COMPARISON OF ACCEPTABLE NOISE LEVEL AND SIGNAL TO NOISE RATIO USING DIRECTIONAL MICROPHONE AND FM SYSTEM

Bhavya M

Register Number: 07AUD002

A dissertation submitted in part of fulfilment for the degree of

Master of Science (Audiology)

University of Mysore, Mysore

ALL INDIA INSTITUTE OF SPEECH & HEARING,

MANSAGANGOTHRI, MYSORE-570006

MAY 2009.

This work of mine is dedicated to

My family and mamatha maam

Certificate

This is to certify that this dissertation entitled “Comparison of Acceptable Noise Level and Signal to Noise Ratio using Directional Microphone and FM system” is a bonafide work in part of fulfillment for the degree of Master of Science (Audiology) of the student Registration number: 07AUD002.This has been carried 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.

Dr. Vijayalakshmi Basavaraj
Director
All India Institute of Speech & Hearing,
Manasagangothri, Mysore-570006

MYSORE
May 2009

Certificate

This is to certify that this dissertation entitled "Comparison of Acceptable Noise Level and Signal to Noise Ratio using Directional Microphone and FM system" has been prepared under my supervision & guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

Guide

Ms. Mamatha. N. M

Lecturer, Department of Audiology,

All India Institute of Speech & Hearing,

Mansagangothri, Mysore-570006

MYSORE

May 2009

Declaration

This is to certify that this master's dissertation entitled "Comparison of Acceptable Noise Level and Signal to Noise Ratio using Directional Microphone and FM system" is the result of my own study and has not been submitted earlier to any other university for the award of any degree or diploma.

MYSORE Registration number: 07AUD002

May 2009

Acknowledgements

Appa and Amma… this work is dedicated to you. Your advice and support have gotten me through a lot.

A heartfelt thanks to my guide, Ms. N.M. Mamatha, Lecturer, Dept., Audiology, for being more than a teacher to me and for guiding me in every step. Words are never enough to thank you.

I would like to thank Dr. Vijayalakshmi Basavaraj, Director, AIISH, who permitted me to conduct this study.

My sincere thanks to Prof Asha Yathiraj, Head of Dept., Audiology, for allowing me to conduct the study.

My sincere thanks to Animesh sir, Vinay sir, Manjula ma'm, Sandeep sir and Rajalakshmi ma'm

Thanks to the staff of Dept of Audiology for all the support, insights, and help they have provided me over the past 6 years. Special thanks to Rama ma'm, Sujit sir, Dhanya, and Sreeraj….

Thanks to all the participants who participated in the study

Prashanth….thanks for being with me always. Your inspiring words infused energy in me to do the work. Without you by my side I would have been lost. You have guided me althrough the life. You have been a wonderful brother.

Rohith….even though we fought and argued a lot of time, your sense of humor made my life filled full of joy even in the gloomiest days. You are like a gentle breeze that wipe all my tears and bring smile. I learned to be cool after seeing you.

I wish to convey my thanks to all my classmates – sinthiys, sruthy,, sharath,, tammyy, hamai, rams, vivek, suchi, manasa, gurdeep, arun, Ismail, antu,menu, muthu, megha, pooja, nikhil, & sasmi for such a wonderful support I received from all of you.

A special thanks to Navi, Prathi, manasa, meenu my treasured buddies….. thanks for being with me always..

Muthu, words are not enough to thank you. You have been with me in each and every step. Thank you for putting so much thought and care into our friendship...
for sharing so many nice times and making so many special memories with me.

A special thanks to Vasanthalakshmi ma'm..for helping me with statistical analysis.

Antu, Megha ,guru, suchi and Aruna….for helping me throughout my dissertation in the posting days and for answering my questions when I was perplexed.

Very special thanks to Jayakumar sir for the spectral analysis of my data.

Table of Contents

List of Tables

List of Figures

CHAPTER 1

Introduction

Annoyance from amplified background noise is one of the most common performance related complaints with hearing aids (Kirkood, 2005). Hearing aid users have reported difficulty with background sounds as the most critical issue related to hearing aid benefit, satisfaction, and use (Surr, Schuchman, & Montgomery, 1978; Franks & Beckman, 1985; Kochkin, 2002). The major reason for dissatisfaction with hearing aid is the background noise (Surr, Schuchman, & Montgomery, 1978).

Unfortunately, for individuals with hearing impairment, traditional amplification strategies may provide little or no improvement in noisy environment. A hearing impairment is composed of two factors, one is the attenuation factor which reduces the overall level of both speech and noise, and the other is the distortion factor, where individuals with hearing impairment need a higher speech to noise ratio to reach the same degree of speech recognition as individuals with normal hearing (Hagerman, 1984; Plomp, 1986). Amplification through hearing aids compensates for the attenuation factor, but the distortion factor is difficult to deal with. Hearing aid use improves speech perception in quiet conditions mainly due to increased audibility. However, in presence of noise, there are reports of both benefit (Alcantara, Moore, Kuhnel, & Launer, 2003) as well as of no benefit (Gustafsson & Arlinger, 1994) from hearing aid use in speech recognition tasks.

Thus the main challenge for an audiologist, while fitting a hearing aid is to decrease the negative effects of noise without affecting or minimally affecting the speech intelligibility, and also acceptance of hearing aid in the presence of noise. There are several noise reduction technologies that have been shown to improve speech intelligibility on noise (Crandell & Smaldino, 2000). These technologies include directional microphones, digital noise reduction and personal frequency modulation (FM) systems.

Directional microphones are the option available in hearing aids which improves the Signal to noise ratio (SNR) by taking the advantage of spatial differences between speech and noise. They are more sensitive to sound coming from the front than the sounds coming from the back and the sides. Many studies have assessed directionality and have found that aided speech recognition in noise is improved significantly with directional microphones in comparison to omnidirectional microphones (Ricketts, Henry, Gnewikow, 2003; Bentler, Niebuhr, Getta, & Anderson, 2004). In addition to directional microphone, the other noise reduction technology which has provided a remarkable benefit in noisy situation is the FM system.

An FM system delivers desired sound directly to the ear by reducing the background noise. It preserves the desired signal strength and enhances the speech to noise ratio (SNR) at the listener's ear and thereby facilitates speech recognition. Currently no hearing aid option has been shown to provide as much benefit as that documented with FM systems. Hawkins (1984) reported a mean signal to noise ratio advantage of 15.3 dBHL in unilateral FM condition compared to the conventional hearing aid condition.

Traditionally these two technologies are evaluated for their benefit using speech perception in noise measures (SNR). Speech in noise test measures an individual's ability to understand speech in the presence of noise which is quantified by estimating the signal to noise ratio required to achieve a certain degree of intelligibility, such as 50% correct scores. There is an assumption that, individuals with good scores for speech perception in noise may have more success or wear their hearing aids more often than individuals with poor scores for speech perception. However, poor correlation have been found between speech perception scores in noise (SNR) and hearing aid benefit, satisfaction, or its use (Humes, Halling, & Coughlin, 1996). Hence there was a need to develop a test procedure that predicts the hearing aid satisfaction and use.

Nabelek, Tucker, and Letowski (1991) hypothesized that the willingness to listen to speech in background noise may be more indicative of hearing aid use than speech perception scores obtained in background noise. This hypothesis led to the development of a procedure called "acceptable noise level" (ANL), which is a measure of willingness to accept background noise while listening to speech. This procedure was originally termed as tolerated signal to noise ratio. The ANL was defined as the difference between the most comfortable listening level (MCL) for running speech and the maximum background noise level (BNL) that a listener is willing to accept.

Nabelek, Freyaldenhoven, Tampas, Burchfield, & Muenchen (2006) reported that unaided conventional ANLs can predict hearing aid use with 85% accuracy. Nabelek, Tampas, & Burchfield (2004) reported that ANLs vary from approximately 0 to 30 dB in both individuals with normal hearing as well as individuals with hearing impairment. They demonstrated that hearing aid use was related to an individual’s ability to accept background noise and individuals who accepted high levels of background noise (i.e., had low ANL i.e., 7dB or less) were likely to become successful hearing aid users than individuals who could not accept background noise (i.e., had high ANL i.e., 13dB or more) were likely to become unsuccessful hearing aid users.

Need for the study

Although there has been much information regarding the potential benefits of directional microphones for both speech intelligibility and listening comfort, there is little published data to support these claims. Freyaldenhoven, Nabelek, Burchfield, & Thelin, (2005) reported that hearing aids with directional microphones allowed listeners to accept more background noise than when listening through hearing aids with omnidirectional microphones. However further investigations on these findings are required.

FM technology improves speech perception in noise by 10 to 20 dB compared to the unaided condition (Crandell & Smaldino, 2001). Further there is a need to validate the benefit provided by the FM system. Despite the documented enhancement in speech perception with directional microphones and FM technologies, till date, only one investigation has been attempted to compare these technologies. Hence it would be of interest to compare these technologies which would help in selecting the appropriate digital technology based on benefits provided by them.

Traditionally, speech recognition ability is measured in speech spectrum noise available in the clinical audiometer. However, environmental noise such as cafeteria noise and speech babble are the common background interfering noise which many people encounter in real life environment. Hence, it is uncertain whether the speech recognition ability measured in speech-spectrum shaped noise, would predict one's speech understanding in real life situations. So there is a need to measure the speech recognition ability of an individual in environmental noises such as cafeteria noise and speech babble. In addition, the benefits provided by the directional microphone and FM system in the environmental noise needs to be investigated.

Speech scores in noise are poor predictors of hearing aid outcome such as hearing aid satisfaction and use (Bentler, Niebuhr, Getta, & Anderson, 1993). However, a differents procedure called as Acceptable noise level measures the hearing aid outcome (Nabelek, Tucker, & Letowski, 1991). There is little published literature on the effect of directional microphone on ANL. Till date, no investigation has been attempted to investigate the effect of FM system on ANL. Hence it would be of interest to study the effect of directional microphone and FM system on ANL and compare the outcomes of these technologies based on ANL procedure.

There were equivocal findings in the literature on the effects of different noises on ANL. Freyaldenhoven & Smiley (2006) demonstrated that ANLs are dependent on type of background noise and indicated that ANLs obtained using different competing stimuli should not be compared directly. On the other hand, Nabelek, Freyaldenhoven, Tampas, Burchfield, & Muenchen, (2006). reported that ANL is independent of different noises. Thus, a need for a detailed evaluation of the effect of various types of noise (Speech babble, & Cafeteria noise) on ANL would be of interest which is common in daily listening situations.

Hearing aid fitting should include a complete description of the negative effects of noise on speech perception. This includes not only speech recognition performance (SNR) but also a measure of acceptance of noise (ANL) which measures the hearing aid outcome objectively. Nabelek, Tampas, and Burchfield (2004) reported that ANL and Specch perception in noise scores were not significantly correlated. On the other hand, Nabelek, Burchfield, & Webster, (2003) reported that individuals with hearing impairment who exhibit low acceptance of background noise when listening to speech (i.e., persons with large ANLs) demonstrate dissatisfaction with hearing aids consistently and tend to use them occasionally or reject them altogether. This dissatisfaction with hearing aids is similar to difficulty exhibited by individuals with abnormally high SNR loss, as described by Killion, (1997). Hence the relation between speech recognition performance and acceptable noise levels needs to be explored. Further it would be of interest to see if there is similar effect of directional microphone and FM system on ANL and SNR, as there is a dearth of literature in comparing the ANL and SNR using directional microphone and FM system.

Objectives of the study

The present study has the following aims:

1. To evaluate the effect of directional microphone and frequency modulation system (FM) on SNR using two different competing stimuli (Cafeteria noise & Speech babble).
2. To evaluate the effect of directional microphone and frequency modulation system (FM) on ANL using two different competing stimuli.
3. To compare ANL and SNR using directional microphone and frequency modulation system using two different competing stimuli.

CHAPTER 2

Review of literature

Hearing loss and other perceptual problems related to aging causes communicative difficulties (Dubno, Dirks, & Morgan, 1984; Gelfand, Piper, & Silman, 1986; Gordon-Salant, 1986; Nabelek, 1988). Due to these communication difficulties, reduced psychosocial function has often been reported. In particular, there is decline in social interaction, intimate relations, self concept, psychological status, and cognition (Harless & McConnell, 1982; Weinstein & Ventry, 1982; Sherer & Frisnia, 1998). Many older people with hearing loss can obtain improvement in communication with hearing aids (Mulrow, C., Tuley, M., & Aguilar, 1992). Unfortunately, only a small percentage of elderly people buy and use hearing aids. Among the major reasons identified in various surveys for dissatisfaction with hearing aids were problems with background noise (Surr, Schuchman, & Montgomery, 1978) and unpleasantness of loud sounds (Franks & Beckmann, 1985; Kapteyn, 1977).

Background noise is one of the major problems for hearing impaired persons compared to individuals with normal hearing because individuals with hearing impairment require a more favorable signal to noise ratio (SNR) to achieve acceptable speech understanding in a given amount of background noise. Furthermore, one of the most common performance related complaints with hearing aids is annoyance from amplified background noise (Kirkwood, 2005). Conventional amplification technologies may provide little or no improvement to the signal to noise ratio (SNR) in adverse listening environments (Crandell & Smaldino, 2001). A hearing aid amplifies the background noise together with the speech, so that the signal to noise ratio (SNR) is not increased. This results in poorer speech intelligibility, due to increased upward spread of masking at high listening levels, distortion caused by the hearing aid, and limited bandwidth of the hearing aid (Plomp, 1978). Currently, hearing aids are implemented with various clinical strategies and circuitry schemes imposed in an attempt to improve speech understanding both in quiet and noisy environments. These include: binaural amplification, reduction of low frequency amplification, compression amplification, directional microphones, digital noise reduction and an option for coupling FM system. The technologies which are found to remarkably improve the speech understanding in noise are FM system and Directional microphone.

Directional microphones.

Directional microphones are designed to take the advantage of spatial differences between speech and noise. They are more sensitive to sound coming from the front than the sounds coming from the back and the sides. In a single microphone design, the directional microphone has an anterior port and posterior microphone port. The acoustic signal entering the posterior port is acoustically delayed and subtracted from the signal entering the anterior port at the diaphragm of the microphone. Thus hearing aids with directional microphone improves speech perception significantly in presence of noise (Kuk, Kollofski, Brown, Melum, & Rosenthal, 1999). Directional microphone gives a speech reception threshold (SRT) improvement of approximately 3 dB in difficult listening conditions (Hawkins & Yacullo, 1984).

Directional microphones have the maximum sensitivity at 0^0 azimuth (Olsen & Hagerman, 2002). The maximum sensitivity of a hearing aid with an omnidirectional microphone is found to be on the same side as the position of the hearing aid on the head (Fortune, 1997). Speech recognition in noise is improved significantly with directional microphones in comparison to omnidirectional microphones (Nielson, 1973). This difference between microphone modes is reffered to as the directional benefit.

The magnitude of directional benefit can be predicted with reasonable accuracy from the positional relationship of the noise sources and nulls in a particular hearing aid's directional pattern (Ricketts, 2000). Directional patterns acquired from a single plane are graphically represented in a polar coordinate system as represented via a polar plot. Polar plots graphically represent the pattern of attenuation in response to sound inputs from various angles on a single plane. Polar nulls, described as an angle of directional pattern for which there is significantly greater attenuation than for most other angles, are commonly present. Greater directional benefit will be measured if competing noise sources are placed at angles corresponding to nulls in the directional pattern than when they are placed at angles of greater sensitivity. As a result, in environments with a single noise source, there is a potential to improve speech recognition by matching the null in a hearing aid's pattern of attenuation (directional pattern) to the position of the noise source. Directional microphones exhibit four distinct types of polar patterns: bipolar (or bidirectional, dipole), hypercardioid, supercardioid, and cardioid. The least sensitive microphone locations (nulls) of these polar patterns are at different azimuths relative to the most sensitive location (0ºazimuth).

