Effect of Low Pass Noise on Speech Perception in Individuals with Hearing Impairment

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A dissertation submitted in part fulfillment for the degree of
Master of Science (Audiology),
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April 2008

DEDICATED TO

LORD SHIVA, GURUJI
&
MY FAMILY MEMBERS

Certificate

This is to certify that this dissertation entitled **"Effect of Low Pass Noise on Speech Perception in Individuals with Hearing Impairment"** is a bonafide work in part fulfillment for the degree of Master of science (Audiology) of the student Registration no: **06AUD014.** 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 Diploma or Degree.

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This dissertation entitled **"Effect of Low Pass Noise on Speech Perception in Individuals with Hearing Impairment"** is the result of my own study and has not been submitted in any other university for the award of any diploma or degree.

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INTRODUCTION

Speech is a complex process and the ability to comprehend spoken conversation involves a series of processes which starts from the cochlea. Any damage to the inner ear has been found to lead to various degrees of hearing loss and a variety of other changes in the perception of sounds, like the difficulty in understanding speech, especially when background sounds or reverberations are present (Plomp, 1978; Duquesnoy & Plomp, 1980; Nabelek & Robinson, 1982). Also, psychoacoustic abilities have been found to be impaired in individuals with sensorineural hearing loss, which has an influence on speech intelligibility. Researchers have shown considerable interest in determining the perception of speech in a quiet situation and in the presence of noise (Carhart &Tillman, 1970; Cohen & Keith, 1976; Stelmachowicz, Jesteadt, Gorga & Mott, 1985; Stelmachowicz, Lewis, Kelly & Jesteadt, 1990). Special emphasis has been given to the perception of speech in quiet and in the presence of noise in individuals having a hearing impairment.

In those with a hearing impairment, speech perception in quiet has been reported to be influenced by the degree of hearing loss, whereas speech perception in noise is heavily dependent on frequency resolution (Bonding, 1979; Dreschler & Plomp, 1980; Festen & Plomp, 1983). Poor frequency resolution is also associated with poor consonant discrimination and vowel identification (Van Tasell, Fabry & Thibodeau, 1987). The other psychoacoustic problems which have been noted in individuals with sensorineural hearing loss are, upward spread of masking, widened critical bands and abnormal response growth (Stelmachowicz, Lewis, Kelly & Jesteadt, 1990). The interest in evaluating the individuals with sensorineural hearing loss in the presence of noise is due to the fact their perception is highly altered in the presence of noise (Cooper & Cutts, 1971; Cohen & Keith, 1976). Pederson and Studebaker (1972) also reported that the level of background noise has an adverse effect on speech intelligibility. Also, the word recognition score was noted to be substantially poorer for the listeners with sensorineural hearing loss than the listeners with normal hearing in noise (Cooper & Cutts, 1971).

To evaluate the perception of speech in the presence of noise, studies have been carried out with latter being modified either spectrally or temporally. Modification of the spectrum of noise has been done in terms of low-pass filter noise (Erber, 1971; Cohen & Keith, 1976; Stelmachowicz, Jesteadt, Gorga & Mott, 1985; Stelmachowicz, Lewis, Kelly & Jesteadt, 1990), white noise (Keith & Talis, 1972), speech noise (Carhart & Tillman, 1970; Duquesnoy, 1983), cafeteria noise (Cooper & Cutts, 1971) and multitalker babble (Dirks, Morgan & Dubno, 1982; Gordon-Salant & Fitzgibbons, 2004). Most studies reported in literature have used speech spectrum noise, broadband noise or multi-talker babble (Cooper & Cutts, 1971; Dirks, Morgan & Dubino, 1982; Fallo, Trehub, & Schneider, 2000; Pittman & Wiley, 2001; Hall, Grose, Buss, & Dev, 2002). These forms of noises have been preferred as they are common form of noise in everyday life. However, very few studies have determined the effect of low pass noise on speech perception, despite this also being a common form of noise in the environment. Many environmental signals contain primarily low frequency energy (Kryter, 1970). The few studies in which low pass filtered noise was used, did show large difference in speech perception between normal hearing listeners and individuals with hearing impairment (Liden, 1967; Cohen & Keith, 1976; Stelmachowicz, Lewis, Kelly & Jesteadt, 1985). Stelmachowicz, Jesteadt, Gorga and Mott (1985) reported higher signal-to-noise-ratio for low-pass filter noise than broadband noise in individuals with hearing loss in comparison to individuals with normal hearing.

Need for the Study

Information regarding the perception of speech in noise would be helpful in the differential diagnosis of different sites of lesion. Further, understanding the influence of the spectral characteristics of noise on speech perception would be useful in counseling individuals regarding expectations of speech perception in the presence of noise. It would also be of utility in the designing of noise reduction systems in digital hearing aids. This in turn would help in the prescription of hearing aids. Also, knowledge of the impact of noise on speech perception would be of considerable use while fine-tuning hearing aids. It needs to be studied whether some frequency components of noise can be retained or all frequency components of environmental noise have to be removed for optimal speech perception.

Aim of the Study

The aim of the study was to:

- Study the perception of speech in the presence of different low pass filtered noises in individuals with normal hearing,
- Study the perception of speech in a group of adults with acquired hearing loss in the presence of different low pass filtered noises,
- Compare the speech perception in the presence of different low pass filtered noises in individuals with normal hearing with that of individuals with hearing impairment.

Prior to carrying out the study, a detailed review of literature was done. This was done to get information regarding the effects of different types of noise on speech perception.

REVIEW OF LITERATURE

A variety of noises are present in the environment, but for the purpose of research specific kinds of noises have been used in studies. These include cafeteria noise, multitalker babble, broad-band noise, narrow-band noise and speech noise. Cafeteria noise is noise recorded from a cafeteria which has voices, clattering of dishes, silverware and trays which can be subjectively detected (Cooper & Cutts, 1971). Multitalker babble contains energy below 8 kHz. It usually consists of eight voices, both male and female reading from newspapers (Bilger, Nuetzel, Rabinowitz & Rzeczkowski, 1984).

Yet another kind of noise used extensively is filtered noise. Filtering involves the restricted passage of energy from a noise band either above a certain frequency (high-pass filter), below a certain frequency (low-pass filter), or within a frequency range (band-pass filter). The filtering of the noise is done electrically before it reaches the transducer. The upper and lower cutoff of the frequencies of the filtered noise is the frequency points on both sides of the center frequency of that noise at which the energy is less than the energy of the center frequency. Examples of filtered noises are broad-band noise and narrow band noise. Broad-band noise (BBN) is derived from a white-noise signal. White noise consists of an infinite number of frequencies which have equal power per cycle. Narrow-band noises (NBN) contain bandwidth narrower than those of broad band noise (e.g., third-octave, half-octave, and octave bandwidth). Narrow-band noises are generally characterized with reference to their bandwidth (the range in frequencies between the 3-dB-down points), center frequency, and rejection rate. Speech noise is BBN with a narrower frequency range extending from at least 250 Hz to 4000 Hz. The slope of the noise spectrum is +3 dB per octave from 250 Hz to 1000 Hz and -12 dB per octave from 1000 Hz to 4000 Hz. The acoustic spectrum of speech noise follows the configuration of the acoustic spectrum of a speech signal (Silman & Silverman, 1991).

Noise has been reported to affect individuals in a variety of ways. Besides affecting the auditory system, noise has been found to have an adverse affect on the physiology and psychology of humans. These affects are further discussed.

Non-Auditory Effect of Noise

As a result of high levels of noise exposure, a variety of non-auditory effects have been observed by researchers. Both physiological as well as psychological problems have been associated with noise exposure.

