair cells (OHCs), leads to reduce sharpens of tuning on basilar membrane and in neurons of auditory nerve. Hence the frequency selectivity of individuals with cochlear hearing loss is expected to be poorer than that of normals. This leads to the broadening of the auditory filters in individuals with cochlear hearing loss (Glasberg & Moore, 1986; Tyler, 1986). Impaired frequency resolution has been identified as the main reason for speech perception deficits in cochlear hearing loss with greater than moderate degree of hearing loss (Thornton & Abbas, 1980; Glasberg & Moore, 1989). Frequency selectivity can be studied using psychoacoustic tuning curves (PTCs). Carney and Nelson (1983) compared simultaneous tuning curves from normal hearing and hearing impaired listeners using probe tones that were either at similar SL's or at similar SPL's for both type of listeners. For the normal listeners sharp PTCs were obtained. Tuning curves from hearing impaired listeners were having different shapes which included flat, erratic broad and inverted patterns. This suggests that the auditory filters of individuals with cochlear hearing loss are broadly tuned (Glasberg & Moore, 1986; Tyler, 1986).

Individuals with cochlear hearing loss also have difficulty in perceiving the temporal fine structure. Lorenzi, Gilbert, Cam, Gamier and Moore (2006) studied the role of temporal fine structure of sounds in the speech perception of hearing impaired. Speech sounds were processed by filtering them into 16 adjacent frequency bands. The signal in each band was processed by using the Hilbert transform so as to preserve either the envelope (relatively slow variations in amplitude over time) or the temporal fine structure (the rapid oscillations with rate close to the center frequency of the band). The band signals were then recombined and the stimuli were presented to subjects for identification. After training, normal-hearing subjects scored perfectly with unprocessed speech, and were 90% correct with envelope and temporal fine structure speech. Both young and elderly subjects with moderate flat hearing loss performed almost as well as normal with unprocessed and envelope speech but performed very poorly with temporal fine structure speech, indicating a greatly reduced ability to use temporal fine structure cues.

Reduced phase locking abilities are also reported in these individuals. This might be due to the travelling wave propagation which is affected by the presence of cochlear hearing loss, which in turn disrupts the processing of temporal information by central mechanisms. (Leob, White & Merzenich, 1983).

Effect of masking is more pronounced in individuals with cochlear hearing loss than normal hearing individuals. In listeners with high-frequency sensorineural hearing loss, upward spread of masking is typically considered to be ‘‘excessive’’ because higher masked thresholds are seen in regions of hearing loss than observed in normal-hearing listeners for the same low frequency masker (Dubno & Schaefer, 1991; Murnane &Turner, 1991; Dubno & Schaefer, 1995). This means that a listener with a high-frequency hearing loss may not hear certain higher-frequency sounds in the presence of a low-frequency masker, even though those sounds may be more intense than the elevated high-frequency threshold, a situation that may be particularly relevant to the problem of listening to speech in background noise.

All these impaired processes in individuals with cochlear hearing loss have adverse effect on speech perception both in quiet and in noise.

Speech Perception in individuals with cochlear hearing loss

Vowel and consonant perception

The relative effects of cochlear damage on the perception of various speech features are well established. It has been shown, for example, that in subjects with sensorineural hearing loss, suprasegmental features are perceived better than segmental features, vowels better than consonants, word-initial consonants better than word-final consonants, and consonant voicing and continuance better than consonant place (Erber, 1972; Martony, Risberg, Spens & Agelfors, 1972; Smith, 1975; Walden & Montgomery, 1975; Bilger & Wang, 1976; Pickett, Martin, Johnson, Brandsmith & Risberg, 1976; Hack & Erber, 1982).

Van Tasell, Fabry, and Thibodeau (1987) measured confusions among 7 synthetic steady state vowels for 10 normal subjects and 3 cochlear hearing loss subjects. Confusions were greater for hearing impaired subjects than for the normal subjects.

Although these experiments support the idea that reduced frequency selectivity can adversely affect vowel identification, every day experience and studies using natural speech indicate that vowel identification by subjects with moderate cochlear hearing loss is often rather good. This may happen because of 2 reasons: spectral differences between vowels are often very large, so that frequency selectivity has to be grossly impaired to prevent the differences being detected. Secondly, naturally produced vowels contain temporal cues (such as duration), as well as spectral cues, and these cues may be used to compensate for the effects of reduced frequency selectivity.

The typical adult with hearing impairment tends to miss the ends of words, in part due to lower audibility (Dubno, Dirks & Morgan, 1984). They also tend to confuse speech sounds in the higher frequencies, where the typical loss of sensitivity for hearing occurs. Many consonants are composed predominantly of high frequency energy, and the inability to perceive these consonants contributes greatly to problems with speech understanding for the hearing-impaired listener. Consonants that are voiced (/ b/, /d/) are easier to detect and identify than consonants that are not voiced (/p/, /t /) because there is more power in voiced speech sounds.

Nasal perception is less affected than other consonants in individuals with sensorineural hearing loss (Revoile, Pickett & Spytek, 1991). In case of fricative perception the recognition scores are well below normal because the frication cue is inaudible to them and they fail to utilize the brief transition cue (Zeng & Turner, 1990).

Speech perception in noise

It is known that individuals with cochlear hearing loss have broader auditory filters. This means that their ability to determine the spectral shape of speech sounds and to separate components of speech from background noise is reduced. Broader auditory filters produce a more highly smoothed representation of the spectrum (the excitation pattern) than normal auditory filters. If spectral features are not sufficiently prominent, they may be smoothed to such an extent that they become imperceptible. Adding a noise background to speech fills in the valleys between the spectral peaks and thus reduces their prominence, exacerbating the problem of perceiving them for people with broadened auditory filters.

A second possible reason for reduced speech perception in noise is connected with the temporal patterns at the outputs of individual auditory filters. Background noise disturbs this time pattern, which may lead to reduced accuracy in determining these frequencies. This effect would be greater in people with reduced frequency selectivity, since broader filters generally pass more background noise. (Rosen & Fourcin, 1986; Young & Sachs, 1979).

Methods to improve speech perception in individuals with cochlear hearing loss

It is known that these individuals have reduced dynamic range. Thus fitting them with hearing aids having linear amplification might have adverse effects. Hearing aids incorporating compression can help to compensate for the effects of reduced dynamic range Multi band compression also helps to reduce the effects of upward spread of masking. This is done by increasing the gain selectively to the high frequency sounds (Moore, 1995).

Digital signal processing to enhance spectral contrast may be of some help in compensating for the effects of reduced frequency selectivity (Moore, 1995). Simpson, Moore, and Glasberg (1990) describe a method of digital signal processing of speech in noise so as to increase differences in level between peaks and valleys in the spectrum. The processing involves manipulation of the short-term spectrum of the speech in noise using the overlap-add technique. Simpson, Moore and Glasberg (1990) measured the intelligibility of sentences in speech-shaped noise using subjects with moderate cochlear hearing loss. The results show small but statistically significant improvements in speech intelligibility for the processed speech, typically of 6 to 7%.

Studies of the effects of spectral enhancement have given mixed results. Some studies have shown no benefit, whereas others have shown a little benefit (Moore & Glasberg, 1990; Simpson et al., 1990).

Anatomical and physiological changes in individuals with auditory dys-synchony

Auditory dys-synchrony is recently described hearing disorder characterized by abnormal auditory nerve functioning in presence of normal cochlear receptor hair cell activity (Starr, Picton, Sininger, Hood & Berlin, 1996).

It is difficult to explain the exact cause of auditory neuropathy. Auditory neuropathy may result from a loss of inner hair cells (IHC), dysfunction of the IHC-nerve synapses, neural demyelination, axonal loss, or a possible combination of multiple sites. The most common pathophysiology for a cochlear afferent disorder, particularly in adults, is a neuropathy affecting the afferent nerve fibers (Star et al., 1996).

Neuropathy may be caused by a (a) primary demyelination or by an (b) axonal disease. A primary demyelinating neuropathy is characterized by a slowing of conduction velocity. If the demyelination affects all the fibers of a peripheral nerve to a similar degree, each fiber will be similarly slowed down and the amplitude of the compound action potentials would be unaffected despite severe slowing of the conduction velocity.

If the amount of slowing varies from one fiber to the next, the amplitude of the compound action potentials becomes small and broad-ended. Axonal neuropathy is characterized by normal conduction velocity and reduced amplitude of CAPs. The nerve fibers function normally in terms of speed of conduction but are reduced in number (Star et al., 1996).

These anatomical changes adversely affect the functioning of the auditory system in individuals with auditory neuropathy. Zeng and Liu (2006) said that individuals with auditory neuropathy have poor pitch processing at low frequencies. Zeng , Oba, Garde, Sininger and Starr (2001) also found impaired frequency discrimination ability in 12 subjects with auditory neuropathy/dys-synchrony type hearing loss. In these studies, difference limen for frequency's (DLFs) was obtained at octave frequencies (250 Hz-8 kHz). Results for the AN/AD cases were considerably poorer than those obtained for a control group of normally hearing subjects A notable finding in the Zeng et al. (2001) subjects was that discrimination in the high-frequency range appeared to be less impaired, approaching the normal range at the 8-kHz test frequency. This result pattern may reflect a disruption of the low-frequency temporal discrimination processes in these individuals with auditory dys- synchrony.