FM system

With an FM system, the speech signal is picked up via a wireless microphone located near the speaker's mouth. The close proximity of the FM microphone minimizes the effects of reverberation, distance and noise on speech percepion (Crandell, Smaldino, & Flexer, 1995). The FM system converts the acoustic signal to an electric waveform and transmits the signal via FM radiowaves from the transmitter to the receiver. Both the transmitter and the receiver are tuned to the same transmitting and receiving frequency (usually 216-217MHz). At the receiver, the electrical signal is amplified and converted back to an acoustical waveform and conveyed to the listener. Personal FM systems can improve speech perception in presence of noise for individuals with hearing impairment by as much as 20 dB compared to no environmental Microphone conditions (Crandell & Smaldino, 2000).

The need to understand the outcomes of hearing aid and signal enhancing technologies has resulted in the proliferation of satisfaction and benefit self assessment scales. They include the following; the Hearing Handicap Inventory for the Elderly (Maniloff & Weinstein, 1989), the profile of Hearing Aid Performance (Cox & Gilmore, 1990), the Hearing Aid Performance Inventory (Walden, Demorest, & Helper, 1984), the Client Oriented Scale of Improvement (Dillon, James, & Ginis, 1997), and the Glasgow hearing Aid Benefit Profile (Gatehouse, 1999). These scales provide useful information about subjective satisfaction and benefit; however, it has been shown that this information is not related to successful use of hearing aid and different digital technology. These scales cannot be administered prior to the hearing aid fitting or even during hearing aid evaluation. Traditionally to evaluate the performance of these noise reduction strategies during hearing aid fitting, two measures can be used.

1. Speech recognition in noise (SNR)
2. Acceptable noise levels (ANLs)

Speech recognition in noise

It is well known that the ability to understand speech in noise is poorly predicted by pure tone thresholds or the ability to understand speech in quiet (Plomp & Mimpen 1979, Smoorenburg, 1992). Carhart and Tillman (1970) suggested that in addition to measures of pure-tone sensitivity and word recognition in quiet, communication handicap should be quantified in terms of word recognition in a background of competing speech.

Several tests can be used to assess speech communication in noise such as SPIN (Kalikow, Stevens, & Elliot, 1977) and Synthetic speech identification (Speaks & Jerger, 1965). These tests have been designed to measure percent intelligibility at fixed speech and/or noise levels. This test produce reliable estimate of performance, but percent intelligibility measures are inherently limited by floor and ceiling effects. An alternative to percent intelligibility measures is the speech reception threshold (SRT) which is not subjected to floor and ceiling effects. The SRT is defined as the presentation level necessary for a listener to recognize the speech materials correctly a specified percent of the time, usually 50%. The technique for measuring SRT's is derived from an adaptive measure where the presentation level of the stimulus is increased or decreased by a fixed amount, depending upon the listener’s ability to repeat the speech material correctly. Hence a simple up down adaptive procedure with fixed step size is used to measure the Speech Reception Threshold in noise, SRT_n (defined as the signal to noise ratio corresponding to 50% intelligibility) is developed. The difference in SNRs-50 between people with normal hearing and hearing loss is called SNR-loss (Killion, 1997b).The SNR of conversation in public places is typically around +5 dB to +10 dB (Pearson et al, 1976). However, according to studies by Tillman, Carhart, Olsen (1970) and Gengel (1971), SNRs of +10 dB to +15 dB are necessary for the hearing aid wearer. Every 4-5 dB improvement of the signal to noise ratio may rise the speech intelligibility by about 50 % (Groen, 1969; Plomp, 1978).

Speech recognition in noise using directional microphones

Rickets, Henry and Gnewikow (2003) examined the hearing aid benefit using speech recognition and self assessment methods in 15 adults with mild to moderate sensorineural hearing loss using omnidirectional and directional hearing aid. Measures included the Profile of Hearing Aid benefit (PHAB), Connected Sentence Test (CST), and the Hearing in Noise Test (HINT). These measures were carried out in three conditions; such as omnidirectional (O), directional with low frequency gain compensation (D), and user selectable directional/omnidirectional (DO). Results indicated significantly more hearing aid benefit in directional modes than in omnidirectional mode. PHAB results indicated more benefit on the background noise subscale (BN) in the DO condition than in the O condition; however, this directional advantage was not present for the D condition.

Hawkins and Yacullo (1984) determined the SNR required for recognition of Nu 6 in presence of multitalker babble in 12 individuals with normal hearing and 11 individuals with hearing impairment. The SNR was recorded in monoaural and binaural omnidirectional and directional hearing aids in rooms with reverberation times of (Rt) 0.3, 0.6 and 1.2 seconds. Results indicated an average advantage for directional microphone of 6.3, 4.7, and 0.6 dB for RT of 0.3, 0.6 and 1.2 respectively for monoaural listening condition. For the binaural listening condition, results revealed average advantage for the directional microphone of 3.6, 5.5, and 1.5 dB for RT of 0.3, 0.6, and 1.2 seconds respectively. The results revealed a directional advantage when RT was less than 1.2 seconds and the directional advantage was equal to 0.3 and 0.6 second for monoaural and binaural listening. The range of directional advantage for the hearing impaired subjects ranged from 1.6 to 7.3 dB.

Madison, David and Hawkins (1983) determined the SNR advantage of directional microphones in reverberant and non-reverberant condition in a group of 12 normal hearing young adults. Different lists of NU 6 and noise were presented monoaurally and noise was held constant at 65dB SPL, and the signal level was varied to determine the signal to noise ratio required for 50% correct response. The results revealed that the directional microphones offered an SNR advantage of 10dB in non reverberant environment and 3.4 dB in reverberant environment compared to omnidirectional microphones.

Speech recognition in noise using Frequency modulation system:

Fabry (1994) evaluated a frequency modulated auditory trainer which uses a remote Frequency modulated (FM) microphone and/or an ear level environmental microphone (EM) in 5 hearing impaired subjects in the age range of 33-65 years with moderate to severe sensorineural hearing loss participated in the study. The frequency response of the EM was configured either to match that of FM response, or to provide a high pass filter characteristic similar to a noise reduction hearing aid. SRT in noise was measured using the HINT (Nilsson, Sullivan, & Soli, 1991) under various conditions: FM only, EM only for the high pass system (EM-HP), EM only with standard frequency response (EM-S), FM/EM combined mode for the high pass system (FM/EM-HP), FM/EM combined mode for the standard set up (FM/EM-S). Results indicated that remote FM microphone improved S/N ratio by nearly 10dB over the standard EM only condition. For combined FM/EM conditions, the signal to noise ratio advantage was reduced by approximately 3dB and 7dB for the EM-HP and EM-S conditions, respectively.

Boothroyd (2004) determined the speech perception ability using the FM system in quiet and noisy condition in a group of 12 participants in the age range of 52 to 85 with mild to severe hearing loss. Phoneme recognition was measured under three conditions: aided, quiet, aided in spectrally matched noise and FM assisted in noise. Speech was presented at a distance of 3 feet at 0^{0} azimuth. Spectrally matched noise was presented from two loudspeakers at a distance of 3 feet and +60 and -60 azimuth. Results revealed that FM assisted phoneme recognition in noise equaled aided phoneme recognition in quiet.

Comparison of speech recognition scores in noise across directional microphone and frequency modulation system.

Lewis, Crandell, Valente and Horn (2004) compared speech perception performance across directional microphones and frequency modulation system in 22 subjects with mild to severe sensorineural hearing loss in the age range of 24 to 84 years. Speech perception was assessed using the HINT sentences (Nilsson, Soli, & Sullivan, 1994). HINT Sentences were presented via compact disc recording that uses a male speaker. Correlated (the same noise source was presented from 45,^{0} 135,^{0} 225, ^{0} 315^{0} azimuth) speech spectrum noise was presented as the competing stimulus. All loudspeakers were located one meter from the participants. Reception threshold for sentences in noise were determined for subjects under five different listening conditions namely, binaural BTE hearing aids alone in omnidirectional mode, binaural BTE hearing aids alone in directional mode, binaural but fit with one BTE hearing aid utilized with one Phonak microlink FM receiver in the FM only mode and one BTE hearing aid in the omnidirectional microphone mode in the opposite ear and binaural BTE hearing aids utilized with two phonak Microlink FM receivers in the FM only mode. Results indicated that speech perception was significantly better with the FM system over that of any of the hearing aid conditions, even with the use of directional microphone. The mean difference between the monoaural FM and the hearing aids in the omnidirectional microphone mode was 20.3 dB and 16.9 dB for directional microphone comparison. For the binaural FM setting, the mean difference between FM and the hearing aids in the omnidirectional microphone mode was 22.7 dB and 19.3 dB for the directional microphone condition. Directional microphone performance was 2.2 dB better than omnidirectional mode.

To evaluate the performance of these technologies assessment needs to be done in an environment which mimics the real world situations. Hence speech recognition in various noises can be included as an evaluation measure.

Speech recognition in different noises.

Speech understanding is influenced by the type of background competing signal. Noise related differences in speech understanding is due to the difference in the frequency spectra of noises (Kaplan and Pickett, 1982). Noise with speech like components interferes more with understanding of the primary message than noise which is not similar to speech (Speaks and Karmen,1968).

Arslan (1991) examined speech discrimination scores using sentences as primary test material in four different noise conditions: speech noise, cocktail party noise, traffic noise and continuous discourse. Speech recognition ability of young adults with normal hearing and mild sensorineural hearing loss were compared with that of older adults with normal hearing and mild sensorineural hearing. Results revealed better performance in speech noise and cocktail party noise were generally better across all the subjects compared to that of traffic noise and continuous discourse at unfavorable SNRs (0 dB or below). The authors attributed the differences to lower energy at high frequencies and more amplitude fluctuation in traffic noise and continuous discourse, than the speech noise and cocktail party noise. These factors favor speech understanding in the former two noises because high frequency information aids speech understanding. Speech discrimination scores of the two normal hearing groups were basically the same, while the performance was worse in the old hearing impaired group. However, the sentence test material, and the definition of the speech noise and the continuous discourse background used in this study were not documented, which makes it difficult to compare these results with other study.

Kaplan and Pickett (1982) examined the speech discrimination scores for modified Rhyme test in 26 elderly individuals with bilaterally mild to moderate sensorineural hearing losses in the age range of 61-91 years. Speech discrimination was measured using modified Rhyme test of Kreul et al., (1968) using speech babble and cafeteria noise under the following aided conditions

1. Monotic
2. Low frequency attenuated: the frequency band below 1000Hz was attenuated by 5, 10, 15 dB relative to the high frequency band above 1000Hz
3. Dichotic: The frequency band above 1000Hz was presented to the preferred ear and the low frequency band to the other ear
4. Diotic: The same signal was presented simultaneously to both ears.

Results revealed that cafeteria noise needed 50 to 70% higher than speech babble to maintain monotic discrimination. With the cafeteria noise, the low frequency attenuated conditions were either poorer or essentially the same as the monotic condition. In contrast, in the speech babble, low frequency attenuation resulted in improved discrimination. The monotic-dichotic and monotic-diotic differences in the two types of noise were more similar, both indicating dichotic and diotic superiority.

Speech perception scores obtained in the background noise do not predict success with hearing aid use (Bentler, Niebuhr, Getta, & Anderson, 1993; Humes, Halling, & Coughlin, 1996). Nabelek, Tucker, & Letowski, (1991) proposed a test which assesses an individual's acceptance of background noise, which is different from assessing speech perception in the presence of background noise. These investigators reasoned that for successful hearing aid use, speech understanding in noise may not be as important as the individual's allowable signal to noise ratio which is now called the acceptable noise level (ANL).

Acceptable noise levels

Nabelek, Tucker, & Letowski, (1991) hypothesized that the willingness to listen to speech in background noise may be more indicative of hearing aid use than speech perception scores in background noise. This hypothesis led to the development of a procedure to quantify the amount of background noise that listeners are willing to accept when listening to speech called the "acceptable noise level"(ANL). The ANL was defined as the difference between the most comfortable listening level (MCL) for running speech and the maximum background noise level (BNL) that a listener is willing to accept.

Nabelek, Freyaldenhoven, Tampas, Burchfield, & Muenchen, (2006) conducted as study to determine if ANL can be used to predict hearing aid use. Adults with hearing impairment using binaural hearing aids, from a minimum of three years were included in the study. They were categorized themselves as full time users, part time users, or nonusers using a questionnaire. ANL was determined using running speech recorded by a male talker as the primary stimulus (Arizona Travelogue, Cosmos, Inc.) and 12 talker speech babble as the competing background noise. Both aided and unaided ANLs were measured. Results indicated that ANLs were related to hearing aid use and full time hearing aid users accepted more background noise compared to part time users or nonusers. Results also indicated that unaided ANLs could predict a listener's success of hearing aids with 85% accuracy.

Factors related to ANL

1. Language:

Von Hapsburg, and Bahng (2006) hypothesized that ANL might be language-independent measure. The purpose of the study was to explore whether ANLs obtained from Korean listeners in both English and Korean were comparable to ANLs obtained from monolingual English listeners. 30 listeners with normal hearing sensitivity were divided into three groups (two groups of Korean English bilingual listeners and one group of monolingual English listeners). The ANL measure was obtained in English and Korean language using procedures established by Nabelek, Tampas, and Burchfield (2004). The results revealed that ANLs obtained in English (ANL-E) did not differ significantly for the bilingual and monolingual listeners. In addition, a cross language comparison, within bilinguals, revealed that ANLs obtained using Korean (ANL-K) speech stimuli were not significantly different from ANL-E. The results suggested that the ANL measure is a language independent measure and neither second language proficiency differences nor language of test seemed to affect ANLs.

2. Monaural and Binaural mode of presentation:

Freyaldenhoven, Plyler, Thelin, and Burchfield (2006) investigated the effects of monaural and binaural amplification on acceptance of noise in 39 adults (mean age= 69 years) in the age range from 30 to 89 years. The criteria for inclusion were binaural hearing aid users who had worn hearing aids (both analog & digital) for at least three months. The participants were both analog and digital hearing aid users. ANL was assessed for the monaural right, monaural left and binaural amplification conditions. A recorded male running speech served as the speech stimuli and was delivered from a loudspeaker located at 0^0 Azimuth. Multitalker speech babble served as the competing stimulus and was delivered by a loudspeaker located at 180^0 Azimuth. Two ANL trials were conducted for each amplification condition and the results were averaged to obtain a mean ANL for each participant. When testing monaurally, only one hearing aid was used, and the non-test ear was plugged with a foam earplug. The results demonstrated that the speech understanding in noise improved with binaural amplification; however acceptance of background noise was not dependent on monaural or binaural amplification for most listeners. In addition it was noticed that, the monaural amplification resulted in greater acceptance of noise for some listeners, which indicated that binaural amplification might reduce some individual’s willingness to wear hearing aids.