A blood circulatory response dominated by vasoconstriction of the peripheral blood vessels with other adjustments of blood pressure through out the body and minor changes in heart rate has been observed as a result of exposure to noise (Davis, Buchwald & Frankman, 1955, cited in Kryter, 1970). Changes in Galvanic skin response and pattern of breathing, resulting in slow deep breathing was reported by Davis, Buchwald and Frankman (1955, cited in Kryter, 1970), when individuals were exposed to noise. A brief change in skeletal-muscle tension was also noted by them. Other non-auditory effects of noise that have been reported are changes in gastrointestinal motility (Davis & Berry, 1964; Stern, 1964, cited in Kryter, 1970), chemical changes in the blood and urine from glandular stimulation (Hale, 1952; Levi, 1967, cited in Kryter, 1970) and cutaneous sensations from the ear like tickle and discomfort (Ades, Graybiel, Morrill, Tolhurst & Nivenl, 1958; Plutchik, 1961, cited in Kryter, 1970). People who are working in noisy environment have been found to develop coughs, hoarseness, lesions, and pains in their throats from the strain of talking in the presence of noise (Brewer & Breiss, 1960). Noise exposure also promotes negative psychological reaction (Job, 1988; Fields, 1994; Job and Hatfield, 1998) and psychological stress (Evans, Hygye & Bullinger, 1995).

Auditory Effect of Noise

Noise has been reported to affect hearing in a variety of ways. At low levels, noise has been reported to interfere with communication without causing either short-term or long-term damage to the auditory system (Kryter, 1970). At higher levels noise can cause a temporary hearing loss that may last for a relatively short period after the cessation of noise. It has been noted that as the intensity of sound increases beyond a critical level, the noise may cause damage to the internal structures of the cochlea resulting in a permanent hearing loss and may even damage structures of the peripheral mechanism such as the tympanic membrane and the ossicular chain (Melnick, 1978). Subsequent changes in more central areas of the auditory system have also been observed (Miller, 1992). Though there are several auditory effects of noise, the present review will mainly focus on the perception of speech in the presence of different types of noise.

Effect of Different Type of Noise on Speech Perception

Simonton and Hedgecock (1953) studied the speech discrimination scores in noise and in quiet and found no difference between subjects with normal hearing and those with conductive loss. Patients with sensorineural deafness, however, showed increased discrimination loss when tested in the presence of noise. Similar results were found by Palva (1955) with a signal-to-noise ratio of 10 dB and Ross, Huntington, Newby and Dixon in 1965.

In 1978, Plomp described the speech-reception threshold (SRT) as a function of the level of steady-state noise with a model. In this model, SRT was defined as the level of speech for a fixed 50% score. The model contains two parameters, one for the threshold in quiet and one for the threshold in noise, and it assumed a fixed 'effective' speech-to-noise ratio at threshold. The effective noise level in the model was determined by the sum of an internal noise (responsible for the absolute threshold) and the externally applied noise. For listeners with normal hearing, this model fit the data by Hawkins and Stevens (1950). For listeners with hearing-impairment, the model contained two extra parameters. One parameter was the elevation of the threshold in quiet, which was assumed to occur due to a higher level of the internal noise. The other parameter was the increase in the speech-to-noise ratio needed to reach the SRT in noise. This model was validated in a number of experiments for listeners with hearing-impairment (Plomp, 1986). In general, the second parameter, called hearing loss for speech in noise, was only small (0-10 dB).

Depending on the kind of noise, the perception of speech has been found to alter. Several studies have been reported in literature regarding the effects of different kinds of noise on speech perception. These effects are further discussed in the below given section.

a) White noise

As early as 1969, Rupp and Phillips evaluated the effect of white noise and speech spectrum noise on speech discrimination function in 35 subjects with normal hearing. CID auditory test W-22 words lists were presented in +10, 0, -10 and -20 dB signal-to-noise ratio. Verbal responses were recorded. The results indicated that speech spectrum noise was markedly more interfering in its effect in comparison to white noise at the same SNR.

In 1971, Erber studied auditory detection of spondaic words in wide-band noise in 10 adults with normal hearing and five subjects with profound hearing loss. The stimuli were presented at -28, -25, -22, -19,-16,-13 and -10 for subjects with normal hearing and -13,-10, -7, -4, -1 and +*2* dB for subjects with hearing loss. The subjects' were required to judge each 4-sec noise burst for presence or absence of a speech signal. The subjects with profound hearing loss required about 9 dB greater S/N ratio than the subjects with normal hearing.

Keith and Talis (1972) studied the effect of white noise on PB scores of 10 persons with normal hearing, 10 persons with high frequency hearing loss, and 10 persons with relatively flat hearing loss. CID auditory test W-22 words lists 1 and 2 were presented in quiet and also in presence of white noise at 40 dB sensation level or the sensation level necessary for PB max. Three signal-to-noise (S/N) ratios were used (+8, 0, and -8 dB S/N). The subjects' verbal responses were recorded on paper by the examiner. The PB scores of listeners with normal hearing deteriorated approximately 52% from the quiet condition to the -8 dB S/N ratio. Listeners with high-frequency hearing loss had a deterioration of approximately 57% and for listeners with a flat hearing loss the deterioration was approximately 67%.

The number of studies using white noise is relatively less. This is probably because white noise has not been considered as effect a masker as other types of noises.

b) Low pass filtered noise

In 1971, Erber presented common words in the presence of low-frequency noise to three groups of children. The groups included children with normal hearing, severe hearing impairment and profound deafness. The participants had to detect the acoustic patterns or to recognize the words under a range of acoustic speech-to-noise (S/N) ratios. Children with profound deafness and severe hearing-impairment required a higher S/N ratio for auditory detection of words than children with normal hearing. The group with normal hearing was superior to the group with severe hearing-impairment in auditory recognition of words in noise, while the deaf were unable to recognize words by ear alone.

Likewise, Cohen and Keith (1976) studied whether word recognition scores obtained in noise were more sensitive to the presence of a hearing loss than recognition scores in quiet. Ten subjects with normal hearing, ten with high-frequency cochlear hearing loss, and ten with flat cochlear hearing loss were tested in quiet and in the presence of a 500-Hz low-pass noise. Two signal-to-noise conditions were employed, - 4 and - 12 dB, with the words being presented at 40 dB SL. The results indicated that the word recognition scores of groups were similar in quiet. However, the more negative the signal-noise-ratio, the greater was the separation of the group scores, with the subjects with hearing impairment having poorer recognition scores than subjects with normal hearing. This study was an extended version of a study by Liden (1965), who used 500 Hz low pass noise.

Similarly, Stelmachowicz, Jesteadt, Gorga and Mott (1985) reported that in the presence of low pass noise filtered at 500 HZ large differences in performances between normal and hearing impaired were observed. In contrast, with broadband-noise condition, only small differences in speech perception were present.

In 1990, Stelmachowicz, Lewis, Kelly and Jesteadt extended the study conducted by Stelmachowicz et al. (1985). They studied speech perception with low pass filtered noise at nine different cutoff frequencies (500, 750, 1000, 1500, 2000, 2500, 3000, 4000, and 5000 Hz). This was done on five listeners with normal hearing at two speech levels (50 and 75 dB SPL) and four listeners with hearing impairment at one speech level (75 dB SPL). The results showed that the listeners with hearing impairment required a better S/N ratio than the listeners with normal hearing at either presentation level for all except the widest bandwidth, where their S/N ratio began to converge with the normal values. In addition, the S/N ratios for the listeners with hearing impairment plateaued at relatively narrow bandwidths (0.75 to 2.5 kHz) compared to the group with normal hearing (3.0 to 5.0 kHz).

From the above literature it is evident that low pass filter noise does effect speech perception. It has been found to have a differential effect on subjects with normal hearing and subjects with hearing impairment.

c) Speech noise

The effects of speech noise on the speech recognition threshold (SRT) and speech identification abilities have been studied to a larger extent when compared to other kinds of noise. The majority of studies have determined its effect on speech identification, rather than on (SRT).

Duquesnoy (1983) determined the binaural SRT for sentences masked by either competing speech or noise matched in spectrum and level to the masking speech. Two groups of listeners, a younger group with normal hearing and an elderly group with presbyacusis were tested. The results showed that the unmasking occurring for competing speech in the group with normal hearing was absent for those with presbyacusis.