Psychophysical studies have demonstrated poor temporal and spectral processing in participants with auditory neuropathy and they attributed this as the reason for poor speech perception (Zeng , Oba, Garde, Sininger & Starr, 1999; Starr et al., 2003; Rance, McKay & Grayden, 2004). Vinay and Moore (2007) obtained psychophysical tuning curves for subjects with auditory neuropathy with near-normal hearing to moderate hearing loss. They found that PTCs did not show shifted tips in those subjects. They concluded that these individuals have poor frequency resolution. They also tested using the TEN (HL) test for diagnosis of dead regions. Results for the majority of subjects met the TEN (HL)-test criteria at one or more frequencies (often at several or all frequencies). High thresholds for detecting the test tones in the TEN (HL) were not the result of dead regions (off-place or off-frequency listening), but resulted instead from relatively poor detection efficiency.

Speech perception deficits in these individuals are more pronounced than that of individuals with cochlear hearing loss.

Speech Perception in individuals with Auditory Neuropathy/Dys-synchrony

Vowel and consonant perception

Speech perception difficulties are a consistently reported consequence of hearing impairment. In post-linguistically deafened adults with sensory neural loss, a reasonably strong relationship exists between the behavioral audiogram and open-set speech understanding. In contrast, speech perception ability in adults diagnosed with auditory neuropathy/dys-synchrony-type hearing loss has shown no correlation with the pure-tone audiogram (Starr, Sininger & Praat, 2000; Zeng et al., 2001), and in most cases, has been significantly poorer than would have been expected for sensorineural losses of equivalent degree.

Kumar and Jayaram (2010) reported that the poor speech perception abilities are predominantly due to temporal processing deficit. They also saw a poor correlation between pure tone thresholds and speech perception abilities and concluded that audibility is not a major factor that causes impaired speech perception in individuals with auditory neuropathy.

However, not all cases have shown unusually poor speech understanding (at least in quiet listening conditions). For example, 25% of the ears presented by Starr et al. (1996) and 30% of the Sininger and Oba (2001) subjects showed speech perception scores within the normal range for sensorineural losses of equivalent degree.

Perception of the stop, nasal, semivowel and diphthong categories was reported to be poor for the auditory dys-synchrony patients (Rance, Gary, Barker & Janet, 2008). Identification of nasals requires discrimination of low frequency spectral cues. This poor result is consistent with psychophysical evidence suggesting that discrimination in the low spectral range (which relies in part on temporally precise neural firing in the auditory pathway to produce stimulus 'phase-locking' cues) is severely disordered in patients with auditory dys-synchrony (Rance et al., 2004; Zeng, Kong, Michalewski & Starr, 2005).

Discrimination of semivowel and diphthong phoneme groups requires not only accurate low frequency pitch perception, but also the ability to track rapid spectral changes within the speech sounds. Hence, where these subjects could cope well with vowels (which have constant acoustic properties throughout the sound), perception of diphthongs (which are vowel-like but involve changes in formant frequency over the course of the phoneme) was significantly impaired (Rance et al., 2008).

The phonemes involving the stop-consonant pairs /p & b/, /t & d/ and /k & g/ are similar in their articulatory features apart from consonant voicing, and hence, the most salient acoustic difference between the items was the 'voice onset time'. Voice onset time is the period required for vocal cord vibration to begin after the release of a closure in the vocal tract. In the phoneme pair /p & b/ (where the closure occurs at the lips), voicing resumes 10–30 ms sooner for the voiced sound /b/ than it does for the unvoiced /p/. For the /t & d/ pair there is typically a 20–40 ms difference, and for /k & g/ a 20–45 ms difference (Bennett & Ling, 1973). The capacity of the subjects with auditory dys-synchrony to make these discriminations was poor, particularly for the /p & b/ and /t & d/ comparisons, which required the perception of more subtle timing differences. This result is entirely consistent with the psychophysical evidence suggesting an inability to detect brief acoustic cues (Zeng et al., 2005) in individuals with auditory dys-synchrony.

As high frequency discrimination tends to be unaffected by auditory dys-synchrony the subjects with auditory dys-synchrony were able to make high frequency-based phoneme pairs /s & f/ and /z & v/ discriminations reasonably accurately.

Thus mainly those sounds with rapid transitions and low frequency components are difficult to perceive due to the temporal processing deficits and poor pitch processing at low frequencies.

Speech perception in noise

Difficulty in speech understanding, particularly in noise, that is disproportionate to the degree of hearing loss measured by pure-tone thresholds in individuals with auditory dys-synchrony is reported by many authors (Rance, Cone- Wesson, Wunderlich & Dowell, 2002; Rance et al., 2004, Zeng et al.,2005).

The effects of noise in auditory dys-synchrony cases do, however, tend to be more compared to subjects with sensorineural hearing loss. Zeng and Liu (2006) recently studied in detail the perception of 14 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). The mechanisms underlying these perceptual difficulties in noise are unclear.

Methods to improve speech perception in individuals with auditory dys synchrony

Most of the studies using hearing aids found little or no benefits in improving the speech perception in individuals with auditory dys-synchrony (Berlin, Hood, Hurely & Wen, 1996 ; Sininger, Hood, Starr, Berlin & Picton , 1995).

In contrast to the consistently poor findings with amplification in adult subjects with auditory neuropathy/dys-synchrony, a number of studies have provided reports of positive outcomes in at least some children with auditory dys-synchrony. Katona et al. (1993) presented preliminary findings for a profoundly deaf auditory dys-synchrony child fitted with high-powered hearing aids in infancy. These authors found no tolerance problems and reported good sound awareness and subjective performance at 8 months of age.

Recently many studies focused on speech enhancement techniques to improve speech perception in these individuals. Narne and Vanaja (2009) in their study reported improvement in speech identification scores for the majority of individuals with auditory dys-synchrony when the envelope of the speech signal was enhanced. However, envelope enhancement was not able to improve speech identification scores for individuals with auditory neuropathy who had very poor unprocessed speech scores. Overall, the results of their study suggest that applying envelope enhancement strategies in hearing aids might provide some benefits to many individuals with auditory dys-synchrony.

Hassan (2011) reported prolonging the consonant duration and the pauses between CV pairs was more helpful for the subjects to perceive consonant differences. There is also some evidence that electrical signals produced by cochlear implants may stimulate the auditory pathway more efficiently in some dys-synchrony subjects than is possible with acoustic stimulation. Cochlear implantation has shown benefits in subjects with auditory neuropathy (Shallop, Peterson, Facer, Fabry & Driscoll, 2001).

To conclude in many cases of adult auditory dys-synchrony, speech signal disruption can occur that is more extreme than that observed in sensorineural hearing loss. There is not any specific single management strategy which can improve the speech perception in these individuals effectively.

Most of the speech perception studies in individuals with cochlear hearing loss and in individuals with auditory dys-synchrony have focused mainly on their ability to perceive speech sounds and also their ability to perceive speech in noise. Very few studies have tried to explore the ability of these individuals to integrate the speech information given in different frequency bands and perceive speech. This process which integrates information across frequency bands can be named as spectral integration.

Spectral integration

Many studies in speech perception have used vocoders to simulate the spectral channels of cochlear implants. Shannon, Zeng, Kamath, Wygonski and Ekelid (1995) developed a noise-band vocoder to simulate CI speech processing for normal hearing (NH) listeners. They found that high level of speech recognition was possible with as few as four spectral channels of information. This result was obtained with simple sentence materials and in quiet listening conditions. This study was supported by Dorman, Loizou and Rainey (1997) also found that excellent speech recognition could be achieved with four to six channels of spectral information.

All these studies (Shannon et al., 1995; Dorman et al., 1997) have done the speech recognition under ideal listening conditions and the results were consistent across the studies. They concluded that only three to four channels of spectral information were needed to produce sentence recognition better than 50% correct and six spectral channels were sufficient to produce near perfect sentence recognition. These results confirm that speech recognition does not require fine spectral resolution under ideal listening conditions. However in difficult listening conditions like in presence of noise or when using more difficult speech materials such as filtered speech more number of spectral channels are required to get a good speech identification score (Shannon et al.,1995).

Individuals with normal hearing have the ability to integrate narrow band of speech from widely spaced spectral regions (Grant & Braida, 1991; Warren, Riener, Bashford & Brubaker, 1995; Lippmann, 1996; Kasturi, Loizou, Dorman & Spahr, 2002). Grant and Braida (1991) reported that in normal-hearing listeners, narrow bands of speech from widely spaced spectral regions can combine to produce speech identification scores well above the sum of the speech identification scores associated with each band separately. For example when the low and high frequency bands presented alone support less than 20% correct speech identification. In contrast when the bands where presented together it gave 70% identification. This may be due to the fact that the bands are likely to contain non redundant, complementary information.