3. Gender:

Rogers, Harkrider, Burchfield & Nabelek (2003) investigated the influence of gender on the acceptance of background noise. Fifty adults (25 male, 25 female) with normal hearing sensitivity in the age range of 19-25 years participated in the study. An audiotech digital recording of running male discourse was used as the primary stimulus. Speech babble (SPIN test; Kalikow, Stevens, & Elliot, 1977) was used as the competing stimulus. Comfortable listening levels for speech (MCL) and accepted levels of speech-babble background noise (BNL) were obtained binaurally, via the sound field. Results indicated that males had higher comfortable listening levels and accepted higher levels of background noise than females. However ANL values were not different between males and females.

4. Stimulant medication:

Freyaldenhoven, Nabelek, Burchfield, & Thelin, (2005). (2005) examined the effect of stimulant medication on acceptance of background noise in individuals with attention deficit hyperactive disorder (ADHD/ADD). They also investigated the effect of speech presentation level on acceptance of noise in persons with ADHD. Fifteen female college aged students with a reported diagnosis of ADHD and with a normal hearing sensitivity participated in the study. They were on a regular use of stimulant medication for the treatment of ADHD. ANL was obtained using three different speech presentation levels (29dBHL, MCL, and 76dBHL) and with and without medication. Results showed that medication significantly increased the acceptance of background noise for individuals with ADHD.

5. Physiological activity of central auditory system:

Tampas and Harkrider (2006) studied the auditory evoked potentials in 21 young females with normal hearing to determine whether differences in judgements of the background noise are related to individual differences in physiological activity measured from the peripheral and central auditory systems. ANL was measured by using the recording of a running speech with a male voice as the primary stimulus against an eight person multitalker babble as competing stimulus. ABRs, MLRs, and LLRs which represent physiologic activity from the auditory nerve to the cortical regions of the auditory system were measured from individuals with low and high ANLs. Results indicated that females with low ANLs had longer wave III and V latencies and smaller Na-Pa, P1-N1, and N1-P2 amplitudes than females with high ANLs. In addition, Results showed reduced responsiveness of the central afferent auditory nervous system and/or increased strength of cortical inhibition which contribute to greater acceptance of background noise.

Noise reduction technologies and ANLs.

Till to date only two studies have documented the effect of noise reduction technology using directional microphone and Digital noise reduction on acceptable noise levels. No study has been done to find the effect of FM system on ANL.

Directional microphones and ANLs:

Freyaldenhoven, Nabelek, Burchfield, and Thelin (2005) evaluated the efficacy of ANL procedures for assessing directional benefit in hearing aids in a clinical population. ANL procedure were compared with the masked speech reception threshold (SRT) and front-to-back (FBR) measures (Ricketts & Mueller, 1999). ANL,SNR and FBRs were compared for two microphone modes, omnidirectional and directional using two different stimuli (i.e., speech babble and speech spectrum). Twenty-seven males and thirteen females between the ages of 30 and 89 years with a pure tone average of 47.3 dBHL participated in the study. For the ANL and the FBR, a recording of male running speech was used as speech stimulus. The speech stimulus for masked SRT was a male recording of a list of spondee words. All the speech stimuli were delivered by the loudspeaker located at 0^0 Azimuth. Revised speech perception in noise multitalker speech babble (Bilger, Neutzel, Rabinowitz & Rzeczkowski, 1984) was used as the competing background noise for all the procedures and delivered by loudspeaker located at 180^0 Azimuth. Results of the study revealed that the mean directional benefits assessed with the ANL, masked SRT and FBR procedures are not significantly different suggesting that ANL is comparable to assess directional benefit. Further, results also revealed that ANL obtained with speech spectrum and speech babble were significantly different.

Digital noise reduction and ANLs

Mueller, Weber, and Hornsby (2006) investigated the effects of Digital Noise Reduction on the ANL. 22 adults with mild to moderate sensorineural hearing loss were fitted with 16-channel wide dynamic range compression hearing aids containing DNR processing. Hearing in Noise Test was used to assess both speech intelligibility and acceptable noise level (ANL) with DNR turned on and DNR turned off condition. The results indicated that DNR provides a significant improvement of 4.2 dB in the ANL test. The mean MCL remained same for the DNR turned off versus the DNR turned on conditions. There was no significant mean improvement for the HINT for the DNR on condition, and on an individual data analysis, the HINT score did not significantly correlate with aided ANL (either DNR turned on DNR turned off).

Comparison of acceptable noise levels using different noises.

Although competing human speech is the most common interference in conversation, environmental noise such as traffic or industrial noise are also common background interfering noise people encounter (Plomp, 1978). There is no consensus as to what type of noise to use in the audiological evaluation and selection of hearing aids. Dirks and Wilson (1969) used broad band white noise with Modified Rhyme test. Cooper and Cutts (1971) used cafeteria noise. Other types of competition reported in the literature include cocktail party noise (Groen, 1969), competing sentences (Carhart, 1969), and continuous discourse (Hayes & Jerger, 1979).The characteristics of the background noise differ from place to place in real life situations and it is uncertain whether the performance measured in speech-spectrum shaped noise, which is used in many of the speech audiometry, would predict one’s performance in real life situations. Hence hearing aid performance using different noises needs to be measured.

Freyaldenhoven, Smiley, Muenchen, and Konrad (2006) assessed the reliability of the acceptable noise level (ANL) measure using speech spectrum and speech babble noise as the competing stimuli. They also investigated the relationship between ANL and personal preference for the background sound in 30 adults in the age range of 18-25 years with normal hearing sensitivity. Participants were evaluated during three test sessions approximately one week apart. Speech and noise stimuli were delivered via a cassette tape deck and a CD player respectively. Running speech recorded by a female talker was used as a primary speech stimulus. Competing stimuli were Twelve person multitalker speech babble noise and speech spectrum noise. ANL was determined for each background noise. In addition, participants were given a questionnaire to determine the preference for background sound. Results indicated that mean ANLs were affected by type of background noise. Mean ANLs obtained using speech babble noise were approximately 2dB lower than mean ANLs obtained using speech spectrum noise. These results indicated that the ANLs obtained using different competing stimuli should not be compared directly. The results also showed that the participant’s rating of preference for background sound was consistent over time but not related to their ANL.

Comparison of speech recognition in noise with acceptable noise levels

It has traditionally been assumed that hearing aid users with improved speech perception in the presence of background noise will be more satisfied with their hearing aids than the users with relatively poor speech perception for the same listening condition. However hearing aid rejection appears to be related to lack of background noise acceptance while listening to speech, and unrelated to either speech perception in general or speech perception in background noise (Nabelek, Freyaldenhoven, Tampas, Burchfield, & Muenchen, (2006).

Rowland, Dirks, Dubno, and Bell (1985) compared speech recognition scores in noise with assessment of communicative skills for both normal and hearing impaired listeners. For hearing-impaired listeners, they observed only weak correlations between the results of speech recognition tests and the subjective evaluation of communicative difficulty in either quiet or noisy environments.

Nabelek, Tampas and Burchfield (2004) compared the speech perception in background noise with acceptance of background noise. 41 full time users and 9 part time users participated in the study. Both ANL and SPIN scores were obtained in both aided and unaided conditions. The results revealed that for both full time and partial hearing aid users, ANL and SPIN scores were unrelated, even though both the ANLs and SPIN scores were collected in similar levels of noise. Although the SPIN scores improves with amplification, the ANLs are unaffected by amplification suggesting that ANL is inherent to an individual.

Harkrider and Smith (2005) compared monotic phoneme recognition in noise (PRN) and ANL with dichotic ANL measures (speech in one ear, noise in the opposite ear). They also studied whether individual differences in the level of efferent activity in the lower brainstem are contributing to the wide range of ANL and PRN scores. 31 individuals with normal hearing sensitivity in the age range of 19 to 40 years participated in the study. The dichotic ANL procedure involves the modification of traditional ANL procedure which involved the simultaneous presentation of the running speech and the competing noise (multitalker babble) to opposite ears. Speech perception in noise was assessed with a phoneme recognition which involved the presentation of 50 monosyllabic words embedded in the multitalker babble. Both Ipsilateral and contralateral acoustic reflex thresholds(ARTs) were obtained in response to broad band noise. In addition each participant's Medial Olivary Cochlear Bundle efferent activity was indirectly measured by quantifying the suppression of TEOAEs resulting from the introduction of a contralateral BBN. Results indicate that monotic ANL and PRN are unrelated suggesting that each provides unique information about a listener's speech in noise performance. Monotic and dichotic ANL are related, suggesting that nonperipheral factors beyond the level of superior olivary complex mediate ANL. The results revlaled that intersubject variability in ANL and PRN cannot be accounted by individual differences in the level of efferent activity in the MOCB or AR pathways. But this may be influenced by the ipsilateral pathway.

A review of the literature revealed that investigations have not documented a clear relationship between speech-in-noise performance and hearing aid success or rejection. In contrast, persons with hearing impairment exhibit low acceptance of background noise when listening to speech (persons with large ANLs) consistently demonstrated dissatisfaction with hearing aids and tend to use them occasionally or reject them altogether (Nabelek, Burchfield, & Webster, 2003). This dissatisfaction with hearing aids is similar to problems for individuals who exhibit abnormally high SNRs, as described by Killion (1997). Hence relation between SNR loss and accepting background noise while listening to speech needs to be explored.

CHAPTER 3

Method

The aim of the present study was to evaluate the benefit of directional microphone and frequency modulation system (FM) on acceptable noise level (ANL) and signal to noise ratio (SNR) using two different background competing stimuli (cafeteria noise & speech babble). The study also aimed at comparing ANL and SNR across different aided conditions (hearing aid with directional microphone turned off, hearing aid with directional microphone turned on and FM system) for two different competing background stimuli.

A. Participants

28 participants (21 male & 7 female) in the age range of 20-60 years with a mean age of 51 years satisfying the following criteria were included in the study.

- ✓ Post lingual hearing impairment
- ✓ Bilateral Moderate to moderately severe sensorineural hearing loss
- ✓ Speech identification scores (SIS) of ≥ 80 %
- ✓ Uncomfortable level (UCL) of ≥ 95 dB HL for speech
- ✓ Naïve hearing aid users
- ✓ Native speakers of Kannada language
- ✓ No indication of neurologic and cognitive deficit
- ✓ No indication of middle ear pathology

B. Test environment

All the tests were conducted in a sound treated double room situation. The ambient noise levels were within permissible limits as per ANSI S3.1 (1991).

C. Equipment

1. Audiometer & immittance meter

- ✓ A calibrated dual channel diagnostic audiometer (Madson orbiter 922) with TDH-39 headphone enclosed in MX 41/AR ear cushion, B-71 bone vibrator and two Martin (c115) freefield speakers were used for audiological evaluation and hearing aid testing respectively.
- ✓ A calibrated immittance meter (GSI-Tympstar) was used to rule out middle ear pathology.

2. Hearing aid

A non linear 4 channel digital behind the ear hearing aid with the following features was used in the present study. The fitting range of the hearing aid ranged from mild to severe degree of hearing loss with the frequency range of 125 Hz - 8 kHz. The hearing aid had an option for directional microphone and telecoil setting for coupling the FM system through the neck loop. Directional Microphone used in the present study has a hyper cardioid polar pattern which suppresses the noise coming from one direction (rear end) while retaining good sensitivity to sound arriving from the other direction (front end).

Personal computer and HIPRO

- ✓ A Pentium IV computer with NOAH-3 CONNEXX (sifit V 6.1) software and HIPRO, a hardware interface was used for connecting the hearing aid to the personal computer for the programming of the hearing aid.

3. FM device

- ✓ Multifrequency FM transmitter and neckloop was used in the present study. To connect the FM receiver to the hearing aid, an appropriate neck loop was used.

D. Material

1. Speech material

The speech material used for the purpose of determining the ANL included six different passages in Kannada which is given in the appendix No.1. The passages were spoken in conversation style by a male native speaker of kannada with a normal vocal effort and were digitally recorded in a acoustically sound treated room using audobe audition (version no. 2) with sampling frequency of 44.1 kHz in a 16 bit analog to digital converter. Scaling was done to ensure that the intensity of all the speech sounds were at the same level.

The speech material used for determining the SNR included phonetically balanced word list in kannada developed by Yathiraj and Vijayalakshmi (2005) which is given in the Appendix No. 2. The speech material were spoken in conversation style with normal vocal effort by a female native speaker of kannada and were digitally recorded in acoustically treated room using audobe audition (version no. 2) with sampling frequency of 44.1 kHz in a 16 bit analog to digital converter. Scaling was done to ensure that the intensity of all the speech sounds were at the same level.

The passages which were used for determining the ANL and the phonetically balanced word list which was used for determining the SNR were normalized. This was recorded and stored on to a personal computer (PC) and was routed through the auxiliary input of the double channel audiometer. The speech material were presented through one channel of the audiometer at 0^0 azimuth.

2. Background competing stimuli

Two types of background competing stimuli were used. Kannada speech babble noise developed by Manjula and Anitha (2005) was used as one of the competing stimulus in the study. Other competing stimulus was the Cafeteria noise which was recorded digitally at a restaurant. These two background competing stimuli were presented through the other channel of the audiometer at 180^0 azimuth.

The output levels of both the speech material and the background competing stimuli were calibrated at a distance of 1m from the loudspeaker and were checked periodically throughout the study.

Procedure

Audiological evaluation

- The pure tone thresholds were measured between 250 Hz to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction on a 2 channel diagnostic audiometer (OB922) using Hughson Westlake modified method. (Carhart & Jerger, 1959).
- Speech recognition scores were obtained using “The Common Speech Discrimination Test for Indians” developed by Maya Devi (1974)
- Speech identification scores were obtained by using “Phonetically Balanced Word List” developed by Vandana (1998).
- Tympanometry and acoustic reflexometry were carried out to rule out any middle ear pathology.

Hearing aid fitting and FM fitting

- After the audiological evaluation, the participants fulfilling the stated criteria were included for further study.
- The participants were seated comfortably on a chair and were fitted with the hearing aid on the test ear using an appropriate sized ear tip.
- The hearing aid was connected to the programming hard ware (Hi-Pro) through a suitable cable and then detected by the programming software.

- The hearing aid was programmed either for the right/left ear depending on SIS scores. The hearing threshold of the participant's test ear was fed into the programming software and the target gain curves were obtained using the NAL-NAL1 prescriptive formula.
- Acclimatization level was kept at one. The gain of the hearing aid was set to the default target gain and fine tuned according to the participant's preference by manipulating the low cut, high cut and the cross over frequency values.
- The hearing aid chosen for the study had 3 programs. In the first program, the directional microphone was deactivated. In the second program, the directional microphone was activated and in the third program, telecoil mode was activated for using it with the FM system. These three different programs were saved in the hearing aid for each of the participant. Other parameters of the hearing aid were kept at default settings.
- In addition to the hearing aid fitting, the participant was also fitted with the FM receiver by placing the neck loop. Synchronization of the FM transmitter and the receiver was done according to the protocols specified by the manufacturer. The FM transmitter was placed at a distance of 7.5 cm from the loudspeaker and at a height of 0.5 meters to simulate ideal user position.

The present study was conducted in 2 different phases for three different aided conditions (hearing aid with and without directional microphone and FM system) using two different background competing stimuli (cafeteria noise & speech babble).

Phase 1: Determining the Acceptable noise level (ANL)

Phase 2: Determining the Signal to noise ratio (SNR)

Phase I: Determining Acceptable noise level (ANL)

The conventional ANL procedure (Nabelek, Tucker, & Letowski, 1991) was involved in determining the ANL. Here the examiner adjusted the level of the passage to the most comfortable listening level (MCL) of the participant. Then, a background noise was introduced, and the examiner had to adjust the noise to a level at which the participant would be willing to accept or "put up with" without becoming tense or tired while following the words of the passage. This level was called as the "background noise level (BNL)". The ANL was calculated by subtracting the BNL from the MCL.