Likewise, Wagener and Brand (2005) studied sentence intelligibility in noise for listeners with normal hearing and hearing impairment. They reported that on an SRT test that stationary, speech-shaped noise produced identical results on the two groups. In contrast, speech-simulating fluctuating noise yielded about 14 dB lower speech recognition thresholds (SRT) for subjects with normal hearing and about 10 dB lower SRTs for 20% of the subjects with hearing impairment. Of the subjects with hearing impairment, 30% did not benefit from the modulations and showed similar SRTs as for stationary noise. Using continuous noise yielded lower SRTs compared to gated noise. However, the difference between the results in continuous and gated noise was not significant for the subjects with hearing impairment.

Hall III, Grose, Buss and Dev (2002) evaluated spondee recognition in a two-talker masker and a speech shaped noise masker in 14 adults and 19 children with normal hearing. The children were made to point a picture which represents the target word. Adult also indicated their choice via a keyboard response. The threshold for the two-talker masker was higher than for the speech-shaped noise masker. This effect was greater in the children than in the adults. In the gated masking condition, the greater masking effect associated with the two-talker masker was either diminished in children or eliminated in adults.

Several studies have evaluated the effect of speech noise on speech identification. A few of these studies have used competing sentences instead of noise yielding similar results.

Carhart and Tillman (1970) measured discrimination for monosyllables against competing sentences for various groups of listeners. They evaluated one group with normal hearing, one group with conductive hearing loss and two groups with sensorineural hearing loss. The group with sensorineural hearing loss was disturbed by the competing sentences, which were 12-15 dB greater than for listeners with normal hearing or listeners with conductive hearing loss.

Similar, results were got by Bacon, Opie and Montoya (1998) who measured speech recognition in three groups of listeners. The groups were those with sensorineural hearing loss (HL), those with normal hearing (NH), and those with normal hearing who listened in the presence of a spectrally shaped noise that elevated their pure-tone thresholds to match those of individual listeners in the HL group (NM). Performance was measured in four backgrounds that differed only in their temporal envelop: steady state (SS) speech-shaped noise, speech-shaped noise modulated by the envelop of multitalker babble (MT), speech-shaped noise modulated by the envelop of single-talker speech (ST), and speech-shaped noise modulated by a 10 Hz square wave (SQ). The threshold signal-to-noise ratios (SNRs) were best in the ST and especially the SQ conditions, indicating the masking release in those modulated backgrounds. SNRs in the SS and MT condition were essentially identical to one another. The masking release was largest in the listeners with NH, and it tended to decrease as hearing loss increased. In five of the 11 listeners with HL, the masking release was identical to that obtained in the NM group matched to those listeners; in the other six listeners, the release was smaller than that in the NM group. The reduced masking release was simulated best in those HL listeners for whom the masking release was relatively large. These results suggest that reduced masking release for speech in listeners with sensorineural hearing loss can only sometimes be accounted for entirely by reduced ability.

In 1989, Beattie studied the word recognition function for the CID W-22 test in multitalker noise for 18 subjects with normal hearing and 12 subjects with mild-to-moderate sensorineural hearing loss. In the first experiment, word recognition functions were generated by varying the signal-to-noise ratio (S/N), while in the second experiment a constant S/N was used and the stimulus intensity was varied. The results of the first experiment revealed that the scores for the listeners with normal hearing were about 20% higher than that obtained on listeners with hearing impairment. The functions also indicated that thresholds (50% point) were obtained at an S/N of ~6 dB for subjects with normal hearing and at S/N of ~11 dB for the subjects with hearing impairment. The slope of the recognition function was steeper for individuals with normal hearing than for the individuals with hearing impairment. The results for the second experiment revealed that the word recognition scores were poorer for the subjects with hearing impairment than for the subjects with normal hearing. This difference was most evident for the speech-in-noise condition.

Summers and Molis (2004) studied speech recognition with fluctuating and continuous maskers. The subjects were six listeners with normal hearing (NH) and six listeners with hearing impairment (HI). They were tested for sentence recognition at moderate and high presentation levels in the presence of three competing signals: speech-shaped noise, in competing speech by a single talker, and in competing time-reversed speech by the same talker. Participants were instructed to repeat the sentences. The listeners with NH showed more accurate recognition at moderate than at high presentation levels and better performance with fluctuating maskers than in unmodulated noise. For these listeners, modulated versus unmodulated performance tended to decrease at high presentation levels. The listeners with HI performed more poorly than listeners with NH across presentation level and masker condition. In particular, hearing loss reduced the benefit from masker fluctuations, making performance more similar in steady-state or fluctuating background.

In 1992, Hygge, Ronnberg and Arlinger compared the performance on a conversation-following task by 24 persons with hearing impairment with that of 24 matched controls with normal hearing in the presence of three background noises: speech-spectrum random noise, a male voice, and the male voice played in reverse. The subjects' task was to readjust the sound level of a female voice (signal) every time the signal voice was attenuated, to the subjective level at which it was just possible to understand what was being said. The results showed that the subjects with hearing impairment were equally affected by the three background noises and the persons with normal hearing were less affected by the background speech than by noise. The performance of the persons with normal hearing was superior to that of the subjects with hearing impairment.

From these studies it is clear that group with hearing impairment has higher threshold in the presence of speech noise in comparison to group with normal hearing. Compared to other kinds of noises, speech noise was found to interfere more with the recognition of speech.

e) Cafeteria noise

Cooper and Cutts (1971) studied speech discrimination in cafeteria noise using 16 subjects with normal hearing and 15 subjects with sensorineural hearing impairment. NU auditory test No. 6 was presented at signal-to-noise ratios of 4, 8 and 12 dB. Although the sensorineural group had poorer means, the slopes for the two groups were not significantly different, 3.57% per dB for normal and 3.47% per dB for sensorineural. The wide range of variability demonstrated by both groups indicates the importance of determining a patient's discrimination potential in noise. This study clearly shows, to evaluate subjects with hearing impairment in presence of noise.

f) Multitalker babble

Finitzo-Hieber and Tillman (1978) studied the effect of multitalker babble on monosyllabic word discrimination ability on normal hearing children and children with hearing impairment. They found that the performance of children with hearing impairment degraded considerably more in the presence of noise when compared to the children with normal hearing.

In 1982, Dirks, Morgan and Dubno determined the speech recognition performance for listeners with sensorineural hearing loss, while listening in the presence of multitalker babble. The performance was measured for two types of speech material (spondaic words and monosyllables) using adaptive strategies to determine the signal-to-babble ratio. The listeners had to achieve a preselected level of performance at several speech presentation levels encountered in normal conversation or when listening through an amplification system. When compared to the results from the listeners with normal-hearing, listeners with sensorineural hearing loss evidenced a significant deficit when listening in babble.

Gordon-Salant and Fitzgibbons (2004) investigated whether or not listeners are affected by alterations in the presentation rate of background speech babble, relative to the presentation rate of the target speech signal. Younger and older adults with normal hearing and with mild-to-moderate sensorineural hearing losses served as listeners. Speech stimuli included sentences, syntactic sets, and random-order words. The listeners' task was to write down the responses. The presentation rate was altered via time compression applied to the entire stimulus or to selected phrases within the stimulus. Older listeners performed more poorly than younger listeners in most conditions involving time compression, and their performance decreased progressively with the proportion of the stimulus that was processed with time compression. Older listeners also performed more poorly than younger listeners in all noise conditions, but both age groups demonstrated better performance in conditions incorporating a mismatch in the presentation rate between target signal and background babble compared to conditions with matched rates.

These studies show that multitalker babble or change in presentation rate of speech babble also affects speech recognition. The amount of disruption in the understanding of speech also depended on the age of the participants.

d) Modulated noise

Studies have used modulated noise to find speech reception threshold and speech identification abilities in subjects with hearing impairment. The majority of studies have evaluated the effect of modulated noise on speech identification.