This ability is very important when listening in the presence of background noise. When the signal to noise ratio is very low, many part of the speech signal may be masked by the noise and the listener may not have access to the entire spectrum of a speech target. In this condition performance may depend upon the ability to integrate speech fragments that are separated in frequency (Assmann & Summerfield, 2004; Buss, Hall & Grose, 2004; Cooke, 2006; Hall, Buss & Grose, 2008).

Mlot, Buss and Hall (2010) studied the development of the ability to combine speech information from different frequency regions. They also studied bandwidth required to achieve a low criterion level of speech identification for two frequency bands. The speech material consisted of Bamford–Kowal–Bench sentences. The participants taken were children and adults with normal hearing. They found that children required more bandwidth to identify the stimulus but their ability to integrate the information was similar to that of adults.

A recent study by Grant, Tufts and Greenberg (2007) examined the intelligibility of speech filtered into relatively narrow spectral bands for both normal-hearing listeners and listeners with sensorineural hearing impairment. The conditions most relevant to the present study involved either a relatively low-frequency band alone (298–375 Hz) or the low-frequency band plus a high-frequency band (4762–6000 Hz). Both normal-hearing and hearing-impaired listeners achieved approximately 20% correct performance for the low band alone, but whereas the normal-hearing listeners improved to approximately 60% for both low and high bands presented together, the hearing-impaired listeners improved to only about 40% correct with both bands present.

Hall et al. (2008) studied spectral integration of speech bands in normal hearing and hearing impaired listeners. They considered bandwidth of speech centered either on 500 or 2500Hz. They varied the bandwidth adaptively to determine the criterion speech bandwidth require to get a score of 15 to 25%. Speech recognition was assessed for low and high bands presented alone, and for the bands presented together. The speech material consisted of Bamford–Kowal–Bench sentences. There was no apparent relation between the criterion normalized bandwidths at the two center frequencies. There were relatively large individual differences in the bandwidth necessary for criterion performance in the hearing-impaired listeners, with criterion normalized bandwidth ranging from approximately 0.28 to 1.06 Hz at 500 Hz, and from approximately 0.14 to 0.54 Hz at 2500 Hz. The criterion speech bandwidths obtained for the hearing-impaired listeners were broadly similar to those obtained by the normal hearing listeners. They found that listeners with mild–moderate sensorineural hearing loss do not have an essential deficit in the ability to integrate across-frequency speech information as their results were comparable with that of individuals with normal hearing.

Most of the studies in the literature aimed at relating the impaired speech perception to the deficits in phase locking, frequency resolution and temporal processing. Few other studies have seen the speech perception scores in the presence of noise. There are only few studies which compared the ability to combine speech information from different frequency regions in individuals with hearing loss. Hence the present study was taken to compare the spectral integration abilities in individuals with different types of hearing loss.

CHAPTER 3

METHOD

The aim of the study was to know what is the minimum frequency bandwidth having low and high center frequency information, required by the individuals with normal hearing, cochlear hearing loss and auditory dys-synchrony to achieve 15 to 25% speech identification scores separately. The study also aimed to know how well these groups of people can integrate the information from these two frequency bandwidths.

Participants

To achieve the goal three groups of individuals were considered in the present study. The first group being the control group and the next two groups being the clinical groups. The control group consisted of individuals having normal hearing. Individuals having cochlear pathology formed the first clinical group and second clinical group was formed by individuals having auditory dys-synchrony.

Control Group: Individuals with normal hearing sensitivity

- This group consisted of 29 individuals with normal hearing sensitivity in the age range of 18 to 50 yrs with a mean age of 28.12 yrs, matched for age with the participants in the clinical group
- All the participants in the control group had normal hearing sensitivity (pure tone thresholds within 15 dB HL in octave frequencies between 250 Hz to 8000 Hz) in both the ears
- Participants had greater than 90% speech identification scores in quiet and more than 60% speech identification scores at 0dB SNR

- Immittance evaluation showed type 'A' tympanogram with the presence of acoustic reflexes
- None of them had any history of otological symptoms (ear discharge, ear pain, giddiness, or ototoxicity)
- They did not have any past or present history of neurological dysfunction that was relevant to the present study
- All participants were fluent Kannada speakers and did not have any speech or language problems

Clinical group 1: Individuals with cochlear hearing loss

- Consisted of 12 participants in the age range of 18 to 50 years with a mean age of 30.3 years
- Participants had acquired mild or moderate sensory hearing impairment as determined by air and bone conduction pure tone audiometry. The pattern of hearing loss was either flat across frequencies or gradually sloping (increase in threshold of around 5-12 dB per octave and the difference between the highest and lowest threshold being no more than 35 dB) from 250 Hz to 8000 Hz
- All of them had speech identification scores proportional to their degree of hearing loss indicating that the hearing loss was predominantly due to cochlear pathology in all the individuals
- Immittance evaluation showed type 'A' tympanogram with either presence, elevated or absence of acoustic reflexes
- All participants had absent DP OAEs suggestive of outer hair cell dysfunction

- Click evoked ABR was present (proportional to their degree of hearing loss) at 80 dBnHL with a repetition rate of 11.1 clicks/second
- There was no past or present history of neurological dysfunction that was relevant to the present study
- All participants were fluent Kannada speakers and did not have any speech or language problems

Clinical group 2: Individuals with auditory dys-synchrony

- Consisted of 17 participants in the age range of 18 to 50 years with a mean age of 25.95 years
- All of them had bilateral acquired auditory dys-synchrony, with hearing loss not exceeding moderate degree (PTA of 41-55 dB HL)
- Their speech identification scores were either disproportionate to their degree and configuration of hearing loss or very poor speech perception in noise (SPIN) scores at 0 dB SNR
- Only those individuals who had speech identification scores more than 30% in quiet at 40 dB SL were selected for the present study as the present study required them to identify filtered words
- All participants had absent auditory brainstem response (beyond that was expected with the degree of pure tone hearing threshold) at 80 dBnHL with a repetition rate of 11.1 clicks/second
- All the participants had DP OAEs and/or cochlear microphonics present
- These participants had normal tympanometric findings with absent ipsilateral and contralateral acoustic reflexes

- No other neurological abnormality was present, which was ruled out by an experienced neurologist
- All participants were fluent Kannada speakers and did not have any speech or language problem

Equipments:

Equipments were used to obtain hearing thresholds, to check the middle ear functioning, OHC's functioning, and also to check retrocochlear involvement. To do so following equipments were used.

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:

- Pure tone threshold at different frequencies for both air conduction and bone conduction and
- Speech identification scores with or without presence of ipsilateral maskers

Immittance meter

A calibrated GSI –TS (Grason - Stadler Tympstar) was used. Each ear of the subject was tested for the type of tympanogram and presence or absence of acoustic reflexes.

Otoacoustic emission Analyser

Capella OAE analyzer was used to measure DPOAEs (DP gram). This was measured to know whether the hearing loss is due to a cochlear damage or not.

Auditory Brainstem Responses

Biologic Navigator Pro was used for testing. The stimulus was presented through the insert earphones SINCER 008.

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

Test Environment

Recording of OAEs and all other audiological evaluations, including tests administered to collect data were carried out in a sound treated room. The ambient noise of the test rooms were within the permissible limits as recommended by ANSI (S3.1, 1999).

Test Procedure

All the subjects underwent puretone audiometry, immittance audiometry, OAEs and ABR testing. This was done to check whether the criteria selected for the study, as specified earlier were met by the subjects.

Pure tone audiometry

The behavioral pure tone thresholds were obtained 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. Thresholds were tracked using modified Hughson and Westlake method (Carhart & Jerger, 1959).

Speech identification scores (SIS) were obtained in all the three groups of subjects. This was done at 40 dB SL (with reference to SRT). Phonetically and phonemically balanced word list developed by Yathiraj and Vijayalakshmi (2005) was used to obtain the SIS. Speech identification scores were also obtained in the presence of ipsilateral masker (speech noise) at 0 dB SNR. The presentation level of both the speech and noise was at 40 dB SL.

Tympanometry

To rule out middle ear pathology, tympanogram was obtained using 226 Hz probe tone by sweeping 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.

Auditory Brainstem Responses

Auditory brainstem responses were obtained for clicks at 11.1 repetition rate. The stimulus was presented at 80 dB nHL through insert earphones ER-3A. Analysis window of 12ms was considered and 2000 sweeps were used in the present study.

Otoacoustic emissions

DP OAEs were obtained at 65/55 dB SPL. A suitable probe tip was fitted on to the probe and inserted into the ear canal of the test ear for measuring OAEs.

The subjects who fulfilled the selection criteria underwent the actual experiment. The detailed procedure adopted to obtain data is discussed below.

The experiment was carried out in three phases:

- *Preparation of the stimulus*
- *Obtaining the Criterion Speech Bandwidth (ie., the minimum bandwidth required to get 15 to 25% SIS)*
- *Determining the Spectral integration score*

Preparation of the stimulus

The speech stimuli used in this study was bisyllabic words developed by Sreela and Devi (2010) in Kannada. This test contains four lists, each list having 25 bisyllabic words which are phonemically balanced. All the 25 words in each list are equally difficult. For the present study, all the four lists were taken.