In order to obtain the MCL, an Independent Hearing Aid Fitting Forum's 7-point categorical scale (Mueller & Hall, 1998) was used. The scale consisted of 7 different response options. They were Uncomfortably loud (7), Loud, but OK (6), Comfortable, but slightly loud (5), Comfortable (4), Comfortable, but slightly soft (3), Soft (2), and , Very soft (1).

The participants were shown these different rating options at the outset of the experiment before they were given verbal instructions for the MCL. The options were also visible as a printed material to the participants throughout the test sessions.

Establishing MCL

The passages were initially presented through the loudspeaker at the level of the SRT, which was determined during the audiological assessment. The level of the speech in the passage was increased in steps of 10 dB until the listener indicated that it was “very loud.” It was then decreased by 10 dB until the participant indicated that it was “very soft.” At this point, the level of the passage was adjusted up and down in 5 dB increments until the participant’s MCL was found. The step was repeated twice, and the average level was taken as the MCL. This level was noted down as the MCL of the participant. After establishing the MCL, subject’s Background Noise Level (BNL) was determined.

Establishing BNL

The passages were presented at the subject’s MCL through the loudspeaker at 0^0 azimuth. Noise was presented along with the passage through the loud speaker located at 180 ^{0} azimuth. The loudness level of the noise was started at 0 dB HL and was increased in steps of 10 dB until the participant indicated that the noise was “too loud”. The level of the noise was then decreased by 10 dB until the participant indicated that the noise was soft enough that the speech was “very clear.” At this point, the level of the noise was adjusted up and down in 2 dB increments until the participant indicated that it had reached the highest level which could be accepted while following the words without becoming tense or tired. This level was considered as the participant’s BNL.

The ANL was calculated by subtracting the BNL from the MCL (ANL = MCL - BNL). The BNL procedure was repeated twice for every participant (within the same test session). The average of the two ANLs was taken as the final ANL.

In the first phase, data was collected in the following different aided conditions.

a) Determining the aided ANL with directional microphone turned off using two different background competing stimuli.
b) Determining the aided ANL with directional microphone turned on using two different background competing stimuli
c) Determining the aided ANL with FM system using two different background competing stimuli.

a. **Determining the aided ANL with directional microphone turned off using two different background competing stimuli**.

The hearing aid was set at 1st program. The participant was made to listen to a passage. Different passages were used to avoid any practice effect. In the aided condition, initially MCL was obtained and then BNL for two different background competing stimuli were determined following the entire procedure of ANL described in phase I, and the ANL was established.

b. Determining the Aided ANL with directional microphone turned on using two different background competing stimuli.

To activate the directional microphone, the hearing aid was set at program 2. This program had all the settings such as compression ratio, compression knee point and antifeedback similar to the 1st program, except for the activation of the directional microphone. With this program setting, the entire procedure described in phase I was repeated to find the MCL. BNL was found for two different background competing stimuli. Then ANL was then calculated. To account for possible order effects, the presentation of the type of background noise was randomized while determining the BNL.

c. Determining the Aided ANL with FM system using two different background competing stimuli.

In order to activate the telecoil for using it with FM system, the hearing aid was set at 3rd program. The neckloop was placed on the participant. The FM transmitter was placed on a stand located at a distance of 7.5 cm from the loudspeaker at a height of 0.5 meters to simulate ideal user position. ANL was obtained for each of the participant with the FM system by following the procedure described in phase I. The order of measuring ANL for different aided conditions was counterbalanced to account for the order effect.

Phase II: Determining the Speech recognition threshold in noise to obtain Signal to Noise Ratio (SNR).

The modified version of the Tillman and Olsen, (1973) procedure was used in determining the SNR, in which SNR was defined as the level at which the participant was able to repeat two out of four words (50% criterion) in the presence of noise**.** Recorded PB word list was presented from a loudspeaker at 0^0 azimuth and background competing stimuli were presented at 180 ^{0} azimuth. The participants were asked to repeat the words presented.

An adaptive procedure was used to establish the SNR. The intensity of the speech was held constant at 40 dBHL. The noise level was initially presented 15 dB below the speech level and the PB words were presented. If the participant correctly identified two words out of four words, the noise was increased by 2dB steps until the participant missed three consecutive words out of four words presented. At this level, noise was reduced by 2 dB until the participant repeats two words out of four words. This noise level was subtracted from the speech level to find the SNR. Both cafeteria noise and speech babble noise were used as competing background stimuli for obtaining the SNR.

In phase II, the data was collected in the following different aided conditions using two background competing stimuli

1. Determining the aided SNR with directional microphone turned off using two different background competing stimuli.

2. Determining the aided SNR with Directional microphone turned on using two different background competing stimuli.
3. Determining the aided SNR with FM system using two different background competing stimuli.

1. Determining the aided SNR with directional microphone turned off using two different background competing stimuli.

   In order to determine the SNR for the first aided condition without directional microphone, the first program of the hearing aid was switched on. SNR was obtained by the procedure described in phase II.

2. Determining the aided SNR with directional microphone turned on using two different background competing stimuli.

   The hearing aid was set to program 2. With this program setting, SNR was found out by the procedure described in phase II. A different list of words was used to avoid any practice effect.

3. Determining the aided SNR with FM system.

   The hearing aid was set at program 3 to activate the telecoil mode. Placement of the FM transmitter and the neckloop was done in a manner described earlier in the ANL procedure. To account for possible order effects, the presentation of the type of background noise was randomized. SNR was found out by following the procedure described in phase II. The order of measuring SNR in different aided conditions was counterbalanced.

Analysis:

1) Descriptive statistics was done to calculate the mean and the standard deviation for MCL, BNL, ANL and SNR.
2) Analysis was done to compare MCL, BNL, and ANL across each different aided condition for different background competing stimuli.
3) Analysis was done to compare ANL and SNR between each aided condition for two background competing stimuli.

Chapter 4

Results and Discussion

The aim of the present study was to evaluate the benefit of directional microphone and FM system using two procedures, namely acceptable noise level (ANL) and signal to noise ratio (SNR). Study also aimed at comparing ANL and SNR using two different competing background stimuli in a digital hearing aid with and without directional microphone and FM system. The data was collected from 28 participants (21 male and 7 female) with bilateral moderate to moderately severe flat sensorineural hearing loss with a mean pure tone average of 51.8 dB HL. The participants were native speakers of kannada language and all were naïve hearing aid users. The data obtained was appropriately tabulated and statistically analyzed using SPSS (Version 16.0).

The variables present in the study were as follows.

- Independent variables were different aided conditions (Hearing aid with directional microphone off, hearing aid with directional microphone on and FM system) and two different competing stimuli (Cafeteria noise, speech babble).
- Dependent variables were Acceptable noise level and Signal to noise ratio.

The following statistics were used for the analysis of the data

1. Descriptive statistics to obtain the mean and the standard deviation for MCL, BNL, ANL and SNR.

2. One way repeated measure Analysis of Variance (ANOVA) for finding the main effect of various aided conditions (Hearing aid with directional microphone off, hearing aid with directional microphone on and FM system) for MCL.
3. Two way repeated measure ANOVA for finding the main effect of various aided conditions (Hearing aid with directional microphone off, hearing aid with directional microphone on and FM system) using two different competing stimuli for both ANL and SNR and interaction effect between these different aided conditions and different noises
4. Bonferroni multiple comparisons was done to see the pair wise differences across different aided conditions for ANL and SNR when repeated measure ANOVA showed a significant difference across the three aided conditions.
5. Paired sample t test was done to see the difference between two different competing noises (Cafeteria noise & Speech babble) for ANL and SNR in all the three aided condition.

The results of the present study are discussed under the following heading.

Phase I: Determining the Acceptable noise level (ANL)

A. Comparison of Most comfortable level (MCL) in all the three aided conditions
B. Comparison of Background noise level (BNL) in all the three aided conditions in two background competing stimuli (Cafeteria noise & Speech Babble)
C. Comparison of Acceptable noise level (ANL) in all the three aided conditions in two background competing stimuli.

Phase II: Determining the Signal to noise ratio (SNR).

A. Comparison of Signal to noise ratio (SNR) in all the three aided conditions in two background competing stimuli (Cafeteria noise & Speech Babble)

Phase III: Comparison of ANL and SNR in all the three aided conditions in presence of two background competing stimuli (Cafeteria noise & Speech Babble).

Phase I: Acceptable noise level (ANL) measurement.

The Acceptable noise level for each of the participant was obtained by subtracting the BNL from the MCL in all the three different aided conditions namely hearing aid with and without directional microphone and FM system using two background competing stimuli. The MCL, BNL and ANL values were obtained for all the three aided conditions and tabulated. The Mean and Standard deviation (SD) obtained for MCL, BNL and ANL are shown in the Table 1.

Table 1.

Mean and Standard Deviation (SD) of MCL, BNL and ANL (in dB HL) Obtained Using Cafeteria noise (CN) and Speech-Babble Noise (SB) in Hearing aid With Directional microphone off (HA), Hearing aid With Directional microphone on (DM) and FM system

Conditions	MCL/BNL/ ANL	CN/SB	Mean	SD
Hearing aid without directional microphone	*MCL*	-	44.82	4.99
	BNL	*CN*	36.00	6.33
		SB	34.67	6.56
	ANL	*CN*	8.82	3.42
		SB	10.14	3.95
Hearing aid with directional microphone	*MCL*	-	44.82	4.99
	BNL	*CN*	38.17	6.21
		SB	37.39	6.15
	ANL	*CN*	6.64	3.58
		SB	7.42	3.29
Frequency modulation system	*MCL*	-	41.78	6.69
	BNL	*CN*	41.42	7.48
		SB	40.78	7.16
	ANL	*CN*	0.35	4.77
		SB	1.00	4.72

Note. MCL was obtained without the presence of noise (CN / SB)

A. Comparison of Most comfortable level (MCL) in all the three aided conditions.

For each of the participant, the MCL was found out by using a an Independent Hearing Aid Fitting Forum's 7-point categorical scale (Mueller & Hall, 1998) for loudness in all the three aided conditions. The MCL obtained at three different aided conditions were compared. Table 1 shows the mean MCLs for all the three aided conditions. It is evident that the mean MCL was same for hearing aid with and without directional microphone. The mean MCL for FM condition was lower when compared to hearing aid with and without directional microphone by an average of 3 dB HL.

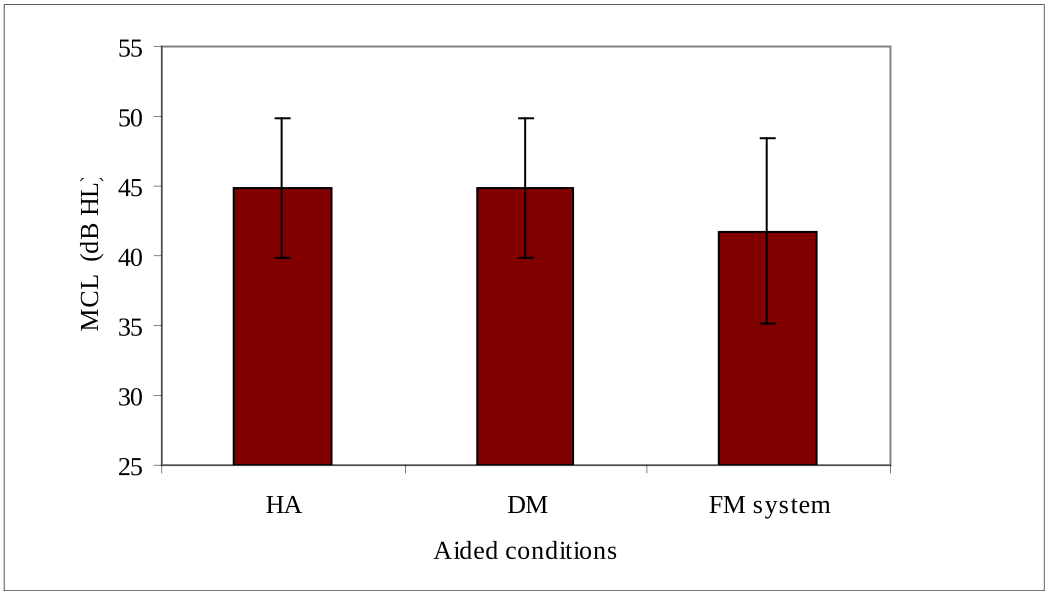

Figure1. Mean MCL and SD for hearing aid with and without directional microphone and FM system

To assess the difference in MCL across three different aided conditions, repeated measure ANOVA was done. Results showed a significant main effect of various aided conditions (Hearing aid with and without directional microphone & FM system) [F (2, 54) = 12.28, $p<0.001$]. To evaluate the significant differences in three different aided conditions, Bonferroni's multiple comparison was used. No significant difference (p >

0.001) was observed between hearing aid with and without directional microphone. However, unlike the expected findings, there was a significant difference between the FM system and the other two different aided conditions ($p < 0.001$) as shown in the Table 2.

Table 2.

Results of the Bonferroni Multiple comparison for MCL across Three Aided Conditions

MCL	DM	FM system
HA	Not Significant	Significant**
DM		Significant**

[** shows significance at 0.001 level]

In the present study the MCL was significantly lower for the FM system significantly compared to aided condition with and without directional microphone condition. The MCL did not show significant difference between hearing aid with and without directional microphone. The lower MCL for the FM system may be attributed to the increase in gain in the FM system. This increase in gain may be due to the increase in overall intensity level of the speech with FM microphone than microphone of the personal hearing aid (Hawkins, 1984; Cornelisse, Gagne, & Seewald, 1991; Lewis, 1991; Lewis, Feigin, Karasek, & Stelmachowicz, 1991). The possible reason for identical MCL for the hearing aid with and without directional microphone could be that the directional microphone may not have provided any benefit in the absence of noise. The other possible reason for obtaining the same MCL for hearing aid with and without directional microphone may be the overall hearing aid gain, which was maintained constant for both the aided conditions. Since this is the first study to report the effect of FM on MCL, findings of the present study needs to be investigated further.

From the findings of the present study it can be implied that MCL varies with the use of FM system. Further, Lower MCL in FM system could be an indication of increase in gain within the FM system.

B. Comparison of Background noise level (BNL) in all the three aided conditions in two background competing stimuli (Cafeteria noise & Speech Babble).

The Maximum background noise that the participant was willing to accept while following the words of the passages, were found out in three different aided conditions. Comparison was done across each aided condition and within each condition for two competing stimuli. The mean and the standard deviation given in Table 1 clearly reveal that, the BNL was maximum for the FM condition and minimum for Hearing aid without directional microphone. On comparison between hearing aid with and without directional microphone, the BNL was comparatively more for hearing aid with directional microphone than hearing aid without directional microphone. These findings were observed for both cafeteria and speech babble noise. Further it was observed that the BNL was higher for the cafeteria noise and lower for the speech babble for all the three aided conditions.