Festen and Plomp (1990) studied the speech-reception threshold (SRT) for sentences presented in a fluctuating interfering sounds ranges from steady-state noise, via modulated noise, to a single competing voice of 80 dBA SPL. For both voices, one male and one female, the SRT was measured as well in noise spectrally shaped according to the target voice as shaped according to the other voice. This was measured on 20 listeners with normal hearing and 20 listeners with sensorineural hearing impairment. The listeners' task was to repeat the sentences. The result showed that, for listeners with normal hearing, the SRT for sentences in modulated noise was 4-6 dB lower than for steady-state noise; for sentence masked by a competing voice, this difference was 6-8 dB. For listeners with moderate sensorineural hearing loss, elevated threshold were obtained without an appreciable effect of masker fluctuations.

Carhart, Tillman and Greetis (1969) studied perceptual masking in multiple sound backgrounds. These included listening in the presence of white noise, white noise modulated four times per second by 10 dB with a 50% duty cycle, the same noise with 75% duty cycle, connected speech by one male talker, and connected speech by a second male talker. They found that the modulated noise with 50% duty cycle produced about 3.5 dB less masking than that produced by unmodulated white noise. Also, the modulated noise with 75% duty cycle allowed only about 1 dB less shift than did the unmodulated noise. Mixing one speech train with noise (either modulated or unmodulated) induced about 3.2 dB excess masking, which they termed as perceptual masking. The perceptual masking rose to 6.6 dB when two speech trains were included in the masker complex, irrespective of whether or not noise was also part of the complex.

Takahashi and Bacon (1992) observed that the scores in a modulated condition were better than in an unmodulated condition. They measured speech understanding of non-sense sentences as a function of signal-to-noise ratio in an unmodulated background noise and a background noise with a modulation frequency of 8 Hz and a modulation depth of 100%.

Likewise, Lorenzi, Husson, Ardoint and Debruille (2006) varied masker modulation rate systematically between 2 and 128 Hz. Masking release (better performance in fluctuating, than in stationary noise) was highest in a masker fluctuating at 8-16 Hz in all normal-hearing listeners. In comparison, masking release was only observed in two out of the four listeners with hearing impairment. In these listeners, masking release was poorer than that observed in individuals with normal hearing, and peaked at lower rates, of 2 or 8 Hz.

Gustafsson and Arlinger (1994) evaluated the masking of speech by amplitude-modulated and unmodulated speech-spectrum noise by the measurement of monaural speech recognition. This was evaluated in young and elderly subjects with normal-hearing and elderly subjects with hearing-impairment, with and without a hearing aid. Sinusoidal modulation with frequencies covering a range 2-100 Hz, as well as an irregular modulation was used. Modulation degrees were 100%, ±6dB, and ±12dB. The root mean square sound pressure level was equal for the modulated and unmodulated maskers. Verbal responses were obtained from the subjects. For the subjects with normal hearing, essentially all type of modulated noise provided some release of speech masking as compared to the unmodulated noise. Sinusoidal modulation provided more release of masking than the irregular modulation. The release of masking increased with modulation depth. It was proposed that the number and duration of low-level intervals were essential factors for the degree of masking. The release of masking was found to reach a maximum at a modulation frequency between 10 and 20 Hz for sinusoidal modulation. For the elderly subjects with hearing loss, the release of masking obtained from amplitude modulation was consistently smaller than the group with normal hearing. The average speech-to-noise-ratio required for 30% correct speech recognition varied greatly between the groups. For the young subjects with normal hearing it was -15 dB, for the elderly subjects with hearing impairment, in the unaided listening condition, it was +2 dB and in the aided condition it was +3 dB.

Using several kinds of masking noises including the modulated noises, Danhauer, Doyle and Lucks (1985) evaluated the perception of a nonsense syllable test (NST) and NU 6 stimuli. The maskers used were white noise, multitalker noise, and white noise which was amplitude modulated by the multitalker noise, presented at a 0 dB signal-to-noise ratio. Verbal responses were taken from the listeners. Analyses revealed that the listeners' performance was always poorer on the NST than on the NU 6 and the scores were better in multitalker noise followed by white noise and amplitude modulated white noise.

In 1994, Souza and Turner obtained speech recognition scores for monosyllables in the high-pass noise alone and in three noise backgrounds. The latter consisted of high-pass noise plus one of three maskers: speech-spectrum noise, speech-spectrum noise temporally modulated by the envelope of multi-talker babble, and multi-talker babble.

Three groups of subjects participated that included young listeners with normal hearing, young listeners with sensorineural hearing loss, and elderly listeners with sensorineural hearing loss. The subjects' repeated the words. The results revealed that, for all conditions, the groups with hearing impairment consistently scored lower than the group with normal hearing. However, there was no improvement of speech recognition in a modulated versus a steady-state background noise. Similar results were found by Bronkhorst and Plomp (1992), Eisenberg, Dirks, and Bell (1995) and Gustafson and Arlinger(1994).

In short, individuals with normal hearing and individuals with hearing impairment get benefit from the modulated noise but it's lesser for subjects with hearing impairment.

g) Interrupted noise

As early as 1950, Miller and Licklider studied the effects of various rates of interruption on speech recognition. Tests were conducted in three different conditions, with speech on and off in quiet; with continuous speech masked by interrupted white noise and; with speech and noise interrupted alternatively, the speech wave being turned on as the noise wave was turned off, and vice versa. The results indicated that when the speech wave was turned on and off infrequently, the percentage of the message that was missed was approximately the same as the percentage of time the speech was off. When the interruptions were periodic and occur more often than 10,000 times per second, the interruptions did not interfere with the reception of the message. In quiet it was easy to understand conversational speech so long as the interruptions occurred more than 10 times per second. When continuous speech waves were masked by noise that was interrupted more than 200 times per second, intelligibility was independent of the interruption frequency and of the percentage of time the noise was on, provided the ratio of average speech power to average noise power was held constant. Interrupted masking noise impaired intelligibility least if the frequency of interruption was about 15 per second. When interrupted speech and interrupted noise alternated at frequencies below 10 alternations per second, the noise did not impair intelligibility. At higher frequencies of alternation the temporal spread of masking became appreciable.

In 1995, Stuart, Philips and Green compared word recognition in continuous and interrupted noise in listeners with normal hearing and in listeners with hearing loss simulated by low pass filtering. The two groups of listener performed similarly with steady-state noise, but the listeners with simulated hearing loss showed significantly less masking release than did the group with normal hearing when the background was temporally varying. The authors noted that the performance of their listeners with simulated loss was similar to the listeners with real high-frequency loss.

Stuart and Phillips (1996) studied the word recognition in continuous and interrupted broadband noise on listeners with young normal-hearing (YNH), older normal hearing (ONH), and listeners with presbyacusis (OHI). Thirty-six participants were presented with NU-6 stimuli at 30 dB sensation level of speech reception threshold, which they repeated. The speech stimuli were presented in quiet and at different signal to noise ratios of 10, 5, 0,-5,-10,-15 and -20 dB. It was observed that the performance was superior in quiet, improved with increasing S/N, and was greater in the interrupted broadband noise than in the continuous broadband noise.

Similar findings were reported by Smits and Houtgast (2007) who studied the recognition of digits in different types of noise for listeners with normal hearing and listeners with hearing impairment. Digits were presented in continuous noise, 16-Hz interrupted noise, and 32-Hz interrupted noise. Also, the standard Dutch triplet speech-reception-threshold (SRTn) in continuous noise was included. Forty-two ears of normal-hearing and hearing impaired were taken in the study. The subjects' entered their response on the keyboard or responded orally, in which case the response was entered by the experimenter. The results showed that there was high efficiency for triplets instead of digits and for 16-Hz interrupted noise instead of continuous noise.

Rappaport et al. (1994) evaluated patients suffering from multiple sclerosis, with normal peripheral hearing yet confirmed demyelinating lesions in the auditory system. In contrast to the findings of other studies, their subjects displayed performance that was equivalent to that of young adults with normal-hearing under the continuous noise. However, performance detriment was seen with interrupted noise.

It is evident from the studies on interrupted noise that SRT or speech recognition scores are better in the presence of interrupted noise than in the presence of steady-state noise. This effect was observed in normal hearing subjects as well as those with hearing impairment. However, the effect was higher in the latter group.