The words were recorded in an acoustically treated room. The words were spoken in conversational style by a female native speaker of Kannada. A unidirectional mic kept at a distance of 10 cm from the speaker's mouth was used. The sampling rate of 44100 Hz and the resolution of 32 bits were used to record the speech stimuli. Each word was recorded thrice to select the best out of three.

***Speech intelligibility rating*:** The best one out of the three was chosen based on the speech intelligibility rating by five native speakers of Kannada. A three point rating scale was used which included:

- Good intelligibility
- Fair intelligibility
- Poor intelligibility

The words which were judged as having good intelligibility were selected. Those words which were judged as having fair intelligibility or poor intelligibility for all the three recordings were recorded thrice once again. These words were again given to five native Kannada speakers to judge, and the words which were judged as having good intelligibility were taken. The same procedure was followed for all the four lists. Each list was then randomized once to get two lists. This made a total of eight lists available for testing in the present study.

Filtering of the words: Each word was filtered using Adobe Audition software (version 3). The slope of the filter was 60dB/ octave. All the words from all the lists were passed through a band pass filter having either 500Hz or 2500Hz center frequency. The first one was having a low frequency center frequency of 500 Hz and the second one was having a high frequency center frequency of 2500Hz respectively. These center frequencies were also used by Hall, Buss and Grose (2008) in their study on spectral integration. They had selected these center frequencies based on the rationale that frequency components in a speech spectrum predominantly lay between 300-3000Hz. Thus, if a center frequency of 500 Hz and 2500Hz are taken these would lie at low and high portions of the speech spectrum respectively. This helps in finding the spectral integration across the speech spectrum. Each word list was filtered using two center frequency having different bandwidths.

Bandwidths considered: The number of bandwidths available for the two center frequencies were different. The words were first passed through a band pass filter with a 500Hz center frequency. The bandwidth of the filter having 500 Hz as the center frequency was varied from 100 Hz till 1000 Hz in 100 Hz steps. For example the filtered speech of 100 Hz bandwidth having 500 Hz center frequency had frequency components between 450-550 Hz. Similarly filtered speech with 200 Hz bandwidth having 500 Hz center frequency had frequency from 400-600 Hz.

Similarly the bandwidth of filter having 2500 Hz center frequency was also varied from 100 Hz till 3000 Hz in 100 Hz steps. For example the filtered speech of 100 Hz bandwidth having 2500 Hz center frequency had frequency components between 2450-2550 Hz.

Initially a pilot study was done on 5 native speakers of Kannada. Initially, filtered speech materials having either low center frequency or higher center frequency were presented to the subjects, with the minimum bandwidth. Gradually the bandwidth of the filtered speech was increased. The minimum bandwidth at which the individuals obtained 15-25% speech identification scores was noted. This is called as criterion speech bandwidth (CSB) as suggested by Hall et al. (2008).

In the pilot study it was seen that filtered words having 500 Hz center frequency with bandwidths of 100 or 200 Hz was not sufficient for individuals with normal hearing to achieve the criterion score of 15-25%. Thus, these two bandwidths were not considered for the study. Similarly for the filtered words having 2500 Hz center frequency bandwidths till 1100 Hz was not sufficient for normal hearing individuals to achieve the criterion score of 15-25%. Thus, bandwidths till 1100 Hz were not considered in the study.

Table given below shows the details of bandwidths of two different center frequencies considered for the study.

Table 3.1: *Bandwidths used for the study having two different center frequencies*

	500 Hz center frequency		2500Hz center frequency	
	Frequency range (Hz)	Bandwidth (Hz)	Frequency range (Hz)	Bandwidth (Hz)
1)	350-650Hz	300Hz	1900-3100	1200
2)	300-700Hz	400Hz	1850-3150	1300
3)	250-750Hz	500Hz	1800-3200	1400
4)	200-800 Hz	600Hz	1750-3250	1500
5)	150-850Hz	700Hz	1700-3300	1600
6)	100-900Hz	800Hz	1650-3350	1700
7)	50-950Hz	900Hz	1600-3400	1800
8)	0-1000Hz	1000Hz	1550-3450	1900
9)	_	_	1500-3500	2000
10)	_	_	1450-3550	2100
11)	_	_	1400-3600	2200
12)	_	_	1350-3650	2300
13)	_	_	1300-3700	2400
14)	_	_	1250-3750	2500
15)	_	_	1200-3800	2600
16)	_	_	1150-3850	2700
17)	_	_	1100-3900	2800
18)	_	_	1050-3950	2900
19)	_	_	1000-4000	3000

Maximum bandwidth considered for 500 Hz and 2500 Hz center frequency was 1000 Hz and 3000 Hz respectively. This was not increased further because it would lead to overlapping of band widths. Example if 3100 was considered it would contain frequency components between 950-4050 Hz and this will overlap with the 500 Hz center frequency having a bandwidth of 1000 Hz (0-1000 Hz).

Obtaining Criterion Speech Bandwidth (CSB)

Criterion Speech Bandwidth was established using two steps.

- Step one to obtain initial bandwidth for CSB
- Second step to establish CSB

Step to obtain initial bandwidth for CSB

To obtain the initial level the stimuli were presented through a calibrated 2 channel diagnostic audiometer GSI-61 with TDH 50P earphones. Presentation level was kept at 40 dB SL for all the subjects and it was monitored through audiometer. Responses were obtained from the subjects by instructing them either to repeat or write the words. Subjects were instructed to guess the words if it was not clearly perceived. Only one ear was considered for all the subjects to reduce the practice effect. The ear which fulfilled the criteria was selected for testing. If both the ears of a single subject passed the criteria then their right ear was considered for testing. Experimenter didn't give any feedback regarding their responses during the testing.

With the goal of predicting the CSB, filtered words were presented to the subjects. At first filtered words having center frequency of 500 Hz were presented. An initially filtered word with largest bandwidth of 1000 Hz was presented for familiarization. Two filtered words were presented at each bandwidth. If the subjects failed to identify both the words then bandwidth was increased by 100 Hz and the next set of filtered words were presented. For example in the table 3.2 after familiarizing the subjects by presenting filtered word with largest bandwidth, filtered words having a band width of 300Hz were presented. Since the subject could not identify both the words at this bandwidth, the band width was increased by 100 Hz ie, 400Hz and again two filtered words were presented. When the subjects were able to identify both the words at a particular bandwidth, this was considered as initiation bandwidth for CSB. In the table 3.2, at the bandwidth of 500Hz subject correctly identified the filtered words. Thus the initiation bandwidth for CSB is 500Hz.

Table 3.2: *Procedure to obtain initiation bandwidth for CSB*

	Bandwidth (center frequency 500 Hz)	Response (Word identification -two words at each band width)	
		1st word	2nd word
1)	1000 Hz, for familiarization	present	present
2)	300 Hz	absent	absent
4)	400 Hz	absent	absent
6)	500 Hz	present	present

The same procedure was also followed for the 2500Hz center frequency to obtain the initiation bandwidth for CSB. This procedure was followed to minimize the presentation of full list to obtain CSB.

Step to obtain CSB

Criterion Speech Bandwidth was the minimum bandwidth required to get 15-25% word identification scores. Thus, in the next step of the study a full list of 25 filtered words were presented to the subjects at their initiation bandwidth for CSB's for both the center frequencies to see whether it could give the criterion score of 15-25%. Each correct word was given a score of 4%, thus 25 words in a list makes a total of 100%.

Hall et al. (2008) also considered criterion score of 15-25%. In case they failed to obtain 15-25% score at their initiation bandwidth for CSB then the bandwidth was increased at the order of 100 Hz and again a full list of 25 filtered words was presented. Bandwidths were increased till the criterion score was achieved. The bandwidth at which the score of 15-25% was obtained was considered as the CSB.

The relatively low criterion of 15 to 25 % was considered to ensure that performance is below 100% when both the bands are presented together.

Determining the Spectral integration

Two CSBs were obtained for all the subjects. The first one for the low center frequency of 500 Hz and the second one for the higher center frequency of 2500 Hz. To determine the spectral integration abilities, words having both the CSB's were presented to the subjects. A full list of 25 words was used and the word identification scores were calculated.

Scoring

For each subjects CSB's for 500 Hz center frequency and 2500 Hz center frequency was noted. These CSB's were then divided by their respective center frequencies to obtain normalized CSB. Speech identification scores were obtained by presenting words having both the CSBs. These values were taken for comparison across groups.

CHAPTER 4

RESULTS

Having the aim to know whether the type of hearing loss has any effect on the bandwidth required to achieve minimum amount of speech identification scores with low and high center frequencies and also ability to integrate information from these two bandwidths, 3 groups of subjects were taken. Data collected from 58 participants (29 individuals with normal hearing, 12 individuals with cochlear hearing loss and 17 individuals with auditory dys-synchrony) were analyzed. Statistical analysis of the data was done using statistical package for social sciences (SPSS) software version 16.

The minimum bandwidth required to achieve minimum speech identification scores of 15-25% at low and high center frequencies (Criterion Speech Bandwidth, CSB) was divided by their respective center frequencies (either 500 Hz or 2500 Hz) to obtain normalized bandwidth, (Normalized Criterion Speech Bandwidth). This transformation was done to make the comparison of the minimum bandwidths at low and high center frequencies easy.