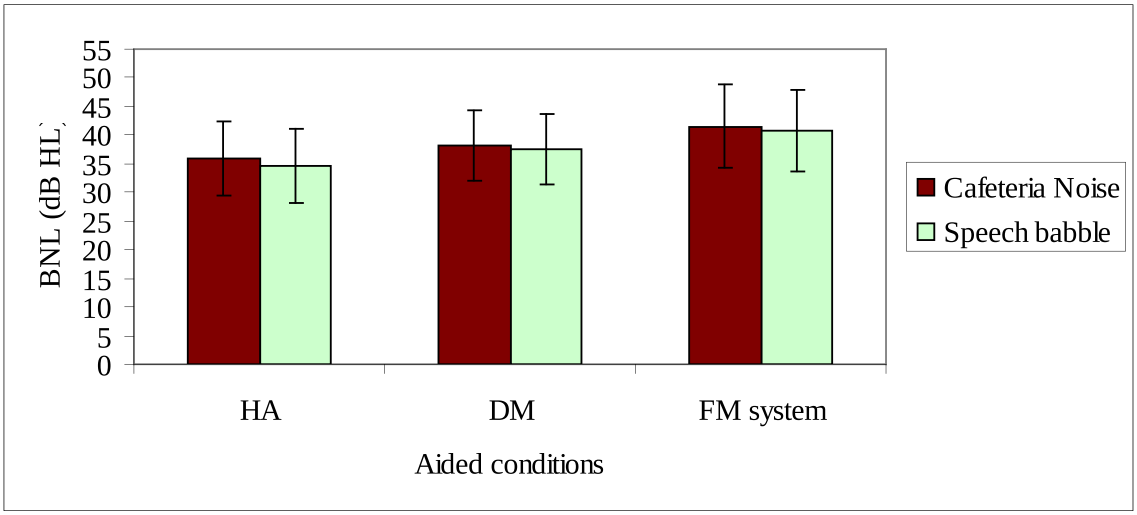

Figure 2. Mean BNL and SD for Hearing Aid with and without Directional Microphone and FM system obtained for Cafeteria Noise and Speech Babble.

To assess the difference in background noise levels across the three aided conditions in two noises (cafeteria, speech babble), two-way repeated measure ANOVA was done. Results showed a significant main effect [F (2, 54) = 23.90, $p<0.001$] of different aided conditions. Further results revealed that there was no significant interaction [F (2, 54) = 0.75, $p>0.001$] between different aided conditions and two noises.

To evaluate the significant difference between three different aided conditions, Bonferroni multiple comparison test was administered**.** Table 3 shows that there was a significant difference between hearing aid with and without directional microphone ($p < 0.001$), hearing aid with directional microphone and FM system ($p < 0.001$) and hearing aid without directional microphone and FM system ($p < 0.001$).

Table 3.

Bonferroni Multiple Comparison Test for BNL across the Three Aided Conditions

BNL	DM	FM system
HA	$P < 0.001$	$P < 0.001$
DM		$P < 0.001$

To find the difference in BNL between the two background competing noises among three aided conditions, paired t test was done. Results of the paired t test showed that there was a significant difference in BNL between two background competing stimuli in hearing aid with and without directional microphone. However, there was no significant difference between the two background competing stimuli in FM system ($p > 0.05$).

The BNL was highest for the FM system followed by the hearing aid with directional microphone and without directional microphone in the present study. With the FM system, the participant accepted a mean BNL of 41 dB HL for both cafeteria noise and speech babble noise respectively. It was also found that, with directional microphone the participant accepted a mean BNL of 38 dB HL and 37 dB HL in cafeteria noise and speech babble noise respectively. While using hearing aid without any noise reduction technology the participants accepted least noise. BNL obtained in the present study without directional microphone was 36 dB and 34 dB speech babble and cafeteria noise respectively.

The results of the present study is in consensus with the previous literature which has documented that technological advances such as directional microphone and FM system in hearing instrument design strive to diminish the effects of noise for hearing aid wearers (Kochkin, 1993). Directional microphone reduces the negative effects of background noise by providing greater amplification for signals arriving from the front of the listeners compared to signals arriving from the rear and/or sides of the listener (Kuk et al., 2000; Dillon, 2001). The close proximity of the FM microphone also minimizes the effects of reverberation and noise on speech perception (Crandell, Smaldino, & Flexer, 1995). Due to the reduction in noise, it may be inferred that the participants were able to accept more background noise with these technologies.

The results of the BNL for aided condition without any noise reduction technology are in agreement with the study done by Nabelek, Tampas and Burchfield (2004) which reported a BNL of 42.5 dB HL and 36.5 dB HL for full time users and part time users respectively in the aided condition without any noise reduction technology. The possible reason for the lower BNL obtained in the present study in the hearing aid condition without any noise reduction technology may be due to the amplification of both speech and noise. The amplification of noise would have resulted in reduced BNL that the participants were willing to accept.

The lower BNL obtained in the present study for speech babble in comparison to cafeteria noise might be attributed to the spectrum of the two noises. Multi talker babble creates a difficult listening environment because there is minimal amplitude modulation of the envelope, and it is aperiodic (Wilson, 2003). There was no difference between two different noises in FM system as expected.

From these findings it can be concluded that BNL increases with the use of noise reduction technology which results in acceptance of more noise. The technology which reduces the effect of noise greater has a higher BNL and vice versa. In addition BNL increases for the noise having a frequency spectra similar to that of speech.

C. Comparison of Acceptable noise level (ANL) in all the three aided conditions in two background competing stimuli.

ANL was determined for each of the participant by subtracting the BNL from the MCL in all the three aided conditions for two background competing stimuli. Comparison was done across each aided condition and within each aided condition for two competing stimuli. From the Table 1 and figure 3 it can be observed that the mean ANL was minimum for the FM condition and maximum for the Hearing aid without directional microphone. On comparison of hearing aid with and without directional microphone, ANL was comparatively lower for hearing aid with directional microphone than the hearing aid without directional microphone. Further it was observed that the ANL was lower for the cafeteria noise and higher for the speech babble noise for all the three aided conditions. In the hearing aid condition without directional microphone, the mean ANL obtained in the cafeteria noise were comparatively lower than speech babble noise by 1.3 dB HL. Similarly the mean ANL were 0.78 dB HL lower in cafeteria noise than speech babble in hearing aid with directional microphone condition.

.

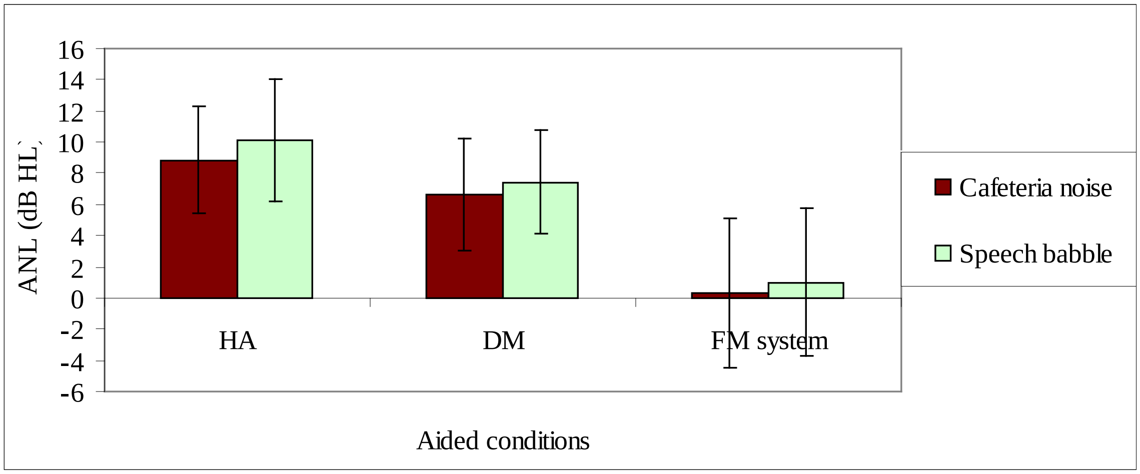

Figure 3. Mean ANL and standard deviation (S.D) for hearing aid with and without directional microphone and FM system obtained for cafeteria noise and speech babble.

To evaluate the difference in ANL across the three aided conditions in two noises two-way repeated measure ANOVA was done. Results showed a significant main effect of different aided conditions [F (2, 54) = 83.31, p<0.001]. Further results revealed that there was no significant interaction between various aided conditions and two types of noises [F (2, 54) = 0.75, p>0.001]. To evaluate the significant differences between three different aided conditions, Bonferroni's multiple comparison was used. Table 4 shows that there was a significant difference between aided condition with and without directional microphone (p < 0.001), hearing aid with directional microphone and FM system (p < 0.001), hearing aid without directional microphone and FM system (p < 0.001).

Table 4.

Bonferroni Multiple Comparison for ANL across Three Aided Conditions

ANL	DM	FM system
HA	$p < 0.001$	$p < 0.001$
DM		$p < 0.001$

To see if the differences in mean ANL scores across the two background competing noises were significantly different, paired t test was done for all the three aided conditions. The results revealed a significant difference between the ANL for two different noises in hearing aid with and without directional microphone ($p < 0.05$). However, unlike the expected findings, there was no significant difference in ANL between two noises in the FM system ($p > 0.05$).

There is a lack of literature on the effect of FM system on ANL. However, efficacy of FM system was assessed using various satisfaction scales (Chisolm, McArdle, Abrams, & Noe, 2004). It was observed that the listening abilities were much better with FM system than hearing aids alone. Since ANL and satisfaction scales tap the same aspect of successfulness of the FM users it can be further extrapolated that participants who showed satisfaction with FM system tend to get reduced ANL. Future studies need to be done to find the reduction in ANL to validate the current findings.

The possible reason for reduced ANL in the FM system in the current study might be due to the close proximity of the FM microphone which minimizes the effects of reverberation and noise on speech perception (Crandell, Smaldino, & Flexer, 1995). Since FM system has shown a benefit in speech recognition in noise, it seems logical to postulate that ANL may also be reduced from the use of FM technology. The other possible reason for reduced ANL in the FM system may be attributed to the reduced presentation level for MCL with FM system in the present study. The MCL may be lowered due to the increase in overall intensity level of the speech by 15–20 dB with FM microphone than microphone of the personal hearing aid (Cornelisse, Gagne, & Seewald, 1991; Hawkins, 1984; Lewis, 1991; Lewis, Feigin, Karasek, & Stelmachowicz, 1991). Earlier ANL research indicated that both individuals with normal hearing and listeners with impaired hearing accepted higher levels of background noise when the presentation level for MCL were reduced (Franklin et al., 2006; Tampas & Harkrider; 2006; Freyaldenhoven et al., 2007). In other terms ANL values were reduced when speech presentation levels for MCL were decreased. The result of the present study supports the findings of the earlier researches.

The findings of the present study with regard to the effect of directional microphone on ANL is in agreement with the study done by Freyaldenhoven etal (2005). They too had reported a mean directional benefit of 3.5 dB for ANL. They had observed a large range of directional benefit which was attributed to the various polar plots, circuitry, and features (compression & noise reduction) present in their hearing aids. The possible reason for the reduced ANL in the directional mode seen in the present study may be due to the low frequency roll off in the directional hearing aid and the consequent reduced output level in the low frequencies in the directional hearing aid. This low frequency roll off could have contributed to the reduction of annoying sounds which in turn would have lead to a greater listening comfort. Due to this listening comfort the participant would have accepted more background noise. Hence ANL might have been reduced in the directional microphone condition.

The results of the present study showed a larger ANL (5 dBHL-12 dBHL for cafeteria noise and 6 dBHL-14 dBHL for speech babble noise) with the aided condition without any noise reduction technology. These results supports the findings of Lytle (1994) who reported that ANL range from 1- 13 dB with a mean ANL of 7.9 dB in monoaural amplification condition without any noise reduction technology.

While establishing the ANL, the MCL was kept constant and therefore the magnitude of ANL was dependent on the BNL. The hearing aid amplifies both speech and noise. Due to the amplification of noise, the BNL that a listener was willing to accept has reduced which would result in larger ANL. Hence the larger ANL obtained in the hearing aid condition without any noise reduction technology may be attributed to the amplification of noise.

The results of the present study revealed a significant difference of about 1.3 dB between the two noises in hearing aid without directional microphone and 0.7 dB HL for hearing aid with directional microphone. The observed results are in accordance with the study done by Freyaldenhoven et al. (2006), who reported that, the mean ANLs obtained using speech babble noise were approximately 2dB lower than the mean ANLs obtained using speech spectrum noise.

Similarly, the results of the present study, rather goes alongside with the study done by Nabelek (2006). Study reported that although the mean ANLs obtained in Multitalker babble, speech spectrum noise, traffic noise, pneumatic drill noise, and "elevator" type music were statistically insignificant, the mean ANLs of these noises differed significantly from the music. This difference in ANL was attributed to the differences in the long-term spectra of the noises, which revealed that the spectrum of the music differed from other spectra by the amount of energy above 2 kHz. The differences were also attributed to the greater short-term variability of the music than other noises.

It is unlikely to attribute the short term variability and differences in frequency spectra of noises to the ANL differences in the present study since ANL appears to be mediated at the level of central processes (Freyaldenhoven, Thelin, et al, 2005; Harkrider and Smith, 2005; Tampas and Harkrider, 2006). The possible reasons for the obtained ANL differences in two noises, could be due to the cognitive load to differentiate between two different noises. Cognitively the two different signals (passages and cafeteria noise) may be easier to process simultaneously than simultaneously presented passages and speech babble. Hence, the ANL may be higher in the speech babble than the cafeteria noise. As expected there was no difference in ANL between two different noises in FM system.

From these findings it can be concluded that the FM system provides a greater acceptance of noise followed by hearing aid with directional microphone and hearing aid without directional microphone. These benefit provided by the FM system and directional microphone is due to the reduction in the background noise level through these technologies. Further it can be inferred that ANL is dependent on the noise characteristics and hence ANLs measured with different competing stimuli should not be compared directly.

Phase II: Speech recognition threshold to evaluate signal to noise ratio (SNR).

Speech recognition in noise measurement was carried out for two noises (cafeteria and speech babble) in 28 subjects for three aided conditions namely, hearing aid with and without directional microphone and FM system. The SNR comparison was done across each aided condition and within each aided condition for two competing stimuli.

Table 5.

Mean and SD of SNR (in dB HL) Obtained Using Cafeteria noise and Speech-Babble Using Hearing aid With Directional microphone (DM), Hearing aid Without Directional microphone (HA) and FM system

Condition	CN/SB	Mean	S.D
HA	CN	9.71	3.57
	SB	10.92	3.65
DM	CN	7.25	3.93
	SB	8.03	4.09
FM System	CN	1.00	4.98
	SB	1.07	5.38

From the Table 5 it can be observed that the mean SNR was minimum for the FM condition and maximum for Hearing aid without directional microphone. In FM system the participants had a mean SNR advantage of 9 dB HL for cafeteria noise and 10 dBHL for speech babble over hearing aid without directional microphone. For hearing aid with directional microphone, the participants had a mean SNR advantage of 2 dBHL and 3 dBHL for cafeteria noise and speech babble respectively. For hearing aid without directional microphone, an average SNR of 9 dBHL and 11 dBHL with a mean variability of 3.5 dBHL and 3.6 dBHL was required for cafeteria noise and speech babble respectively. FM had a mean SNR advantage of 6dBHL and 7 dBHL for cafeteria noise and speech babble over directional microphone. Further it was observed that the SNR was lesser for the cafeteria noise and more for the speech babble for all the three aided conditions.