From the review of literature it is evident that a wide variety of noise that been used to evaluate perception of speech. The type of noise varied in terms of the spectral characteristics or temporal characteristics. In addition, the effects of different signal-to-noise ratios have also been studied. Such studies have been carried out on individuals with normal hearing as well as those with hearing impairment. There seems to be a general consensus that individuals with a hearing loss performed poorer than those with normal hearing. This was noted for most type of noises.

METHOD

The study was carried out on two groups of participants, one group having individuals with normal hearing (group I) and the other group having individuals with acquired sensorineural hearing loss (group II).

Participant Selection Criteria for Group I

Twenty participants who met the following criteria were included in the study:

- Age ranged between 18 to 30 years,
- Fluent speakers of Kannada with ability to read and write the language,
- Pure tone threshold within 15 dB HL for the octave frequencies 250 Hz to 8000 Hz and speech identification score (SIS) greater than 90% in both ears,
- 'A' type tympanogram with reflexes present in both ears,
- No otological deficit, and
- No illness on the day of testing.

Participant Selection Criteria for Group II

Group II also consisted of 20 participants who met the same criteria as group I except that they had:

- Acquired bilateral sensorineural hearing loss. Ten of them had moderate to moderately-severe, flat sensorineural hearing loss and ten had high frequency sensorineural (SN) hearing loss. Only those with a gradual or sharp slope as defined by Lloyd and Kaplan (1978) were included.

- Air-bone gap was within 10 dB.
- Speech identification score (SIS) in quiet was greater than 80%, in both ears.
- 'A' type tympanogram.

Test Material

For determining the speech-recognition threshold (SRT), the Kannada Paired-Word list developed at the Department of Audiology, AIISH, was used as the speech material. The recorded version of the Kannada Phonemically balanced words developed by Yathiraj and Vijayalakshmi (2005) was used for speech identification testing. This material has 8 lists containing 25 words in each list.

Three different low pass filtered noises with cut-off frequencies at 250 Hz, 500 Hz and 1 kHz were generated through the Adobe Audition 2.0 software. The rejection rate for the noise was approximately 20 dB per octave. This material was stored in a Pentium IV computer.

Instrumentation

A calibrated diagnostic audiometer was used to carryout pure-tone audiometry and speech audiometry. An immitance audiometer (GSI - Tympstar) was utilized to find out the middle ear function. With the help of a Pentium IV computer with the Adobe Audition 2.0 software, low pass filtered noises were generated at different cut-off frequencies.

Test Environment

The testing for both groups was done in a sound treated double room. The ambient noise levels were within permissible limits, as recommended by ANSI 1991 (ANSI S3. 1991, cited in Wilber, 1994).

Procedure

Initially, pure-tone thresholds were established for both groups, using a modified Hughson-Westlake procedure. SRT was obtained using the Kannada Paired-Word list. For speech identification testing, the recorded version of speech material (Yathiraj & Vijayalakshmi, 2005) was played through the Pentium IV computer. The output of the computer was routed through the audiometer. The 1000 Hz calibration tone of the speech identification test was used to adjust the volume unit (VU) meter deflection of the audiometer to zero. The output from the audiometer was played at 40 dB SL with reference to the participants' SRT and delivered through TDH-39 earphones. The participants heard the noise and speech in the same ear. The choice of ear was randomized such that half the participants heard the signals through right ear and the other half through the left ear.

The speech identification score was obtained in quiet and in the presence of the three low pass filtered noises, which were presented at +5 dB SNR as recommended by Krishnan (2003). This was done for both groups. The order in which participants heard the lists was randomized to avoid any list effect. The participants were instructed to write down the words heard by them.

Scoring

The written responses of each participant were scored separately in the four conditions in which they were tested. This includes:

- Quiet
- 250 Hz noise at +5 dB SNR
- 500 Hz noise at +5 dB SNR
- 1000 Hz noise at +5 dB SNR

Both word scores and phoneme scores were calculated. In addition, an error analysis was also carried out. The data thus obtained were subjected to statistical analyses. These are discussed in the following chapter.

RESULTS AND DISCUSSIONS

The present study was designed to investigate the effect of three different low pass filter noise on speech identification in individuals with normal hearing and individuals with hearing impairment. The data from 20 participants with normal hearing and 20 participants with hearing impairment were analyzed using Statistical Package for Social Sciences (SPSS) software version 10. The effect of noise was evaluated on the word scores and phoneme scores. In addition, an error analysis was also carried out. The above were analyzed using descriptive statistics, mixed ANOVA, repeated measures ANOVA, and paired sample 't' test.

4.1 Effect of low pass filter on word scores

The mean and standard deviation (SD) for the word scores obtained in the four listening conditions (quiet, low pass filter of 250 Hz, 500 Hz and 1000 Hz) were computed (Table 1). This was obtained for the normal hearing group as well as the group with hearing impairment.

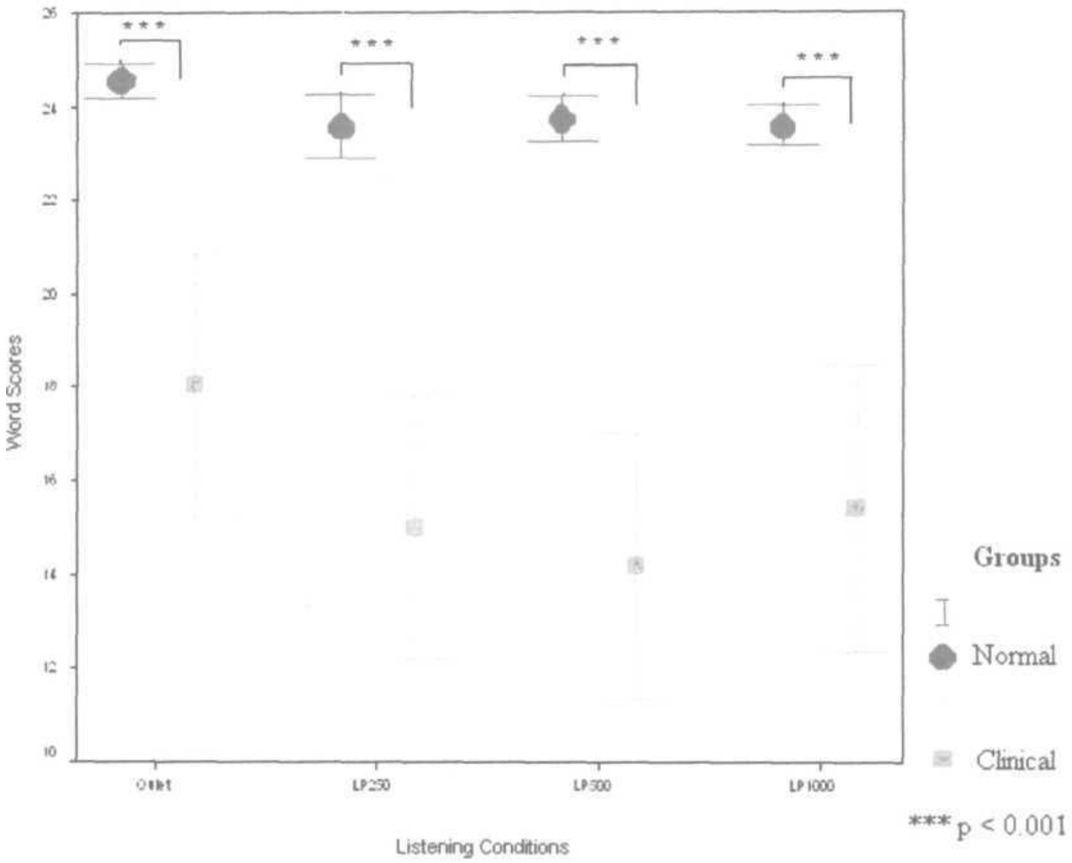
A comparison across listening conditions showed that the mean scores for both the groups were better in the quiet condition compared to all the three masking conditions using 250 Hz, 500 Hz and 1000 Hz low pass noise. This is evident in Table 1 and Figure 1.