The results of the statistical analyses are discussed under the following headings:

Within group comparisons

Individuals with normal hearing

a) Descriptive statistics of all parameters tested

b) Comparison between normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at 500 Hz and 2500 Hz center frequencies

Individuals with cochlear hearing loss

a) Descriptive statistics of all parameters tested

b) Comparison between normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at 500 Hz and 2500 Hz center frequencies

c) Correlation between the spectral integration scores and speech identification scores obtained in quiet without any modification to the speech stimulus

Individuals with auditory dys-synchrony

a) Descriptive statistics of all parameters tested

b) Correlation between the spectral integration scores and speech identification scores obtained in quiet without any modification to the speech stimulus

Between the group comparisons

a) Descriptive statistics of all parameters tested

b) Comparison of normalized minimum bandwidth required to achieve minimum speech identification scores (normalized CSB) at 500 Hz

c) Comparison of normalized minimum bandwidth required to achieve minimum speech identification scores (normalized CSB) at 2500 Hz

d) Comparison of spectral integration scores obtained across the groups

To achieve these, following statistical analyses were carried out:

Within group analyses were done using following statistical procedures:

- Paired t- test was carried out to determine whether a significant difference existed between normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at low and high center frequencies, within each group

- Pearson correlation was done to see the relationship between the spectral integration scores and the speech identification scores obtained in quiet without any modification to the speech stimulus, within each group

Following statistical analyses were carried out between the groups:

- Independent t- test was carried out to see the group differences for normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at 500 Hz, between individuals with normal hearing and individuals with cochlear hearing loss. One way ANOVA was not done for group comparison of normalized bandwidth at 500 Hz because individuals with auditory dys-synchrony could not get a minimum speech identification scores even at the maximum bandwidth at the 500 Hz center frequency used in the study
- One way ANOVA was done to see whether a significant difference existed between normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at 2500 Hz, across the three groups
- One way ANOVA was also done to see whether a significant difference existed between spectral integration scores obtained across the groups
- Duncan’s post hoc analysis was done to see the pair wise differences when the ANOVA results were significant

Individuals with normal hearing

a) Descriptive statistics

The mean and the standard deviation for the normalized minimum bandwidth required to achieve minimum speech identification scores (normalized CSB) at 500 Hz, 2500 Hz center frequency and for the speech integration scores were calculated for all the 29 individuals with normal hearing sensitivity. Details are given in table 4.1.

Table 4.1: *Mean, Standard Deviation (SD), minimum and maximum values for the normalized criterion speech bandwidths at two different center frequencies and also speech integration scores obtained in individuals with normal hearing sensitivity*

	Mean	SD	Minimum	Maximum
Normalized CSB at 500 Hz	0.76 (N=29)	0.2	0.68	0.83
Normalized CSB at 2500 Hz	0.61 (N=29)	0.08	0.58	0.64
Spectral integration	90.34% (N=29)	3.3	89.09%	91.50%

From the table it can be seen that the normalized minimum bandwidth achieving minimum speech identification scores at 500 Hz center frequency was greater than the bandwidth required at 2500 Hz center frequency. It can also be noted that the mean spectral integration score was 90%.

b) **Comparison between normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at 500 Hz and 2500 Hz center frequencies**

Paired t- test was carried out to determine whether a significant difference existed between normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at low and high center frequencies. Results showed that there was a significant difference (t= (3.73), 28 $p<0.001$) between normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at low and high center frequencies.

Correlation between the spectral integration scores and speech identification scores obtained in quiet without any modification to the speech stimulus was not done in this group, since all the subjects in the group got 100% speech identification scores in quiet without any modification to the speech stimulus.

Individuals with cochlear hearing loss

a) **Descriptive statistics**

The mean and the standard deviation for the normalized minimum bandwidth required to achieve minimum speech identification scores (normalized CSB) at 500 Hz, 2500 Hz center frequency and for the speech integration scores were calculated for all the 12 individuals with cochlear hearing loss. Details are given in table 4.2

Table 4.2: *Mean, Standard Deviation (SD), minimum and maximum values for the normalized criterion speech bandwidths at two different center frequencies and for the speech integration scores obtained in individuals with cochlear hearing loss*

	Mean	Standard deviation	Minimum	Maximum
Normalized CSB at 500 Hz	0.92 (N=12)	0.29	0.73	1.1
Normalized CSB at 2500 Hz	0.74 (N=12)	0.17	0.63	0.84
Spectral integration scores	92.3% (N=12)	3.17	90.31%	94.84%

Table 4.2 shows that individuals with cochlear hearing loss also showed similar pattern as it was seen for individuals with normal hearing. Normalized bandwidth required for 500 Hz is more than that required for 2500 Hz center frequency. It can also be noted that the mean spectral integration score obtained was 92%.

b) Comparison between normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at 500 Hz and 2500 Hz center frequencies

Paired t- test was carried out to determine whether a significant difference existed between normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at low and high center frequencies. Results showed that there was no significant difference ($t= (1.96), 11\ p>0.05$) between normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at low and high center frequencies. Thus individuals with cochlear hearing loss required almost equal band widths at both 500 Hz center frequency and at 2500 Hz center frequency to achieve a criterion score of 15-25%.

c) **Correlation between the spectral integration scores and speech identification scores obtained in quiet without any modification to the speech stimulus**

Pearson correlation was done to see the relationship between the spectral integration scores and the speech identification scores obtained in quiet without any modification to the speech stimulus in individuals with cochlear hearing loss. Results of the correlational analysis showed that there was no significant correlation between the spectral integration scores and the speech identification scores obtained in quiet without any modification to the speech stimulus in individuals with cochlear hearing loss ($r=0.35$, $p> 0.05$).

Individuals with auditory dys-synchrony

a) **Descriptive statistics**

Mean for the normalized minimum bandwidth required to achieve minimum speech identification scores (normalized CSB) at 500 Hz was not calculated as none of the individuals with auditory dys-synchrony could get a minimum speech identification score of 15-25%, even at the maximum bandwidth of 500Hz center frequency used in the study.

The mean and the standard deviation for the normalized minimum bandwidth required to achieve minimum speech identification scores (normalized CSB) at 2500 Hz and for the speech integration scores were calculated for all the 17 individuals with auditory dys-synchrony. Spectral integration scores were calculated by presenting filtered words having both CSBs (500 Hz and 2500 Hz center frequency). As none of the individuals with auditory dys-synchrony could get a minimum speech identification scores even at the maximum bandwidth of 500 Hz center frequency, for calculating spectral integration scores maximum bandwidth at 500 Hz center frequency was presented along with the CSB obtained at 2500 Hz center frequency. Details are given in table 4.3.

Table 4.3: *Mean, Standard Deviation (SD), minimum and maximum values for the normalized criterion speech bandwidths at 2500 Hz center frequency and also speech integration scores obtained in individuals with auditory dys-synchrony*

	Mean	SD	Minimum	Maximum
Normalized CSB at 2500 Hz	1.08 (N=17)	0.15	1	1.16
Spectral integration scores	30.11% (N=17)	13.71	23.06%	37.17%

The average spectral integration scores that could be achieved by the individuals with auditory dys-synchrony were 30.11% with a minimum score of 23.06% and a maximum score of 37.17%. There were 2 different patterns of integration seen in these individuals. This included negative spectral integration and poor spectral integration (marginal improvement). Negative spectral integration means when both the low and high center frequency bands were presented together to the subjects instead of getting a better integrated score by combining the information in both the bands, these individuals got a poorer score than the criterion score obtained at 2500 Hz center frequency CSB. Out of the 17 individuals with auditory dys-synchrony 5 had negative spectral integration. The remaining 12 individuals had less advantage of spectral integration (marginal improvement). The details are given in table 4.4

Table 4.4: *Scores/ Criterion scores obtained at 500 Hz and 2500 Hz center frequencies and also the spectral integration scores in individuals with auditory dys-synchrony*

Subjects	Scores obtained at 500 Hz center frequency having maximum bandwidth of 1000 Hz	Criterion score at 2500 Hz	Spectral integration score	Speech identification scores in quiet without any modification made in the speech stimulus
1	**4%**	**24%**	**12%**	**32%**
2	**8%**	**24%**	**16%**	**32%**
3	**0%**	**20%**	**16%**	**36%**
4	**0%**	**24%**	**4%**	**36%**
5	**0%**	**20%**	**16%**	**36%**
6	8%	20%	28%	32%
7	8%	24%	40%	88%
8	0%	20%	32%	88%
9	8%	24%	40%	60%
10	8%	20%	32%	40%
11	4%	24%	52%	88%
12	0%	20%	52%	80%
13	0%	24%	40%	92%
14	0%	20%	24%	68%
15	12%	16%	36%	100%
16	0%	20%	36%	76%
17	0%	20%	32%	76%

From the table 4.4 it is evident that none of the individuals could achieve a criterion score of 15-25% at the 500 Hz center frequency. All of them achieved a criterion score at 2500 Hz center frequency. When the information in both the bands was presented together first 5 subjects got poorer scores, even poorer than their criterion scores obtained at 2500 Hz center frequency indicating a negative spectral integration. All these five subjects had poor speech identification scores in quiet without any modification made in the speech stimulus with their scores ranging from 32% - 36%.