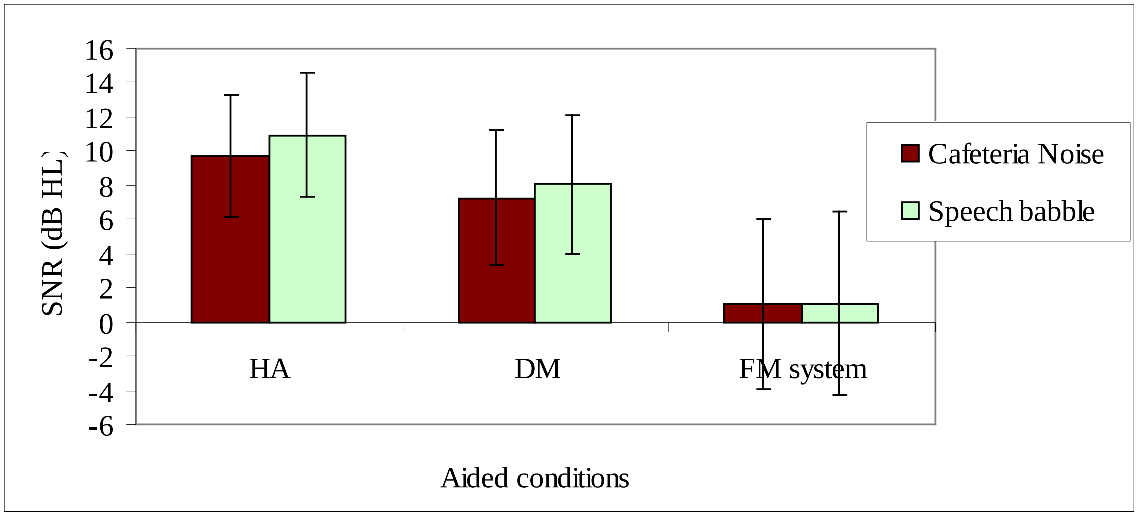

Figure 4. Mean SNR and standard deviation (S.D) for hearing aid with and without directional microphone and FM system obtained for cafeteria noise and speech babble.

From the Figure 4 it can be observed that the SNR was lesser (better performance) with the FM condition than the other two aided conditions. To assess the difference in SNR across the three aided conditions in two noises, two way repeated measure ANOVA was done. Results showed a significant main effect of the three aided conditions [F (2, 54) = 110.6, $p <0.001$]. Further results revealed that there was no significant interaction between various aided conditions and two noise [F (2, 54) = 0.75, $p > 0.05$]. To evaluate the significant differences in three different aided conditions, Bonferroni's multiple comparison was used. Table 6 shows that there was a significant difference between hearing aid with and without directional microphone ($p < 0.001$), hearing aid with directional microphone and FM system ($p < 0.001$) and hearing aid without directional microphone and FM system ($p < 0.001$).

Table 6.

Bonferroni Multiple comparison Test for SNR across Three aided Condition.

SNR	DM	FM system
HA	$P < 0.001$	$P < 0.001$
DM		$P < 0.001$

To find the difference in SNR across the two background competing noises, paired t test was done for all the three aided conditions. The results showed that there was a significant difference ($p < 0.05$) in SNR between two noises in hearing aid with and without directional microphone. However there was no significant difference ($p > 0.05$) in SNR between two noises in FM system.

The results of the present study with regard to the effect of FM system on SNR is in consonance with the study done by Fabry (1994) who reported that remote FM microphone improved SNR by nearly 10dB over the hearing aid condition using Environmental Microphone. Similar results were also found by Hawkins, 1984 who reported an improvement in SNR of 12 to 18 dB in FM system over hearing aid alone condition.

The results of the present study with regard to the lesser SNR in FM system in comparison to the directional microphone is in agreement with the study done by Lewis et al., (2004) who reported a benefit of 14.2 dB and 16.9 dB for FM system over directional microphone condition. The improved SNR in FM condition than the other aided condition might be attributed to the proximity of the FM transmitter to the desired signal which reduces the effects of noise and distance in a such a way that the hearing aid with and without directional microphone conditions are unable to do. However the lesser SNR benefit in the present study compared to the other studies can be attributed to the frequency response of the neckloop. High frequency response is decreased somewhat with the neckloop (Hawkins, 1987). Pascoe (1975) and Schwartz (1980) reported that audibility of high frequency information (upto around 6000Hz) lead to significant improvement in speech recognition scores. Hence the benefit provided by the FM system in the present study might be lesser compared to the earlier studies who had used other means of coupling FM system to hearing aid (such as direct audio input)

The results of the present study are in fair agreement with the study done by Valente et al., 1995, Gravel et al., 1999; Kuk et al., 1999 who reported an improvement of 6 to 8 dB in the directional microphone relative to omndirectional microphone condition. The present study reported a directional benefit of 3 dBHL for both cafeteria noise and speech babble noise.

The benefit of directional microphones in the present study may be due to the specific characteristics of the listening situations. In the present study Since the signal source was located to the front of the listener and spatially separated from the source of the background noise, directional microphone provided a benefit as it reduces the negative effects of background noise by providing greater amplification for signals arriving from the front of the listeners than signals arriving from the rear and/ or sides of the listener (Kuk et al., 2000; Dillon, 2001)

The results of the present study showed an SNR of 10 dBHL and 11 dBHL for cafeteria noise and speech babble respectively in the aided condition without any noise reduction technology. These findings are in consonance with the study done by Dubno, Dirks, & Morgan, 1984; Beattie, 1989; Wilson and Strouse, 2002, who reported that individuals with hearing loss require a signal to be 10-12 dB higher in multilalker babble to obtain a performance level of 50% correct.

The results of the present study with regard to the SNR in different noises is in accordance with the study done by Sperry et al., (1997) who reported that the use of speech babble has a more adverse masking effect on speech perception than other nonmeaningful noises. The possible reason for getting higher SNR (poor performance) for speech babble than cafeteria noise in the presented study can be attributed to the informational masking which occurs when the speech and the competing noise is similar in their temporal and/or semantic structure (Brungart, 2001). The other possible reason for the differential effect of noise may be due to the temporal variation of the noises. Speech babble is a modulated masker. Poorer performance with this modulated masker may be due to the poorer temporal resolution in the participants with sensorineural hearing loss (Bacon & Gleitman, 1992). Hence, the participants in the present study would have showed a higher SNR in the speech babble due to the reduced temporal resolution.

The results of the present study are in contrast with the study done by Kaplan and Pickett (1982). They reported that speech discrimination was better in speech babble noise compared to cafeteria noise. They attributed the noise related differences in the speech discrimination score to the different frequency spectra of the two noises. The frequency spectrum of cafeteria noise used by them was essentially flat through 3500Hz, but contained considerable energy above that frequency. The high frequency speech information was masked less by the low frequencies. Spectral components of speech babble used by them were below 1000Hz, which allowed more release of masking attenuation.

Thus it can be concluded from the findings that the SNR required through FM was lesser followed by hearing aid with directional microphone and hearing aid without directional microphone. In addition, it can be said that temporal and spectral characteristics of various noise varies which affects speech recognition differently. Hence, the result should be interpreted differently for different noises.

Phase III: Comparison of ANL and SNR in all the three aided conditions in presence of two background competing stimuli.

ANL and SNR are the two different measures which assess the performance of individuals with hearing impairment noisy conditions. To know significant difference between ANL and SNR among three different aided conditions for two background competing stimuli, paired t test was done.

Table 7.

Paired t test for (ANL) and (SNR) across Two Background Competing Stimuli in Three Aided Conditions

Conditions with noises	t (27)	Significance level
(ANLHA)CN-(SNR)HACN	1.778	0.087
(ANLHA)SB-(SNR)HASB	1.276	0.213
(ANL)DMCN-(SNR)DMCN	1.026	0.314
(ANL)DMSB-(SNR)DMSB	1.114	0.275
(ANL)FMCN-(SNR)FMCN	1.196	0.242
(ANL)FMSB-(SNR)FMSB	0.136	0.893

Note: HA- Hearing aid without directional microphone, DM- Hearing aid with directional microphone, FM- FM system, SB- speech babble, CN-Cafeteria noise

From the Table 7 it can be concluded that there was no significant difference ($p<0.05$) in Acceptable noise level (ANL) and signal to noise ratio (SNR) between two different noises in hearing aid with and without directional microphone and FM system.

The present study reported a mean ANL of 9 dB HL and 10 dB HL for cafeteria and speech babble for hearing aid without any noise reduction technology. Similarly the mean SNR of 10 dB HL and 11 dB HL was observed in the same condition. These findings are in consensus with the study done by Freyaldenhoven etal., (2005) which had a similar methodology to the present study. They reported a mean ANL of 3.5 dB HL and mean SNR of 3.7 dB HL which was not significantly different.

There is a lack of literature for the comparison of ANL and SNR through FM system. FM system provides a benefit of 10 – 30 dB SNR (Boothroyd & Iglehart, 1998). However the effect of the FM on ANL are not studied till date. It may be postulated that ANL and SNR taps a similar aspect of the performance in noise and can be further said that FM system will provide an improvement to ANL in a manner similar to that of SNR.

Conversely, Nabelek etal., (2006) reported a significant difference between the SPIN scores and ANL. They concluded that ANL and speech perception in background noise are two different measures to moderate levels of noise and provide different contributions to assessment of hearing aid use and improvement of speech understanding in noise. The differences found between this research and the present study may be due in part, to the methodological differences. The present study used the masked SRT in noise to obtain the SNR, whereas the Nabelek etal., (2006) used SPIN test to get the scores. Future research should investigate the relationship between ANL and SNR obtained with both SPIN scores and Masked SRT in noise.

The possible reasons that could be attributed to the similar SNR and ANL obtained in the present study are,

1. For both speech perception in noise measure and ANL, equivocal findings are found with increase in audibility through amplification for individuals with hearing impairment. For speech perception in noise with increase in audibility through amplification, there are reports of benefit (Alcantara et al., 2003; Haskell et al., 2002) as well as no benefit (Gustafsson & Arlinger, 1994). These reports show that speech understanding in noise can become either better or remain same with the use of hearing aids compared to the unaided condition. In a similar manner there are reports of improvement of ANL (reduction of ANL) in the aided condition when individual data were inspected (Nabelek et al., 2006) as well as no improvement of ANL with amplification (Lytle, 1994). From these findings, it can be postulated that the ANL and SNR measure similar reaction to the background noise.
2. Cooper & Cutts (1971); Kailkow et al., (1977); Bentler (2000) indicated that maximum word recognition is achieved at a SNR of +10dB to + 15dB. The mean ANLs reported in a number of studies also have been found to be in the + 10dB to + 15 dB range (Nabelek., 2006). From these findings it can be inferred that, on average, ANL measured at MCL occurs somewhere near the SNR for optimal

word recognition. However, the preceptual demands for ANL and SNR differ. ANL measures willingness to listen to speech in the presence of noise and SNR measures the speech understanding in noise. Hence, it may be possible that there is a common psychological or physiological variable that influence the performance of ANL and SNR. This findings need to be explored further.

3. Patients with lower ANL are likely to become successful, full time hearing aid users (no greater than 7 dB), patients with midrange ANLs (between 7 dB and 13 dB) may either be successful or unsuccessful users and patients with high ANLs (greater than 13 dB) are likely to become unsuccessful hearing aid users. Persons with hearing impairment who exhibit low acceptance of background noise when listening to speech (persons with large ANLs) consistently demonstrate dissatisfaction with hearing aids and tends to use them occasionally or reject them altogether (Nabelek et al., 2003). Individuals with poor speech understanding ability in noise also tend to show dissatisfaction with hearing aids. Killion (1997) reported that individuals who exhibit abnormally high SNR loss demonstrate dissatisfaction with hearing aids. Thus it may be possible that perceptual tasks required by ANL measurement is directly analogous to those required by the SNR test, since the individuals with larger ANL as well as high SNR loss show dissatisfaction with hearing aids.

From the findings of the present study it is observed that ANL and SNR procedures are not different. Hence it can be concluded that ANL procedure can be used as an alternative measure to SNR procedures.

CHAPTER 5

Summary and Conclusions

Difficulty in understanding speech in the presence of noise is the most frequent complaint of adults who use hearing aids (Kochkin, 2002; Cord, Surr, Walden & Dyrlund, 2004). These difficulties are due to the limited benefit provided by the hearing aid in a noisy situations. However, there are several strategies used within hearing aids, which have been shown to be effective in improving the speech understanding in noise. These strategies include directional microphone technology within the hearing aid itself, and hearing aids with boots and neckloops to receive FM transmission.

Traditionally, the benefit of directional microphone and FM system are evaluated by using Speech perception in noise measure (SPIN). SNR measured through SPIN test provides information about the benefit of hearing aid and noise reducing strategies. However, there is dearth of literature regarding speech perception in noise measure which predicts the successfulness of hearing aid and noise reducing strategy. Hence, Nabelek, Tucker, & Letowski (1991) gave a method called as Acceptable Noise Level (ANL) to predict the success of hearing aid use which has not been extensively evaluated. To find the ANL, Most comfortable level (MCL) and Background noise level (BNL) was obtained.

Despite the documented evidence of improvement in speech perception in noise provided by these noise reducing technology, there is lack of literature in comparing the benefits provided by these noise reducing technology. Hence the present study was taken up to compare the benefits of various technologies by using two procedures namely ANL and SNR.

The specific objectives of the study were:

1. To compare the ANL in three aided condition (hearing aid with directional microphone turned off, hearing aid with directional microphone turned on & FM system) using two background competing stimuli (speech babble, cafeteria).
2. To compare the SNR in three aided condition using two background competing stimuli.
3. To compare ANL and SNR in all the three aided conditions using two background competing stimuli.

To arrive at the objectives, 28 naïve hearing aid users, with postlingual onset of hearing loss were taken for the study. Degree of hearing loss varied from moderate to moderately severe hearing loss. The data were collected in two phases. In the first phase, MCL, BNL and ANL were established in the three aided conditions (hearing aid with directional microphone turned off, hearing aid with directional microphone turned on & FM system) using two background competing stimuli (speech babble, cafeteria). In the second phase, SRT in noise was used to obtain the SNR in the three different aided conditions using two background competing stimuli. From the data obtained, the mean, standard deviation and range were calculated and the following statistical analysis were done.

1. One way repeated measure Analysis of Variance (ANOVA) for finding the main effect of various aided conditions (Hearing aid with directional microphone off, hearing aid with directional microphone on and FM system) for MCL.
2. Two way repeated measure ANOVA for finding the main effect of various aided conditions using two different competing stimuli for both ANL and SNR and interaction effect between these different aided conditions and different noises.
3. Bonferroni multiple comparison was done to see the pair wise differences across different aided conditions for ANL and SNR when repeated measure ANOVA showed a significant difference across the three aided conditions.
4. Paired sample t-test was done to see the difference between two different competing noises (Cafeteria noise & Speech babble) for ANL and SNR in all the three aided condition.

The Findings of the present study are as follows.

1. Most comfortable level (MCL).

   The MCL obtained for hearing aid with and without directional microphone condition was same. However, MCL was lower for FM system compared to hearing aid with and without directional microphone. This could be attributed to the increase in the gain in the FM system itself since the gain of the hearing aid was kept constant for all the three aided conditions.

2. Background noise level (BNL).

   a) Acceptance of Background noise level was increased with the use of FM system followed by the directional microphone in comparison with hearing aid without directional microphone. This may be due to the closer proximity of the FM transmitter to the speaker and hence the effect of reverberation and noise are less while using the FM system.
   b) A slight increase in BNL was seen in hearing aid with directional microphone. This may be due to the maximum sensitivity of directional microphone to sound coming from the front than the sounds coming from the back and the sides, which in turn increases the acceptance of BNL.
   c) Further, BNL was different for two noises in the hearing aid with and without directional microphone. This may be due to the difference in the spectral component of the two noises. Noise which has a spectral component similar to that of speech may be more difficult to accept than any other noises which differ in their spectral components to speech.