A comparison of the normal and clinical groups indicated that the mean score for the group with normal hearing was higher than that obtained by the group with hearing impairment for all the four listening conditions (Table 1). Further, the SD was also lower for the normal hearing group. This shows that the variability in scores was much less for the normal hearing group, and was considerably higher for those with hearing impairment.

Table 1: *Mean and standard deviation (SD) for the normal hearing group and group with hearing impairment (HI) for the word scores*

Listening Conditions	**Participant Groups**			
	Normal		**HI**	
	Mean	**SD**	Mean	**SD**
Quiet	24.6 (98.2%)	0.76	18.0. (72.2%)	6.0
LP 250 Hz	23.6 (94.4%)	1.4	15.0 (60%)	5.9
LP 500 Hz	23.8 (95.95%)	1.0	14.2 (56.8%)	6.0
LP 1000 Hz	23.6 (94.4%)	0.9	15.5 (61.8%)	6.6

Note: LP 250 Hz =Low pass noise below 250 Hz
LP 500 Hz = Low pass noise below 500 Hz
LP 1000 Hz = Low pass noise below 1000 Hz



Note: Max scores = 25

Figure 1- Mean, 95% confidence interval and the level of significance for the normal hearing group and group with hearing impairment for word scores across at four listening conditions.

Initially, to check for a main effect and interaction effect, a mixed ANOVA was carried out, with information for groups merged. The results revealed a highly significant main effect for word scores in all the listening conditions [F (3, 114) = 25.88, $p < 0.001$] and a highly significant interaction between the listening conditions and groups [F (3, 114) = 9.64, $p< 0.001$].

Further, the Bonferroni's pairwise comparison test was carried out to check for any significant difference for word scores between all the conditions. It was found that there was a significant difference in word scores between the quiet condition and the three low pass filter noise masking conditions ($p < 0.001$). However, there was no significant difference ($p > 0.05$) in the word scores within the three masking conditions (250 Hz, 500 Hz and 1000 Hz low pass noise).

As the grouped data indicated that there was a significant main effect, separate one-way repeated measure ANOVAs were carried out for each group (with group as independent variable and listening conditions as dependent variable). A highly significant difference was observed between the listening conditions. This was seen for the normal group [$F(3, 57) = 9.365$, $p < 0.001$] and also for the clinical group [$F(3, 57) = 18.989$, $p < 0.001$].

To obtain *a comparison across the listening conditions* the Bonferroni's pairwise comparison test was done. This was done to see whether there was any significant difference for word scores between each of the four listening conditions. The results indicated that there was a significant difference ($p < 0.05$) in word scores for the normal hearing group (Table 2) and the clinical group (Table 3) between the quiet condition and all three masking conditions. However, there was no significant difference between the speech identification scores obtained within the three masking conditions.

Table *2: Pairwise comparison between the four listening conditions for word scores in the normal hearing group*

	LP 250 Hz	**LP 500 Hz**	**LP 1000 Hz**
Quiet	Significant $p < 0.05$	Significant $p < 0.001$	Significant $p < 0.001$
LP 250 Hz	------------------------	Not significant $p > 0.05$	Not significant $p > 0.05$
LP 500 Hz		--------------------------	Not significant $p > 0.05$

Note: LP 250 Hz =Low pass noise below 250 Hz
LP 500 Hz = Low pass noise below 500 Hz
LP WOO Hz = Low pass noise below 1000Hz

Table 3: *Pairwise comparison between the four listening conditions for word scores in the clinical group*

	LP 250 Hz	LP **500** Hz	**LP 1000 Hz**
Quiet	Significant $p < 0.001$	Significant $p < 0.001$	Significant $p < 0.001$
LP 250 Hz	---------------------------	Not significant $p > 0.05$	Not significant $p > 0.05$
LP 500 Hz		---------------------------	Not significant $p > 0.05$

Note: LP 250 Hz -Low pass noise below 250 Hz
LP 500 Hz = Low pass noise below 500 Hz
LP 1000 Hz = Low pass noise below 1000 Hz

To compare the normal and the clinical groups a paired 't' test was performed for each of the listening conditions (Table 4). It can be observed from Figure 1 and Table 4 that there was a significant difference between two groups for all four listening conditions.

Table 4: *Mean and 't' values for listening conditions on word scores in the normal hearing group*

Groups	**Mean & 't' values for listening conditions**							
	Quiet Mean	**'t' value**	**LP 250 Hz Mean**	**'t' value**	**LP 500 Hz Mean**	**'t' value**	**LP 1000 Hz**	**'t' value**
Normal	24.6	4.97***	23.6	5.80***	23.8	7.1***	23.6	5.3***
Clinical	18.0		15		14.2		15.5	

*Note: ***=p< 0.001*

The results of the present study regarding *performance across listening conditions* are comparable with those of Cohen and Keith (1976) and Stelmachowicz, Jesteadt, Gorga and Mott (1985). They too reported a significant difference in word recognition scores using a 500 Hz low pass masking noise in individuals with normal hearing and individuals with hearing impairment.

The current study found that individuals with normal hearing as well as individuals with hearing impairment scored significantly lower for the low pass filter noise conditions when compared to the quiet condition. In both groups the overall word scores were probably lower in the noise condition due to the masking effect of noise. Essential segmental cues were possibly not available in the presence of masking noise, making it difficult for the participants to perceive speech. Similar findings have also been noticed by Gordon-Salant and Fitzgibbon (1993) in individuals with normal hearing and by Stelmachowicz, Lewis, Kelly and Jesteadt (1990) in individuals with hearing impairment.

Within group comparison highlighted that both groups obtained no difference in word scores across the three masking conditions. Thus, irrespective of the low frequency cut off, word score dropped equally in both groups. These findings are unlike that observed by Stelmachowicz, Lewis, Kelly and Jesteadt (1990) who reported that the required SNR to obtain 50 % correct performance on nonsense syllables improved as the low pass cut off increased from 500 Hz to 1000 Hz. The contradiction in finding could be due to the difference in material being used to determine speech identification. In the present study words were used while nonsense syllables used in the study by Stelmachowicz, Lewis, Kelly and Jesteadt (1990).

The *comparison across groups* in the present study indicated that the overall scores were lower in the clinical group when compared to the normal hearing group. This reduction in the speech perception scores could be attributed to certain factors. These include upward spread of masking, widened critical bands, abnormal response growth, or possible central effect, all of which might play a role while perceiving the speech in noise, as observed by Stelmachowicz, Lewis, Kelly and Jesteadt (1990). Also the strategies used by the listeners with hearing impairment, to recover the spoken message, either in quiet or in noise, may have been different from those employed by listeners with normal hearing. Another reason for the poor performance in the group with hearing impairment could be because their speech perception in quiet is influenced by the degree of loss, whereas their speech perception in a noisy condition is heavily dependent on frequency resolution. This has been suggested by Bonding (1979), Dreschler and Plomp (1980) and Festen and Plomp (1983). It has also been suggested that abnormal frequency analysis, presumably occurring at the level of cochlea, might be responsible for the reduced speech processing capabilities often seen in individuals with hearing impairment (Evans, 1978; Scharf, 1978).

4.2 Effect of Low Pass Filter on Phoneme Scores

Descriptive statistics was carried out for the phoneme scores obtained at each listening conditions for both participant groups. This is provided in Table 5.

The *comparison across listening conditions* indicates that just like the word scores, the phoneme scores were better for both the groups in the quiet listening conditions. The mean phoneme scores were higher in the three masking conditions (Table 5 & Figure 2).

Comparing the normal and clinical groups indicated that the normal hearing group had higher phoneme scores with lesser variability than the group with hearing impairment. This occurred at all four listening conditions (quiet, low pass filter of 250 Hz, 500 Hz and 1000 Hz).