The remaining 12 subjects with auditory dys-synchrony got better spectral integration values when compared to the first five subjects with the scores ranging from 28%-52%. Among 12 subjects 10 subjects had speech identification scores 60% or above in quiet without any modification made in the speech stimulus. Only the subjects 6 and 10 had speech identification scores in quiet without any modification made in the speech stimulus less than 50% in this group.

b) Correlation between the spectral integration scores and speech identification scores obtained in quiet without any modification made in the speech stimulus

Pearson correlation was done to see the relationship between the spectral integration scores and the speech identification scores in quiet without any modification to the speech stimulus. The results showed that there was a significant positive correlation between the spectral integration scores and the speech identification scores obtained in quiet without any modification to the speech stimulus ($r=0.641$, $p<0.01$). This means that, better the Speech identification scores in quiet without any modification made in the speech stimulus, better the spectral integration scores and vice-versa.

Across group comparisons

a) Descriptive statistics

Mean, Standard Deviation of normalized criterion speech bandwidths at 500 Hz and 2500 Hz center frequencies were compared across the groups. The results are given in the figure 4.1.

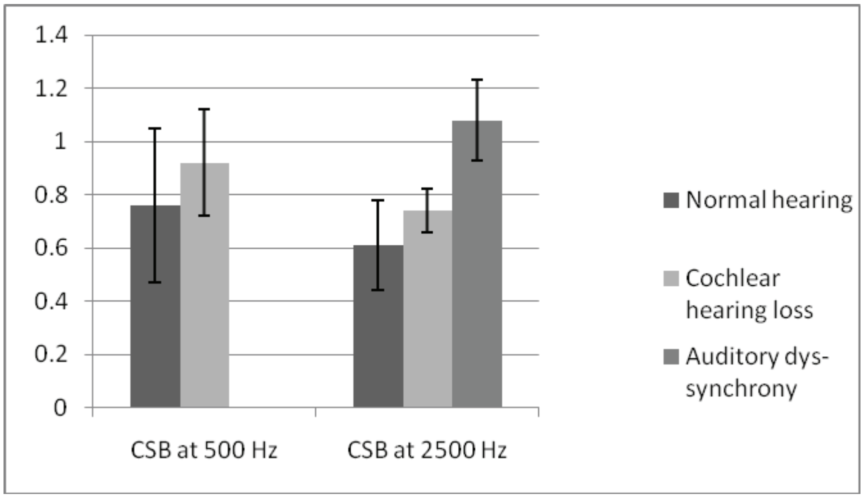

Figure 4.1: Mean, Standard Deviation (SD) at two different center frequencies obtained across all the three groups

None of the individuals with auditory dys-synchrony could achieve a criterion score even at maximum bandwidth at 500 Hz center frequency.

It is seen that individuals with normal hearing obtained the criterion scores with least CSBs at both 500 Hz and 2500 Hz center frequencies followed by individuals with cochlear hearing loss and then the individuals with auditory neuropathy (CSB at 2500 Hz). The variability was relatively great among the individuals with cochlear hearing loss for the CSBs at both 500 Hz and 2500 Hz center frequencies. This is for the reason that few of the individuals with cochlear hearing loss required wider CSBs at both 500 Hz and 2500 Hz center frequencies to get the criterion score.

The mean and standard deviation for spectral integration scores were also compared across the groups. The details are given in table 4.5

Table 4.5: *Mean, Standard Deviation (SD) for the speech integration scores obtained across all the three groups*

		Mean	SD
Spectral integration score	NH	90.34%	3.3
	CH	92.3%	3.17
	AD	30.11%	13.71

When the spectral integration scores were compared across the groups it was seen that both normal hearing individuals and individuals with cochlear hearing loss performed almost equally. Individuals with auditory neuropathy had very less spectral integration scores compared to the other two groups and also the variability was more in this group which is evident from the larger standard deviation value.

b) Comparison of normalized minimum bandwidth required to achieve minimum speech identification scores (normalized CSB) at 500 Hz

Normalized minimum bandwidth required to achieve minimum speech identification scores (normalized CSB) at 500Hz was compared across two groups (between individuals with normal hearing and those with cochlear hearing loss) since the individuals with auditory dys-synchrony could not achieve the criterion score even at the maximum band width of 500 Hz center frequency. Hence, at 500 Hz bandwidth an independent t- test was used to compare the normalized minimum bandwidth required to achieve minimum speech identification scores (normalized CSB) across individuals with normal hearing and those with cochlear hearing loss. Results showed that there was no significant difference in normalized minimum bandwidth required to achieve minimum speech identification scores at 500Hz center frequency between the two groups (t= 2, p>0.05).

c) **Comparison of normalized minimum bandwidth required to achieve minimum speech identification scores (normalized CSB) at 2500 Hz**

One way ANOVA was done to see whether a significant difference existed between normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at 2500 Hz, across the three groups. Results showed that there was a significant difference across group [F (2,55)=77.4 p<0.001].

Duncans post hoc analysis was done to see if all the three groups differed significantly from each other for the normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at 2500 Hz. It was found that all the three groups differed significantly from each other (p< 0.05).

d) **Comparison of spectral integration scores across the groups**

One way ANOVA was done to see whether a significant difference is present across the groups for the spectral integration scores. It was found that there was a significant difference [F(2,55)=356.86, p<0.001] across the groups. Duncans post hoc analysis was done to see if all the three groups differed significantly from each other for spectral integration scores. It was found that individuals with auditory dys-synchrony were significantly different from the other two groups in terms of spectral integration scores (p<0.05).

Results obtained in the present study can be summarized as follows:

Individuals with normal hearing showed

- A significant difference between normalized bandwidth required to achieve minimum speech identification scores at 500 Hz and 2500 Hz center frequencies with 500 Hz having higher normalized CSB than 2500 Hz
- Average spectral integration scores achieved by this group was 90%

Individuals with cochlear hearing loss showed

- No significant difference between normalized bandwidth required to achieve minimum speech identification scores at 500 Hz and 2500 Hz center frequencies
- Average spectral integration scores achieved by this group was 92%
- No significant correlation between the spectral integration scores and speech identification scores obtained in quiet without any modification made in the speech stimulus

Individuals with auditory neuropathy

- Individuals with auditory dys-synchrony have failed to achieve criterion score even at maximum bandwidth at 500 Hz center frequency
- Two types of spectral integration scores were obtained. One group showed reduced spectral integration scores compared to the criterion score obtained at 2500 Hz center frequency. Another group showed marginal improvement in their ability to identify filtered words when the two frequency bands were presented together (spectral integration)

- A positive significant correlation between the spectral integration scores and speech identification scores obtained in quiet without any modification made in the speech stimulus

Across group comparisons showed

- No significant difference in normalized bandwidth required to achieve minimum speech identification scores at 500Hz center frequency between individuals with normal hearing and individuals with cochlear hearing loss
- All the three groups differed significantly from each other for the normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at 2500 Hz
- Individuals with auditory dys-synchrony showed significantly lower spectral integration scores from individuals with normal hearing and individuals with cochlear hearing loss

CHAPTER-5

DISCUSSION

The main aim of the study was to see the effect of different types of hearing loss on the bandwidth required to achieve minimum amount of speech identification scores with low and high center frequencies separately and also to see the ability to integrate information from those two bandwidths. Results obtained from different statistical analyses for each group and across groups are discussed below.

Normalized bandwidth required to achieve minimum speech identification scores at 500 Hz

Results showed that, for individuals with normal hearing the normalized CSB at 500Hz center frequency ranged from 0.68 to 0.83 and for individuals with cochlear hearing loss it ranged from 0.73 to 1.1. There was no significant difference in normalized bandwidth required to achieve minimum speech identification scores at 500 Hz center frequency between individuals with normal hearing and individuals with cochlear hearing loss. However there was more variability in individuals with cochlear hearing loss. Individuals with auditory dys-synchrony could not achieve the criterion score even at the maximum bandwidth at 500 Hz center frequency.

The bandwidth required by individuals with normal hearing and also individuals with cochlear hearing loss at 500 Hz center frequencies in the current study is larger in comparison to the previous studies. Hall, Buss and Grose (2008) in their study said that for individuals with normal hearing the criterion normalized bandwidth at 500 Hz center frequency ranged from 0.27 to 0.57 and for individuals with cochlear hearing loss it ranged from 0.28 to 1.06. The difference in the present study from the study by

Hall et al. (2008) might be due to the type of stimuli used. Hall et al. (2008) used filtered sentences whereas, in the present study filtered words was used as stimuli and this is probably because sentences are more redundant than words.

Across group comparison showed similar results, that have been reported by Hall et al. (2008). They also found that listeners with sensorineural hearing impairment obtained criterion speech bandwidths that were similar to normal hearing individuals at the center frequency of 500 Hz. They also reported higher variability among individuals with sensorineural hearing impairment compared to that of normal hearing individuals.