3. Acceptable noise level (ANL).

   a. The present study indicated that ANL was least with the FM system followed by hearing aid with directional microphone then by hearing aid without directional microphone. These results are due to the closer proximity of FM system to the speaker.

b. Directional microphone showed reduced ANL compared to hearing aid without directional microphone. This may be due to the low frequency roll off in the directional microphone.

c. Hearing aid without directional microphone showed the highest ANL which may be due to the amplification of the noise along with speech.

d. ANL obtained with speech babble was higher than cafeteria noise in hearing aid with and without directional microphone. This may be due to the cognitive load imposed by the speech babble since it is difficult to process speech in the presence of noise with spectral and temporal modulation similar to that of speech.

e. These findings indicate that with the use of directional microphone and FM system, listeners can become successful hearing aid users.

4. Signal to Noise Ratio (SNR).

1. SNR was reduced remarkably with the use of FM system and slightly with the use of directional microphone. There was a slight advantage of directional microphone of about 2 dBHL. These noise reduction technology minimize the effect of noise and hence speech perception is better with the use of these noise reduction technologies.
2. From the present study it was found that SNR was reduced with cafeteria noise than speech babble.

5. Comparison of ANL and SNR across three aided conditions for two background competing stimuli.

The results indicated that ANL and SNR are not significantly different and they are two analogous measures which measures the benefit of hearing aid and satisfaction with hearing aids. For both ANL and SNR there may be a common psychological or physiological variable that influences the performance of ANL and SNR.

Conclusion

- Most comfortable level may be achieved at a lower intensities with FM system.
- FM system is most effective in reducing the background noise followed by the directional microphone.
- While establishing the ANL noise used should be consistent and ANLs measured with different noises should not be compared directly.
- Lesser the ANL value and SNR score, better will be the hearing aid benefit and satisfaction.
- Different real life noises should be used to evaluate the SNR and ANL which gives an insight into the real world benefit in adverse listening conditions. However, Speech babble is most preferable to be used while measuring SNR and ANL since it creates a difficult listening environment for individuals using amplification devices.

The findings of the present study have some clinical implication.

1) ANL measure can be used as a clinical tool for the selection and fitting of hearing aids. It can also be used to predict the success of the hearing aid users. Hearing aids with directional microphone and FM system can be provided for individuals who had shown dissatisfaction with hearing aids.
2) The present study suggest that either ANL or SNR can be used to check the benefit of the hearing aid with noise reduction technology.
3) ANL can be used as an alternate measure to the SNR since the time taken for measuring ANL is comparatively lesser for ANL than for SNR.
4) ANL can be used in everyday hearing aid fitting centers which would help to counsel the patients regarding the realistic expectation of the hearing aid use and satisfaction.

Future direction:

1. The effect of reverberation on ANL needs to be studied to find the efficacy of ANL in a more real world situation.
2. The effect of auditory training (with respect to acceptance of background noise level) on the ANL may be studied.
3. The physiologic characteristics of the auditory system and/or brain that contributing to the large range of ANLs may be studied. Additionally, if physiologic correlates to ANL are found, objective measures could be used to

predict successful hearing aid use by infants, young children, or other populations in which behavioral testing is difficult or impossible.

4. Since the individuals with CAPD has difficulty understanding speech in presence of noise, ANL can could be obtained from these individuals to explore the physiological basis of ANL.

REFERENCES

Alcantara, J. I., Moore, B. C., Kuhnel, V. & Launer, S. (2003). Evaluation of the noise reduction system in a commercial digital hearing aid. *International Journal of Audiology*, *42*, 34-42.

American National Standards Institute (1991). *Maximum Ambient Noise Levels for Audiometric Test Rooms.* (ANSI S3. 1-1991). New York: American National Standards Institute.

Anitha. T., Manjula. P. (2005). Kannada speech babble developed at AIISH.

Arlinger, S. (2003). Negative consequences of uncorrected hearing loss: a review. *International Journal of Audiology*, *42* (Suppl. 2), 17-20.

Bacon, Ronald M, Gleitman**.** (1992). *Journal of Speech and Hearing Research, 35,* 642-653.

Bentler, R., Niebuhr, D., Getta, J., & Anderson, C. (1993). Longitudinal study of hearing aid effectiveness. II: Subjective measures. *Journal of Speech Language Hearing Research*, *36*, 820-831.

Bilger RC, Neutzel JM, Rabinowitz WM, Rzeczkowski C. (1984) Standardization of a test of speech perception in noise. *Journal of Speech Hearing Research, 33*, 343–355.

Beattie RC, Nutzel JM, Rabinowitz WM, Rzeczkowski C. (1984). Word recognition functions for the CID W 22 test in multitalker noise for normally hearing and hearing impaired subjects. *Journal of Speech Hearing Disorder 54*, 20-32.

Boothroyd A, Iglehart F,(1998). Experiments with classroom FM amplification**.** *Ear and hearing,19(3),*202-17.

Boothroyd, A. (2004). Room acoustics and speech perception. *Seminars in Hearing, 25*(2), 155-166.

Brungart. (2001).Informational and energetic masking effects in the perception of multiple simultaneous talkers. *Journal of Acoustic Society of America. 110* ,2527-38.

Carhart,R., & Jerger, J. F. (1959). Preferred method for clinical determination of puretone thresholds. *Journal of Speech and Hearing Research*, 24, 330.

Carhart, R. (1969). Monoaural and binaural discrimination against competing sentences. *Internatinonal audiology, 8*, 182-183

Cord, M. T., Surr, R. K., Walden, B. E., & Dyrlund, O. (2004). Relationship between laboratory measures of directional advantage and everyday success with directional microphone hearing aids. *Journal of the American Academy of Audiology, 15,* 353–364.

Cornelisse, L. E., Gagne, J. P., & Seewald, R. C. (1991). Long-term average speech spectrum at the chest level microphone location. *Canadian Journal of Speech-Language Pathology and Audiology, 15*(3), 7–12.

Costa, P. T., & McCrae, R. R. (1997). Longitudinal stability in adult personality. In: Hogan, R., Johnson, J., & Briggs, S. (Eds), *Handbook of Personality Psychology* (pp. 269-290). San Diego, CA: Academic Press.

Cooper, G. D; Cutts, B. P. (1971). Speech discrimination in noise. *Journal of Speech and Hearing research. 14,* 332-337.

Cox, R. M. & Alexander, G. C. (1995). The Abbreviated Profile of Hearing Aid Benefit (APHAB). *Ear and Hearing*, *16*, 176- 186.

Cox, R. M., & Gilmore, G. C. (1990). Development of the profile of hearing aid performance (PHAP). *Journal of Speech and Hearing Research*, *33*, 343-357.

Cox, R. M., Alexander, G. C., & Gray, G. (1999). Measuring satisfaction with amplification in daily life: the SADL scale. *Ear and Hearing*, *20 (4),* 306-320.

Crandell, C., Smaldino, J.J., & Flexer, C. (1995). Sound-field FM amplification: Theory and practical applications. San Diego, CA: Singular.

Crandell, C. C., & Smaldino, J. J. (2000). Classroom acoustics for children with normal hearing and with hearing impairment. *Language, Speech, and Hearing Services in Schools, 31*(*4*), 362-370.

Crandell, C., Smaldino, J. (2001). Improving classroom acoustics: utilizing hearing assistive technology and communication strategies in the educational setting. *Volta Review 101(5),* 47-62.

Crandell, C. C., Kreisman, B. M., Smaldino, J. J., & Kreisman, N. V. (2004). Room acoustics intervention efficacy. *Seminars in Hearing*, *25*(2), 201-206.

Crandell, C. C., Smaldino, J. J., & Flexor, C. (2005). Speech perception in specific populations. In C. C. Crandell , J. J. Smaldino & C. Flexor (Eds.) *Sound field amplification: Applications to speech perception and classroom acoustics*. NY: Thompson-Delmar Learning.

Crowley, H. J., & Nabelek, I. V. (1996). Estimation of client-assessed hearing aid performance based upon unaided variables. *Journal of Speech and Hearing Research, 39*, 19-27.

Dillon, H., Birtles, G. & Lovegrove, R. (1999). Measuring the outcomes of a national rehabilitation program: Normative data for the Client Oriented Scale of Improvement (COSI) and the Hearing Aid User's Questionnaire (HAUQ). *Journal of the American Academy of Audiology*, *10*, 67-79.

Dillon, H., James, A., & Ginis, J. (1997). Client oriented scale of improvement (COSI) and its relationship to several other measures of benefit and satisfaction provided by hearing aids. *Journal of the American Academy of Audiology*, *8*, 27-43.

Dillon, H. (2001). *Hearing Aids*. Boomerang Press, Sydney.

Dirks, D., & Wilson, R,H. (1969). Binaural hearing of speech for aided and unaided conditions. *Journal of Speech and Hearing Research. 12,* 650-664

Disarno, N. J., Schowalter, M., & Grassa, P. (2002). Classroom amplification to enhance student performance. *Teaching Exceptional Children*, *34*(6), 20-26.

Dubno, J., Dirks, D., & Morgan, D. (1984). Effects of Age and Mild Hearing Loss on Speech Recognition in Noise. *Journal of the Acoustical Society of America, 76(1),* 87-96.

Edwards, C. (2005). From system selection to enhancement of listening skills: Considerations for the classroom. In Crandell, C. C., Smaldino, J. J., & Flexer, C. (Eds.) *Sound field amplification: Applications to speech perception and classroom acoustics* (Second Edition). NY: Thomson Delmar Learning.

Fabry, D. (1994). Noise reduction with FM systems in FM/EM mode. *Ear and Hearing, 15*, 82–86.

Flexer, C., Richards, C., Buie, C., & Brandy, W. (1994). Making the grade with amplification in classrooms. *Hearing Instruments, 45(10),* 24-26.

Flexer, C. (2004). The impact of classroom acoustics: Listening, learning, and literacy. *Seminars in Hearing, 25*(2), 131-140.

Flexer, C. (2005). Rationale for the use of sound field systems in classrooms: The basis of teacher in-services. In Crandell, C. C., Smaldino, J. J., & Flexer, C. (eds.) Sound field amplification: *Applications to speech perception and classroom acoustics* (Second Edition). NY: Thomson Delmar Learning.

Fortune, T. W. (1997). Real-ear polar patterns and aided directional sensitivity. *Journal of American Academy of Audiology, 8,*119-131.

Franklin, C. A., Thelin, J. W., Nabelek, A. K., & Burchfield, S. B. (2006). The effect of speech presentation level on acceptance of background noise in normal-hearing listeners. *Journal of the American Academy of Audiology*, *17*, 141–146.

Franks, J., & Beckmann, N. (1985). Rejection of hearing aids: attitudes of geriatric sample. *Ear and Hearing, 6(3),* 161-166.

Freyaldenhoven, M. C., Nabelek, A. K., Burchfield, S. B., & Thelin, J. W. (2005). Acceptable noise level (ANL) as a measure of directional benefit. *Journal of the American Academy of Audiology, 16(4),* 228-236.

Freyaldenhoven, M. C., Thelin, J. W., Plyler, P. N., Nabelek, A. K., & Burchfield, S.B. (2005). Effect of stimulant medication on the acceptance of background noise in individuals with attention deficit/hyperactivity disorder. *Journal of the American Academy of Audiology, 16*, 677-685.

Freyaldenhoven, M. C., Plyler, P. N., Thelin, J. W., & Burchfield, S. B. (2006). Acceptance of noise with monaural and binaural hearing aid use. *Journal of the American Academy of Audiology, 17*, 659-666.

Freyaldenhoven, M. C., Smiley, D. F., Muenchen, R. A., & Konrad, T. N. (2006). Acceptable noise level: reliability measures and comparison to background noise preference. *Journal of the American Academy of Audiology,* 1*7*, 640-648.

Freyaldenhoven, M. C., Plyler, P. N., Thelin, J. W., & Hedrick, M. S. (2007). The effects of speech presentation level on acceptance of noise in listeners with normal and impaired hearing. *Journal of Speech, Language and Hearing Research, 50 (4)*, 878-85.

Freyaldenhoven, M. C., Nabelek, A. K., & Tampas, J. W. (2008). Relationship between acceptable noise level and the abbreviated profile of hearing aid benefit. *Journal of Speech Language Hearing Research, 51*, 136-46.

Gatehouse, S. (1999). Glasgow Hearing Aid Benefit Profile: Derivation and validation of a client-centered outcome measure for hearing aid services. *Journal of the American Academy of Audiology, 10*, 80-103.

Gelfand, S. A., Piper, N., & Silman, S. (1986). Consonant recognition in quiet and in noise with aging among normal hearing listeners. *Journal of the Acoustical Society of America, 80*(6), 589–1598.

Gengel, R. W. (1971). Acceptable speech-to-noise ratios for aided speech discrimination by the hearing impaired. *Journal of Speech Hearing Research, 11*, 219-222.

Gordon-Salant , S. (1986). Effects of Aging on Response Criteria in Speech-Recognition Tasks. *Journal of Speech and Hearing Research, 29,* 155-162.

Groen, J. (1969). Social hearing handicap' its measurement by speech audiometry in noise. *International audiology. 8*, 182-183.

Gordon Salant, S. (1986). Recognition of natural and time/intensity altered CVs by young and elderly subjects with normal hearing. *Journal of the Acoustical Society of America, 80*(6), 1599–1607.

Gustafsson, H. A. & Arlinger, S. D. (1994). Masking of speech by amplitude-modulated noise. *Journal of Acoustical Society of America*, *95,* 518-529.

Hagerman, B. (1984). Clinical measurements of speech reception threshold in noise. *Scandinavian Audiology, 13,* 57-63.

Harkrider, A. W., & Smith, B. (2005). Acceptable noise level, phoneme recognition in noise, and auditory efferent measures. *Journal of the American Academy of Audiology 16,* 530-545.

Harkrider, A. W., & Tampas, J. W. (2006). Differences in responses from the cochleae and central nervous systems of females with low versus high acceptable noise levels. *Journal of the American Academy of Audiology, 17,* 667-676.

Harless, E. L., & McConnell, F. (1982). Effects of hearing aid use on self concept in older persons. *Journal of Speech Hearing Disorders, 47*(3), 305–309.

Hawkins, D. (1984). Comparisons of Speech Recognition in Noise by mildly-to Moderately Hearing-Impaired Children using Hearing Aids and FM Systems. *Journal of Speech and Hearing Disorders, 49,* 409-418.

Hawkins, D. B., Yacullo, W. S. (1984). Signal-to-noise ratio advantage of binaural hearing aids and directional microphones under different levels of reverberation. *Journal of Speech Hearing Disorders, 49,* 278-286.

Hawkins, D. (1987). Assessment of FM systems with an ear canal probe tube microphone system. *Ear and Hearing, 8,* 301–303.

Humes, L. E., Halling, D., & Coughlin, M. (1996). Reliability and stability of various hearing- aid outcome measures in a group of elderly hearing-aid wearers. *Journal of Speech and Hearing Research, 39*, 923-935.