Table 5: *Mean and standard deviation (SD) for the normal hearing group and the group with hearing impairment (HI) for phoneme scores.*

	Groups			
Listening conditions	**Normal**		**HI**	
	Mean % score	**SD**	**Mean % score**	**SD**
Quiet	99.2	1.5	88.7	11.9
LP 250 Hz	97.7	2.6	80.1	16.9
LP 500 Hz	98.3	1.5	80.9	14.6
LP 1000 Hz	97.8	1.2	82.2	17.8

Note: LP 250 Hz =Low pass noise below 250 Hz
LP 500 Hz = Low pass noise below 500 Hz
LP 1000 Hz = Low pass noise below 1000 Hz

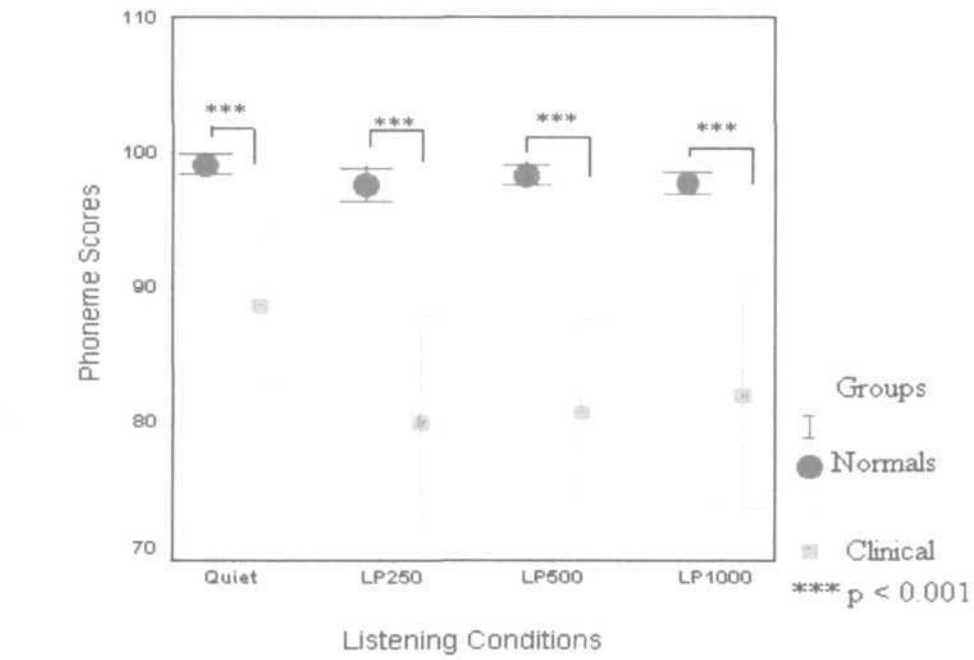


Figure 2: Mean, 95% confidence interval and level of significance for the normal hearing group and the group with hearing impairment, for phoneme scores across at four listening conditions.

Further, mixed ANOVA was done to determine whether any main effect and interaction effect existed. This was done with the information for groups merged. The findings indicated a highly significant main effect for phoneme scores in all the listening conditions (quiet, low pass filter of 250 Hz, 500 Hz and 1000 Hz) [F (3, 114) = 11.993, $p < 0.001$]]. Also a significant interaction between the listening conditions and groups was obtained [F (3, 114) - 6.475, $p < 0.001$].

To get a better understanding regarding the way the variables interacted, the Bonferroni's pairwise comparison test was done. It indicated that there was a significant difference for phoneme scores between the quiet condition and the three low pass filter noise masking conditions ($p < 0.001$). On the other hand, there was no significant difference among the three masking conditions ($p > 0.05$).

To determine whether the two groups differed in their responses in the different listening conditions, separate one-way repeated measure ANOVAs were carried out. The ANOVAs, with groups as independent variables and listening conditions as dependent variables, showed highly significant differences for the normal hearing group F (3, 57) = 4.338, $p < 0.001$] and also for the clinical group [F (3, 57) = 9.563, $p < 0.001$].

To obtain a comparison across the listening conditions, the Bonferroni's pairwise comparison test was done in the normal hearing group. The test revealed the presence of a significant difference between the quiet and masking conditions using 500 Hz and 1000 Hz low pass noise ($p < 0.05$). However, there did not exist a significance difference between the quiet and 250 Hz low pass masking conditions ($p > 0.05$). There also existed no significant difference between the three masking conditions ($p > 0.05$) which is evident in Table 6.

Table 6: *Pairwise comparison of the four listening conditions in the group with normal hearing for the phoneme scores*

	LP 250 Hz	**LP 500 Hz**	**LP 1000 Hz**
Quiet	Not significant $p > 0.05$	Significant $P<0.01$	Significant $p < 0.05$
LP 250 Hz	--------------------------	Not significant $P > 0.05$	Not significant $p > 0.05$
LP 500 Hz		------------------------	Not significant $p > 0.05$

Note: LP 250 Hz =Low pass noise below 250 Hz
LP 500 Hz = Low pass noise below 500 Hz
LP 1000 Hz = Low pass noise below 1000 Hz

On the other hand, for the clinical group, the phoneme scores were significantly different between the quiet condition and all three masking conditions ($p < 0.05$). However, there was no significant difference between the three masking conditions (Table 7).

Table 7: *Pairwise comparison of the four listening conditions in the clinical group for phoneme scores*

	LP 250 Hz	**LP 500 Hz**	**LP 1000 Hz**
Quiet	Significant $P<0.01$	Significant $p<0.01$	Significant $p < 0.05$
LP 250 Hz	---------------------	Not significant $p > 0.05$	Not significant $p > 0.05$
LP 500 Hz		---------------------	Not significant $p > 0.05$

Note: LP 250 Hz = Low pass noise below 250 Hz
LP 500 Hz = Low pass noise below 500 Hz
LP 1000 Hz = Low pass noise below 1000 Hz

To compare the normal and the clinical groups a paired 't' test was performed for each of the listening conditions (Table 8). From Figure 2 and Table 8, it is clear that there was a significant difference in phoneme scores between the two groups for all four listening conditions.

Table 8: *Mean and 't' values for listening conditions on phoneme scores in the normal hearing group*

Groups	**Mean & 't' values for listening conditions**							
	Quiet Mean	**'t' value**	**LP 250 Hz Mean**	**'t' value**	**LP 500 Hz Mean**	**'t' value**	**LP 1000 Hz**	**'t' value**
Normal	99.2	*** 3.9	97.7	*** 4.4	98.3	*** 5.5	97.8	*** 3.8
Clinical	88.7		80.1		80.9		82.2	

Note: *** $=p< 0.001$

The results *across listening conditions* show that there is a lack of difference in phoneme scores between the quiet and 250 Hz low pass masking condition, in the normal significant difference for the three masking conditions using 250 Hz, 500 Hz and 1000 Hz [F (2, 38) = 0.345 p > 0.05] and interaction of feature and listening conditions [F (4, 76) = 0.360, p > 0.05].

To get information about the significance of difference between each of the three features, Bonferroni's pairwise comparison test was done. The analysis showed that there were significant differences in place errors and manner errors (p < 0.001) and manner errors and voicing errors (p < 0.001). In contrast, there was no significant difference between place errors and voicing errors (p > 0.05) for the normal hearing group, which is evident from Table 10.

Table 10: *Pairwise comparison of the different feature errors in the normal hearing group*

	Manner	**Voicing**
Place	Significant p< 0.001	Significant P > 0.05
Manner	-----------------------	Significant p<0.01

Also for the clinical group, the place errors were significantly different from the manner errors and voicing errors (p < 0.001). Also manner errors were significantly different from voicing errors at the 0.01 level of significance (Table 11).

hearing group. This indicates that very low frequency masking noises does not interfere with their speech identification abilities. On the other hand, in individuals with hearing impairment the phoneme scores were more easily hampered with the presence of noise with a low pass cut off as low as 250 Hz. This highlights the differential effect of a similar kind of noise on the two groups (normal hearing & clinical groups).

The *comparison of word scores and phoneme scores across groups* in the present study showed that the phoneme scores were higher for both participant groups than the word scores. However, the difference was more marked in the group with hearing impairment. These findings are similar with those of Olsen, Tasell and Speaks (1997) and Mascarehans (2002). They too noted that phoneme scores were higher than word scores in normal hearing individuals as well as individuals with hearing impairment.