The reason for comparable results in individuals with cochlear hearing loss with that of normal hearing individuals can be explained with the degree and pattern of hearing loss considered in the present study. The current study has taken only individuals with flat or gradually sloping hearing loss of mild-moderate degree. Glasberg and Moore (1989) said that individuals with cochlear hearing loss of only more than moderate degree have major problems with frequency resolution. Thus, most of the subjects in cochlear hearing loss group would not have had a problem with their frequency resolution and temporal coding that much which could bring a significant difference between individuals with normal hearing and individuals with cochlear hearing loss.

The higher variability in this group of individuals with cochlear hearing loss may be because few subjects required wider CSBs at 500 Hz center frequency. This might be due to impaired frequency resolution in those subjects due to higher degree of cochlear hearing loss.

However none of the individuals with auditory dys-synchrony could achieve the criterion score even at the maximum bandwidth at 500 Hz center frequency. This can be attributed to their poor frequency resolution at low frequencies (Zeng & Liu, 2006) due to which their speech perception was severely affected at low center frequency. Zeng, Oba, Sininger and Starr (2009) also said that individuals with auditory dys-synchrony have poorer frequency discrimination at low frequencies. Phase locking is also affected in these individuals which degrades the temporal processing severely. This would have resulted in very poor speech identification scores.

Normalized bandwidth required to achieve minimum speech identification scores at 2500 Hz

Results showed that, for individuals with normal hearing the CSB at 2500Hz ranged from 0.58 to 0.64 and for individuals with cochlear hearing loss it ranged from 0.63 to 0.84 and in individuals with auditory dys-synchrony it ranged from 1 to 1.16. All the three groups differed significantly from each other for the normalized bandwidth required to achieve minimum speech identification scores having 2500 Hz center frequency.

The bandwidth required by individuals with normal hearing and also individuals with cochlear hearing loss at both the center frequencies in the current study were larger in comparison to the previous studies. Hall et al. (2008), in their study said that for individuals with normal hearing the criterion normalized bandwidth at 2500 Hz center frequency ranged from 0.22 to 0.48 and for individuals with cochlear hearing loss it ranged from 0.14 to 0.54. Mlot, Buss and Hall (2010) have also reported similar results as that of Hall et al. (2008). The difference in the present study from the previous studies can be again explained by the type of stimuli used. Both Hall et al. (2008) and

Mlot et al. (2010) had used filtered sentences where as in the present study filtered words were used as stimuli.

Across groups finding in the present study is different from the results discussed by Hall et al. (2008). In their study they found that listeners with sensorineural hearing impairment obtained criterion speech bandwidths that were similar to normal hearing individuals at the center frequency of 2500 Hz, but with higher variability. But in the present study all the three groups differed significantly for the CSB at 2500 Hz.

This can be explained with the explanation given by Lorenzi, Gilbert, Cam, Gamier and Moore (2006) who reported that individuals with cochlear hearing loss has difficulty using the fine structure cues which are of high frequency information. So speech processing varies based on the frequency resolution at a particular frequency and also it varies across listeners Thus in the present study individuals with cochlear hearing loss would have had poorer frequency resolution at high center frequency due to which they required wider CSB than that of normal hearing individuals.

Where as individuals with auditory dys-synchrony required the widest band width among the three groups to achieve minimum speech identification scores (normalized CSB) at 2500 Hz center frequency. Though temporal processing is majorly affected in these individuals they also have spectral processing difficulties (Zeng , Oba, Garde, Sininger & Starr, 1999; Rance, McKay & Grayden, 2004; Starr et al., 2003). Speech perception deficits in these individuals are more pronounced than that of individuals with cochlear hearing loss. Vinay and Moore (2007) reported poor ability in individuals with auditory neuropathy to detect tones in presence of noise and they also attributed this to the poor phase locking in these individuals. Therefore all these reasons would have contributed for poorer performance in this group.

Comparison between normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at 500 Hz and 2500 Hz center frequencies in all the three groups

Results showed a significant difference between normalized bandwidth required to achieve minimum speech identification scores at 500 Hz and 2500 Hz center frequencies in individuals with normal hearing. In individuals with cochlear hearing loss there was no significant difference between normalized bandwidth required to achieve minimum speech identification scores at 500 Hz and 2500 Hz center frequencies. Comparison between normalized bandwidth required to achieve minimum speech identification scores (normalized CSB) at 500 Hz and 2500 Hz center frequencies was not made in the group with auditory dys-synchrony as none of them could achieve the criterion score even at the maximum bandwidth at 500 Hz center frequency.

Individuals with normal hearing required lesser CSB at 2500 Hz center frequency compared to 500 Hz center frequency. This finding is in accordance with the study done by Mlot, Buss and Hall (2010) where they found that normalized CSB was significantly smaller for the band centered on 2500 Hz than that for the band centered on 500 Hz.

This result can be explained with frequency band importance. For example, when CID sentences were assessed for band importance, the third octave band centered on 500 Hz was associated with approximately 5.2% of total speech information, and the band at 2500 Hz with 9.3% of total speech information (ANSI 1997). The greater importance of the higher frequency band may explain the fact that it carries more information essential for determining consonant place, which is more essential in enabling the listener to discriminate among words than the vowel voicing information carried in the low-frequency regions (Kasturi, Loizou, Dorman & Spahr, 2002).

In contrary to the individuals with normal hearing, individuals with cochlear hearing loss had no significant difference between normalized bandwidth required to achieve minimum speech identification scores at 500 Hz and 2500 Hz center frequencies. This result is in contrary to the results discussed by Hall et al. (2008). He found that even individuals with cochlear hearing loss require lesser CSB at 2500 Hz center frequency compared to 500 Hz center frequency. In their study they had given a high frequency boost to the high frequency band to ensure the constant audibility and also to reduce the effect of upward spread of masking among hearing impaired listeners, which was not done in the present study. This might have resulted in reduced ability to use the high frequency information due to which they needed broader bandwidth at 2500 Hz center frequency in turn resulting in comparable normalized bandwidth at 500 Hz and 2500 Hz center frequencies in the present study. Another reason might be the type of the stimuli used in both the studies. Hall et al. (2008), had used filtered sentences where as the present study used filtered words as stimuli. A third reason might be, due to impaired spectral resolution at high frequencies in individuals with cochlear hearing loss would have resulted in a broader CSB at 2500 Hz center frequency (Lorenzi et al., 2006).

Comparison of spectral integration scores obtained across the groups

Results showed that individuals with normal hearing and individuals with cochlear hearing loss performed similar in spectral integration scores (with both groups having more than 90% scores when both bands were presented together). Individuals *with auditory dys-synchrony had significantly poor spectral integration scores than individuals with normal hearing and individuals with cochlear hearing loss.*

Similar findings have been reported in individuals with normal hearing and individuals with cochlear hearing loss by Hall et al. (2008). They compared between normal hearing individuals and individuals with cochlear hearing loss of mild- moderate degree in terms of their ability to integrate across- frequency bands speech information. They winded their study by saying that individuals with sensorineural hearing loss don't have an essential deficit in the ability to integrate across- frequency bands speech information. However the amount to which integration of the information occurred was different in the present study in individuals with normal hearing and individuals with cochlear hearing loss. Hall et al. (2008) in their study found that when the individual band which gives a criterion score of 15-25% were presented together spectral integration scores were better than 70%. Resuts of Mlot et al. (2010) also closely agrees with that of Hall et al. (2008) finding. In the present study when the low and the high frequency bands were presented together both the individuals with normal hearing and individuals with cochlear hearing loss got spectral integration scores of more than 90%. In their studies they obtained criterion score of 15-25% at smaller CSBs than that of the present study. In the study by Hall et al. (2008) the CSBs for low and high center frequencies were 0.41 and 0.35 respectively for normal hearing adults. On contrary in the present study CSBs for low and high center frequencies were 0.76 and 0.61 respectively for normal hearing adults. Thus when a two large spectral bands are presented together integration occurs across many frequencies than when smaller bands are presented together. This might have resulted in better integration scores of more than 90%.

The results in individuals with auditory dys-synchrony were very distinct from the other two groups. *Among the 17 individuals 5 individuals had negative spectral integration and the other 12 had poor spectral integration, compared to that of individuals with normal hearing and cochlear hearing loss.* This can be explained based on the degree of dys-synchrony in these individuals. It is evident from the literature that these individuals have poor phase locking abilities which results in poor pitch processing mainly at low frequencies (Zeng & Liu, 2006). Thus those five individuals who had negative spectral integration would have had very poor pitch processing at low frequencies to the extent that it even interrupted their processing of high frequency information when both the CSBs were presented together. In other words they have failed to utilize the information at and around 500 Hz center frequency, rather the energy of this level would have caused upward spread of masking leading to the masking of high frequency signal which resulted in reduced performance. Individuals with auditory dys-synchrony also shows excessive masking effect (Zeng, Kong, Michalewski & Starr, 2005) which would further enhance the upward spread of masking and this would have resulted in poorer spectral integration scores, even poorer than their criterion scores obtained at 2500 Hz center frequency when the information in both the bands was presented together. This can be further supported by the fact that all the five subjects had poor speech identification scores (32% - 36%) in quiet without any modification made in the speech stimulus.