Hayes, d; Jerger, J. (1979). Aging and use of hearing aids. *Scandinavian Audiology, 8,* 35-40 (1979)

Kalikow, D. N., Stevens, K. N., & Elliot, L. L. (1977). Development of a test of speech intelligibility in noise using sentence materials with controlled word predictability. *Journal of the Acoustical Society of America*, *61,* 1337–1351.

Kaplan., & Pickett, J.M. (1982). Differences in speech discrimination in the elderly as a function of type of competing noise: Speech- babble or cafeteria. *Audiology, 21*, 325-333.

Kapteyn, T. S. (1977). Satisfaction with fitted hearing aids II. An investigation into the influence of psycho-social factors. *Scandinavian Audiology*, *6*, 171-177.

Killion, M. C. (1997b). SNR loss: “I can hear what people say, but I can’t understand them.” *The Hearing Review, 4(12),* 8–14.

Kirkwood, J.K., & Soulsby, E.J. (2005). Quality of life. Vet Rec., *157*, 783-4.

Kirkwood DH. (2006). Survey: Dispensers fitted more hearing aids in 2005 at higher prices. *Hearing Journal, 59,* 40-50.

Kochkin S. (1993). Consumer satisfaction with hearing instruments in the United States. Special issue, Marketing Edge, 1–4.

Kochkin, S. (2000). MarkeTrak V: "Why hearing aids are in the drawer": The consumer's perspective. *The Hearing Journal*, *53(2),* 38-55.

Kochkin, S. (2002). Consumers rate improvements sought in hearing instruments. *The Hearing Review, 9*, 18–20.

Kreul, E.J., Nixon, J.C., Kryter, K.D., Bell, D.W., Land, J.S., Schubert, E.D (1968). A proposed clinical test of speech discrimination. *Journal of Speech and Hearing Reaearch, 11,* 536-552.

Kuk, F. K., Kollofski, C., Brown, S., Melum, A., & Rosenthal, A. (1999). Use of a digital hearing aid with directional microphones in school-aged children. *Journal of American Academy of Audiology, 10,* 535–548.

Kuk, F., Baekgaard, L. & Ludvigsen, C. (2000). Design considerations in directional microphones. *Hearing Review, (9),* 68–73.

Lewis D. (1991). FM systems and assistive devices: Selection and evaluation. In Feigin, J.A., and Stelmachowicz, P.G., (Eds.) *Pediatric Amplification: Proceedings of the 1991 National Conference*, Omaha, NE: BTNRH.

Lewis, D., Feigin, J., Karasek, A., & Stelmachowicz, P. (1991). Evaluation and assessment of FM systems. *Ear and Hearing*, *12,* 268-280.

Lewis, M. S., Crandell, C. C., & Valente, M. (2004). Speech perception in noise: Directional microphones versus frequency modulation (FM) systems. *Journal of American Academy of Audiology, 15,* 426-439.

Malinoff, R. L., & Weinstein, B. E. (1989). Measurement of hearing aid benefit in the elderly. *Ear and Hearing, 10,* 354-356.

Massie, R., Theodoros, D., Byrne, D., McPherson, B., & Smaldino, J. (1999). The effects of sound field classroom amplification on the communicative interactions of Aboriginal and Torres Strait Islander children. *The Australian and New Zealand Journal of Audiology, 21*(2), 93-109.

Mayadevi. (1978). Development and standardization of a common speech discrimination test for Indians. *Unpublished Master's Dissertation. University of Mysore, India.*

Mueller, G., & Hall, J. W. (1998). Hearing aids: Fitting and verification. In *Audiologists' desk reference: Audiologic management, rehabilitation and terminology* (Vol. 2, pp. 165– 282). San Diego, CA: Singular.

Mueller, H. G., Ricketts, T. A. (2005). Digital noise reduction: much ado about something? *The Hearing Journal, 58,* 10-17.

Mueller, H. G., Weber, J., Benjamin W. Y., & Hornsby, B. (2006). The Effects of Digital Noise Reduction on the Acceptance of Background Noise. *Trends in Amplification, 10,* 83-93.

Mueller, H. G., Weber, J., & Hornsby, B. (2006). The effects of digital noise reduction on acceptance of background noise. *Trends in Amplification, 10*(2), 83-93.

Mulrow, C., Tuley, M., & Aguilar, C. (1992a). Correlates of successful hearing aid use in older adults. *Ear and Hearing, 13(2),* 108-113.

Myers, I. B., & McCaulley, M. H. (1985). *Manual: A guide to the development and use of the myers-briggs type indicator (2nd ed.).* Palo Alto, CA: Consulting Psychologists Press.

Nabelek, A., & Mason, D. (1981). Effects of noise and reverberation on binaural and monaural word identification by subjects with various audiograms. *Journal of Speech and Hearing Research*, *24(3)*, 375-383.

Nabelek, A. K. (1988). Identification of vowels in quiet, noise, and reverberation: relationships with age and hearing loss. *Journal of the Acoustical Society of America*, *84*(2), 476–484.

Nabelek, A. K., Tucker, F. M., & Letowski, T. R. (1991). Toleration of background noises: relationships with patterns of hearing aid use by elderly persons. *Journal of Speech and Hearing Research, 34,* 679–685.

Nabelek, A. K., Burchfield, S. B., & Webster, J. D. (2003). Relationship between acceptance of background noise and hearing aid use. *Journal of the Acoustical Society of America*, *113*, 2289.

Nabelek, A. K., Tampas, J. W., & Burchfield, S. B. (2004). Comparison of speech perception in background noise with acceptance of background noise in aided and unaided conditions. *Journal of Speech Language and Hearing Research, 47,* 1001-1011.

Nabelek, A. K., Freyaldenhoven, M. C., Tampas, J. W., Burchfield, S. B., & Muenchen, R. A. (2006). Acceptable noise level as a predictor of hearing aid use. *Journal of the American Academy of Audiology, 17,* 626–639.

Nelson, P. B., & Soli, S. (2000). Acoustical barriers to learning: Children at risk in every classroom. *Language, Speech, and Hearing Services in Schools, 31*(4), 356-361.

Nielsen, H., & Ludvigsen, C. (1978). Effects of hearing aids with directional microphones in different acoustic environments. *Scandinavian Audiology (Suppl 7)*, 217-224.

Nilsson, M. J., Soli, S. D., & Sullivan, J. (1994). Development of a hearing in noise test for the measurement of speech reception threshold. *Journal of Acoustical Society of America 95*, 1985-1999.

Olsen, H. L. & Hagerman, B. (2002). Directivity of different hearing aid microphone locations. *International Journal of Audiology, 41,* 48- 56.

Pascoe D. (1980). Cinical implication of nonverbalmethods of hearing aid selection and fitting. *Seminars in Hearing,1,*217-229.

Plomp, R. (1978). Auditory handicap of hearing impairment and the limited benefit of hearing aids. *Journal of Acoustical Society of America, 63*, 533-549.

Plomp, R. (1986). A signal-to-noise ratio model for the speech reception threshold of the hearing-impaired. *Journal of Speech Hearing Research, 29*, 146-154.

Plyler, P. N., Madix, S. G., Thelin, J. W., & Johnston, K. W. (2007). Contribution of high-frequency information to the acceptance of background noise in listeners with normal and impaired hearing. *American Journal of Audiology, 16(2),* 149-56.

Ricketts, T., & Mueller, H. G. (1999). Making sense of directional microphones. *American Journal of Audiology*, *8*, 117-126.

Ricketts, T. (2000a). Directivity quantification in hearing aids: fitting and measurement effects. *Ear and Hearing, 21*, 45–58.

Ricketts T. (2000b). Impact of noise source configuration on directional hearing aid benefit and performance. *Ear and Hearing, 21*, 194–205.

Ricketts, T., Henry, P., Gnewikow, D. (2003). Full time directional versus user selectable microphone modes in hearing aids. *Ear and Hearing 24*(5), 424-439.

Rogers, D. S., Harkrider, A. W., Burchfield, S. B., & Nabelek, A. K. (2003). The influence of listeners' gender on the acceptance of background noise. *Journal of the American Academy of Audiology, 14,* 374-385.

Rowland, J. P., Dirks, D. D., Dubno, J. R., & Bell, T. S. (1985). Comparison of speech recognition-in-noise and subjective communication assessment. *Ear and Hearing, 6,* 291-296.

Sherer, M. & Frisnia, D. (1998). Characteristics associated with marginal hearing loss and subjective well being among a sample of older adults. *Journal of Rehabilitation Research and Development*, *35*(4), 420-426

Smaldino, J. J. & Crandell, C. C. (2000). Classroom amplification technology: Theory and practice. *Language, Speech, and Hearing Services in Schools*, *31*, 371-375.

Smaldino, J. J., Doggett, F., & Thunder, T. (2004). The complimentary roles of audiologists and acoustic consultants in solving classroom acoustic problems. *Seminars in Hearing, 25*(2), 179-188.

Sperry. (1997). Age-Related and Gender-Related Changes in Monaural Speech Recognition *Journal of Speech, Language, and Hearing Research ,40*, 444-452

Sperry JL, Wiley TL, Chial MR.(1997). Word recognition performance in various background competitors, *Journal of American Academy of Audiology 8,* 71-80

Surr, R. K., Schuchman, G. I., & Montgomery, A. A. (1978). Factors influencing use of hearing aids. *Archives of Otolaryngology*, *104*, 732-736.

Tillman, T. W, Carhart, R., Olsen, W. O. (1970) Hearing aid efficiency in a competing speech situation. *Journal of Speech Hearing Research*, *13*, 789-811.

Tampas, J. W., & Harkrider, A. W. (2006). Auditory evoked potentials in females with high and low acceptance of background noise when listening to speech. *Journal of the Acoustical Society of America*, *119*(3), 1548-1561.

Tillman TW, Olsen WO. (1973). Speech audiometry. In: Jerger J, (Eds). Modern *Developments in Audiology* (pp.37–74). New York: Academic Press.

Turner, C. W., & Henry, B. (2002). Benefits of amplification for speech recognition in background noise. *Journal of the Acoustical Society of America*, *112*, 1675-1680.

Valente, M., Fabry, D. & Potts, L. (1995). Recognition of Speech in Noise with Hearing Aids Using Dual Microphones. *Journal of the American Academy of Audiology*, *6(6)*, 440-450.

Vandana, S. (1998). *Speech identification test for Kannada speaking children*. Unpublished Masters Independent Project submitted to University of Mysore. Mysore.

Von Hapsburg, D., & Bahng, J. (2006). Acceptance of background noise levels in bilingual (Korean-English) listeners. *Journal of the American Academy of Audiology*, *17*, 649-658.

Weinstein, B. E., & Ventry, I. M. (1982). Hearing impairment and social isolation in the elderly. *Journal of Speech Hearing Research, 25*(4), 593–599.

Wilson RH, Strouse A. (1999). Psychometrically equivalent spondaic words spoken by a female speaker. *Journal of Speech Hearing Research 42,* 1336-1346.

APPENDIX 1
Passage A

bangΛlu:ru nΛnnΛ ra:dzyΛdΛ ondu doddΛ u:ru i u:rΛnnu

nΛmmΛ ra:dzyΛdΛ bombai ennuvΛru. indija:dΛ doddΛ

nΛgΛragnlΛlli idu ondu i: u:rΛnnu no:dnʃu dznnΛru

be:re be: re ra:dzjΛgΛlindΛ be:re be: re u:rugΛlindΛ

bΛrnvΛru. idΛlΛde nΛmmΛ ra:dzjadΛlliruvΛ be:lur dzo:g

nΛndi i:vugΛlΛnnu no:dΛlu dznnΛru bΛruvΛru. i:

ha:dinΛlli re:ʃmejΛnnu belejuvΛru.

Passage B

kriʃna: nΛdijv sΛhjΛdri pΛrvΛtngnlΛlli mΛha:bΛle:ʃvΛrΛda

hΛttira huttutΛde. Idu huttuva prΛde:ʃvu ramani:ja sta:na

idu maha: raʃtra, karna:taka mattu a:ndⁿrapradeʃgalalli

hΛridu banga:la kollijannu se:ruttade idakke upanadigalu

h

halavu kojina, tungabⁿ adra ⁿgatprabⁿa bima:. Malaprabⁿa

Avugalalli kelavu. kojina: nadige anekattannu katti

vidjuttΛnnu utpa:dane ma:dutta:re

Passage ‘C’

Ondu a:du bettʌda nettijalli me:jutittu ondu to:la

adannu no:ditu allege ho:galu adakke sa:djaviralilla

adu a:dannu kuritu kelage ba:raja astu

jataradalidare ka:lu dza:ridare e:nu gati alʌde illi hullu

hulusa:gi beledide bahu rutʃijagide e:ndu a:mantrʌna niditu.

Passage D

mʌjsu:rinalli k ⁿedda: bahu prasid ⁿavagide bahu dzanaru

adannu vikʃisalu ka:kana ko:tejalli bahu utsa:hadinda

anija:gutta:re. bⁿ a;ada a:negalannu hidijuvude adara

uddeʃavalla a:negalannu tarabe:ta:da a:negalinda palagisuvudu ondu

mahatka:rja iː gⁿ atanejannu vikʃisuvavaru tʃakitaragvtta:re

ede dz ⁿal jannuvudaralli sandehavilla k ⁿeda:da kelasa

mugijuvantahadalla. takka ka:da:negalannu hidijuvndu paḷagisuvudu sa:ma:njave:nalla ka:rjada pʰ ⁿala tadanantara tiḷijuvudu.

Passage E

Bakka tale:ja manuʃja mattu noṇa

Obba bakka tale:ja manuʃjanidda be:sugejalli ondu dina avanu kelasa ma:ḍi sa:ka:gi kuḷitukonḍa. a: samajakke sarija:gi ondu noṇa bandu avana nunnane:ja taleja sutta ha:radutta bakka talejannu katʃala:rambistu. nonavannu hodejabekendu avanu kai jatti hodeda. nona tappisikonditu e:ṭu avana talege bittu. Ṇona tirugi bantu avanu tirugi hoḍeda. Punaha avanu tirugi hoḍeda. Punaha avana talege e:ṭu bittu a:ga avanige bⁿ budⁿ i bantu sⁿ udra pra:ṇigalannu gamanisuvadarinda namage ha:ni jandukonḍa.

APPENDIX 2

Phonemically Balanced Word List Developed by Yathiraj and Vijayalakshmi (2005).

raiʈa
anna
mola
tʃa:ku
ʈuti
meike
ha:vu
Kaʈʈu
bi:ga
o:ɖu
bale
mu:ru
ra:ni
ʈapa:
ta:ra:
braju
hasu
dzade
nalli
kivi
varʃa
ja:ru
da:na
ʃasmpu
ili

tʃukki
hagga
baʈʈa
mantʃa
bekku
lo:ta
ba:la
dze:bu
mandi
nona
male
ti:vi
ɖi:pa:
rave
mola
railu
ka:ru
divja
a:ru
pu:ri
haɖɖu
suʃma
ʈa:jin
ɖana
a:lu

hulu
su:dzi
rotti
gu:be
akka
e:lu
vi:ne
ɖimbun
vade
go:li
ha:lu
amma
dzana
ravi
ʈande
rakta
suʈʈu
ja:va
tʃandra
ja:ke
a;le
aiɖu
nadi
uppu
kriʃna

va:tʃu
hotte
ɖoni
vadzra
va:ni
ʈale
kaʈʈe
me:dzu
na:ji
ba:lu
ni:li
gombe
ka:ge
aɖu
dratkʃi
baegu
kaʃta
paisa
mara
hu:vu
tinnu
idli
ke:lu
sara
paɖa