The results of the current study revealed that the performance of individuals with hearing impairment were poorer on the phoneme scores in comparison to the normal hearing group. This was similar to what was obtained with the word scores. As mentioned earlier the poorer performance of the group with hearing impairment could be due to factors such as upward spread of masking, abnormal response growth, or central effect which affect speech perception in the presence of noise. Furthermore, the strategies used by the group with hearing impairment to recover the spoken message, either in quiet or noise, might differ from those employed by the group with normal hearing (Stelmachowicz, Lewis, Kelly & Jesteadt, 1990).

4.3 Effect of Low Pass Filter on Error Analysis

The errors in the perception of place, manner and voicing were calculated for both participant groups. From Table 9 it is evident that percentage of errors was very less in the normal hearing group in comparison to the group with hearing impairment. Place errors were maximum, followed by voicing errors. The least errors were seen in for the manner of articulation (place > voicing > manner). This trend was seen for all four listening conditions.

Table *9: Feature errors for normal hearing individuals and individuals with hearing impairment (HI) in the four listening conditions*

Listening Conditions	**Groups**	**Place (%)**	**Manner (%)**	**Voicing (%)**
Quiet	Normal	0.13	0.00	0.00
	HI	1.09	0.00	0.13
LP250 Hz	Normal	0.13	0.00	0.13
	HI	1.3	0	0.33
LP500 Hz	Normal	0.26	0.00	0.05
	HI	1.3	0.05	0.28
LP1000 Hz	Normal	0.23	0.00	0.13
	HI	1.56	0.05	0.26

Note: LP 250 Hz =Lowpass noise below 250 Hz
LP 500 Hz = Low pass noise below 500 Hz
LP 1000 Hz = Low pass noise below 1000 Hz

Mixed ANOVA showed a significant difference between the participant groups on feature errors in the normal hearing group [F (2, 38) = 12.667, $p < 0.001$] and group with hearing impairment [F (2, 38) = 47.432, $p < 0.001$]. However, there was no significant difference for the three masking conditions using 250 Hz, 500 Hz and 1000 Hz [F (2, 38) = 0.345 $p > 0.05$] and interaction of feature and listening conditions [F (4, 76) = 0.360, $p > 0.05$].

To get information about the significance of difference between each of the three features, Bonferroni's pairwise comparison test was done. The analysis showed that there were significant differences in place errors and manner errors ($p < 0.001$) and manner errors and voicing errors ($p < 0.001$). In contrast, there was no significant difference between place errors and voicing errors ($p > 0.05$) for the normal hearing group, which is evident from Table 10.

Table 10: *Pairwise comparison of the different feature errors in the normal hearing group*

	Manner	**Voicing**
Place	Significant $p < 0.001$	Significant $P > 0.05$
Manner	--------------	Significant $p < 0.01$

Also for the clinical group, the place errors were significantly different from the manner errors and voicing errors ($p < 0.001$). Also manner errors were significantly different from voicing errors at the 0.01 level of significance (Table 11).

Table 11: *Pairwise comparison* of *the different feature errors in the clinical group*

	Manner	**Voicing**
Place	Significant $p < 0.001$	Significant $P < 0.001$
Manner	-------------	Significant $p < 0.01$

Thus, it can be seen *when comparing the errors across the listening conditions* that they were similar in the four listening conditions. This is evident from the information given in Table 9 and the mixed ANOVA results. Hence, immaterial of the listening conditions, the pattern and number of feature errors continued to be the same. This result is similar to the findings of Dubno, Dirks and Langhofer (1982) who also reported that the pattern of syllable recognition for the listeners with hearing-impairment was similar to those of the listeners with normal hearing.

Comparing the feature errors across the groups indicated that the percentage of feature errors were relatively more in the group with hearing impairment than the normal hearing group. This result is supported by Cohen and Keith (1976). They too observed that the errors were higher in their subjects with hearing impairment.

Also, in the current study, the percentage of place errors occurred the most, voicing errors lesser and manner errors the least (place > voicing > manner). This result is comparable to the findings of Moumita (2004) and Cox (1969, cited in Revoille & Pickett, 1982) who evaluated feature analysis in listeners with hearing impairment and reported that confusion of place of articulation was more. However, they observed that the number of manner errors was more than the voicing errors. This contradicts the findings of the present study where voicing errors were relatively more than the manner errors. In the quiet situation, it was found in the current study that the normal hearing group had no voicing or manner errors. Also, those with a hearing impairment had a negligible voicing error. This could be due to the fact that under quiet conditions, listeners would get these voicing cues from the low-frequency regions of the speech signal. However, in the presence of a low pass noise, the major cues for voicing could have been masked. It has been reported by Stevens and Blumstein (1981) and Lisker and Abramson (1964; cited in Liberman & Blumstein, 1988) that the major cues for the perception of voicing are present in the low frequency region. In contrast, a few of the manner of articulation cues, such as fricatives and affricates, are present in the higher frequency region. These would have been audible to the listeners despite the presence of low frequency maskers. Thus, the difference in findings between the present study and that of Cox (1969) and Moumita (2004) could be due the difference in listening conditions. While the current study evaluated the presence of feature errors in the presence of low frequency maskers, their studies did not do so. Their evaluation was carried out only in a quiet condition.

From the results of the study it can be summarized that:

- The participants got better word scores and phoneme scores in the quiet condition in comparison to the three masking conditions using 250 Hz, 500 Hz and 1000 Hz.

- The individuals with hearing impairment obtained poorer word scores in comparison to the normal hearing individuals
- The scores for phonemes were higher in normal hearing group in comparison to the group with hearing impairment.
- Error analysis showed that place errors occurred more than voicing errors, which in turn occurred more than the manner errors.
- The place errors were present more often in both groups. However, it was more for individuals with hearing loss.
- The patterns of errors were similar in all the listening conditions for group with hearing-impairment.

SUMMARY AND CONCLUSION

It has been confirmed by several authors that in the presence of noise, speech perception is adversely affected (Cohen & Keith, 1976; Stelmachowicz, Jesteadt, Gorga & Mott, 1985; Keith & Talis, 1972; Dirks, Morgan & Dubno, 1982). This leads to a break down in communication. Knowledge of speech perception in noise would be helpful in the differential diagnosis, counseling individuals about perception of speech in presence of noise and in prescription of hearing aids. Further, it will be helpful in fine-tuning of hearing aids.

The aim of the study was to study the perception of speech and make a comparison of speech perception in the presence of different low pass filtered noises in the individuals with normal hearing and those with hearing-impairment. The study was carried out on two groups of participants, 20 with normal hearing adults and the other having 20 adults with acquired sensorineural hearing loss. Following routine audiological testing their speech identification scores were obtained in a quiet condition and in the presence of three different low pass filtered noises, which were presented at +5 dB SNR. The low pass noises were filtered at cut off frequencies of 250 Hz, 500 Hz and 1000 Hz. The responses of the participants were statistically analyzed using a descriptive statistics, ANOVA and 't' test. Both word scores and phoneme scores were analyzed. In addition an error analysis was also done.

The analyses of the data revealed that:

The participants got better word scores and phoneme scores in the quiet condition in comparison to the three masking conditions using 250 Hz, 500 Hz and 1000 Hz. The individuals with hearing impairment obtained poorer word scores in comparison to the normal hearing individuals. Further, the scores for phonemes were higher in normal hearing group in comparison to the group with hearing impairment.

The error analysis showed that place errors occurred more than voicing errors, which in turn occurred more than the manner errors. The place errors were present more often in both groups. However, it was more for individuals with hearing impairment. The patterns of errors were similar in all the listening conditions for group with hearing impairment.

Implications

The influence of spectral characteristics of noise on speech perception can be understood, which will be useful in designing the noise reduction systems in digital hearing aids. This in turn will be useful in prescription of hearing aids. The results will also help in understanding whether the removal of environmental noise in specific frequencies is necessary for optimal speech perception and in predicting speech perception in individuals with hearing impairment in presence of noise.

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