Remaining 12 subjects had poor spectral integration. Both the individuals with normal hearing and individuals with cochlear hearing loss, the spectral integration *scores were greater than 90%, where as individuals with auditory dys-synchrony the spectral integration scores ranged from 28%-52%.*

The reason for poor performance compared to other two groups can be again explained using the poor pitch processing in individuals with auditory dys-synchrony. Reduced pitch processing in individuals with auditory dys-synchrony limits them from combining the information across the frequency bands effectively as in case of individuals with normal hearing and also of cochlear hearing loss. However these 12 individuals got better spectral integration scores compared to the other 5 individuals with auditory dys-synchrony. This might be because the degree of dys-synchrony might be less in this group. This is supported by the fact that 10 individuals among the 12 individuals with auditory dys-synchrony had their speech identification scores greater than 60% in quiet without any modification made in the speech stimulus, which suggests lesser degree of dys-synchrony.

Correlation between the spectral integration scores and speech identification scores obtained in quiet without any modification to the speech stimulus in individuals with cochlear hearing loss and in individuals with auditory dys-synchrony

Results showed no correlation between the spectral integration scores and speech identification scores obtained in quiet without any modification made in the speech stimulus in individuals with cochlear hearing loss and a positive significant correlation between the spectral integration scores and speech identification scores obtained in quiet without any modification made in the speech stimulus in individuals with auditory dys-synchrony.

In individuals with cochlear hearing loss both average speech identification scores and spectral integration scores were more than 90%. But in individuals with auditory dys-synchrony, only those individuals who had good speech identification had better spectral integration scores. This can be explained based on the frequency resolution at low frequencies. Those individuals who had better frequency resolution could obtain better speech identification scores in quiet which in turn resulted in improved ability to combine information across frequency bands.

To conclude, in the present study individuals with cochlear hearing loss were as good as normal hearing individuals in their ability to combine the information across different frequency bands. However to generalize this statement further studies has to be done in individuals with different degrees and patterns of cochlear hearing loss. Individuals with auditory dys-synchrony had significantly poorer performance, compared to the other groups in their ability to combine the information across different frequency bands.

CHAPTER-6
SUMMARY AND CONCLUSION

Many studies are reported in the literature regarding the speech perception abilities in individuals with normal hearing, cochlear hearing loss and auditory dys-synchrony. Overall results of those studies can be summarized as follows. Most of the studies in 90's and early 2000's focused mainly on the perception of consonants, vowel, words and sentences (Dubno, Dirks & Morgan, 1984; Rance, McKay & Grayden, 2004).

In the late 2000s there have been few studies in speech perception which reported the ability of the individuals with normal hearing and individuals with cochlear hearing loss to combine the information across different frequency bands which is also called as spectral integration. Most of the studies (Mlot, Buss & Hall, 2010; Hall, Buss & Grose, 2008) focused on spectral integration in children, adults with normal hearing, and in individuals with cochlear hearing loss. Thus the present study aimed at finding a criterion speech bandwidth (CSB) which is necessary to get a minimum (15 to 25%) speech identification score separately for two center frequencies (500 Hz and 2500 Hz) and to measure the spectral integration abilities in individuals with normal hearing, cochlear hearing loss and auditory dys-synchrony.

In order to accomplish these objectives three groups of subjects were taken. The control group consisted of 29 individuals having normal hearing with a mean age of 28.12 yrs. The first clinical group was formed by 12 Individuals having cochlear pathology with a mean age of 30.3 yrs, and second clinical group was formed by 17 individuals having auditory dys-synchrony with a mean age of 25.95yrs.

For each subjects CSBs for 500 Hz center frequency and 2500 Hz center frequency were noted and normalized CSB was obtained by dividing the CSB by the respective center frequency. Speech identification scores were obtained by presenting words having both the CSBs together as a part to study spectral integration ability.

Mean and standard deviation for all parameters tested were calculated. Paired t-test was carried out to determine whether a significant difference existed between normalized bandwidth CSB at low and high center frequencies, within each group. Pearson correlation was done to see the relationship between the spectral integration scores and the speech identification scores obtained in quiet without any modification to the speech stimulus, within each group. Independent t- test was carried out to see the group differences for normalized CSB at 500 Hz, between individuals with normal hearing and individuals with cochlear hearing loss. One way ANOVA was done to see whether a significant difference existed between normalized CSB at 2500 Hz and spectral integration scores across the three groups. Ducans post hoc analysis was done to see the pair wise differences when the ANOVA results were significant.

Results obtained are as follows:

- No significant difference in normalized bandwidth required to achieve minimum speech identification scores at 500Hz center frequency between individuals with normal hearing and individuals with cochlear hearing loss
- All the three groups differed significantly from each other for the normalized CSB at 2500 Hz
- Within group comparisons showed a significant difference between normalized CSB at 500 Hz and 2500 Hz center frequencies in individuals

with normal hearing, no significant difference between normalized CSB at 500 Hz and 2500 Hz center frequencies in individuals with cochlear hearing loss. Individuals with auditory dys-synchrony have failed to achieve criterion score even at maximum bandwidth at 500 Hz center frequency, hence the comparison between the two center frequencies was not made in this group

- Individuals with cochlear hearing loss had spectral integration scores comparable to that of normal hearing individuals
- Among the individuals with auditory dys-synchrony, one group of population showed reduced spectral integration scores compared to the criterion score obtained at 2500 Hz center frequency. Another group showed marginal improvement in their ability to identify words when the two frequency bands information were presented together (spectral integration)
- Individuals with auditory dys-synchrony showed significantly lower spectral integration scores from individuals with normal hearing and also individuals with cochlear hearing loss
- There was no significant correlation between spectral integration scores and speech identification scores in quiet without any modification to the stimulus, in individuals with cochlear hearing loss
- There was a significant correlation between spectral integration scores and speech identification scores in quiet without any modification to the stimulus, in individuals with auditory dys-synchrony

Comparable results in individuals with cochlear hearing loss with that of normal hearing individuals for the normalized CSB at 500 Hz can be explained with the fact that most of the subjects in cochlear hearing loss group would not have had a problem with their frequency resolution and temporal coding that much which could bring a significant difference between individuals with normal hearing and individuals with cochlear hearing loss. Where as individuals with auditory dys-synchrony could not achieve the criterion score even at the maximum bandwidth at 500 Hz center frequency. This can be attributed to their poor frequency resolution at low frequencies.

In the present study individuals with cochlear hearing loss would have had poorer frequency resolution at 2500 Hz center frequency due to which they required wider CSB than that of normal hearing individuals. Individuals with auditory dys-synchrony required widest normalized CSB at 2500 Hz, might be due to their poor temporal processing abilities (Lorenzi, Gilbert, Cam, Gamier & Moore, 2006).

Individuals with cochlear hearing loss were as good as normal hearing individuals in their ability to combine the information across different frequency bands. Among the individuals with auditory dys-synchrony who had negative spectral integration would have had very poor pitch processing at low frequencies to the extent that it even interrupted their processing of high frequency information when both the CSBs were presented together. Those individuals with marginal improvement in spectral integration would have had upward spread of masking which would have resulted in poorer scores compared to the normal hearing and cochlear hearing loss group.

In individuals with cochlear hearing loss both average speech identification scores and spectral integration scores were more than 90%. But in individuals with auditory dys-synchrony, only those individuals who had good speech identification had better spectral integration scores. Those individuals who had better frequency resolution could obtain better speech identification scores in quiet which in turn resulted in improved ability to combine information across frequency bands.

Conclusion

To conclude, in the present study individuals with cochlear hearing loss were as good as normal hearing individuals in their ability to combine the information across different frequency bands. Individuals with auditory dys-synchrony had very poor spectral integration abilities. These findings of the study are helpful while selecting hearing aid features for these individuals. Most of the individuals with moderate sensorineural hearing loss of flat or slightly sloping pattern will benefit from multi channel hearing aids as they have very good ability to combine the information across the frequencies. In individuals with auditory dys-synchrony it is better to select a hearing aid with lesser number of channels as they already have very poor abilities to combine information across the frequencies. It is also best to give them a hearing aid with best noise reduction strategies which will help to remove noise which are mainly of low frequencies. Even while prescribing them channel specific gain it is wise to give lesser gain at low frequencies to reduce the upward spread of masking, which can cause deleterious effect, as seen in the present study. While prescribing hearing aids to individuals with auditory dys-synchrony it is better to consider their speech identification scores as those individuals with less than 50% scores are less likely to combine information across the frequencies.

Implications:

- This study can be used as a tool to study the spectral integration abilities in different clinical groups
- This can be used as a tool to assess the speech perception abilities in difficult listening situations as we are using filtered words
- This study can also be used to differentiate between individuals with cochlear hearing loss and those with auditory dys-synchrony
- This can be used to explain physiological basis for the speech perception abilities of different clinical groups to some extent
- Further studies in CSBs required for speech perception, may help us in selection of hearing aids ie as to decide about the number of channels required, required frequency response etc

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