Comparison of Acceptable Noise Level and Signal to Noise Ratio Using Directional Microphone and FM System

Bhavya M. & N. M. Mamatha*

Abstract

The present study was taken up with the aim 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. 28 individuals with moderate to moderately severe sensorineural hearing loss in the age range of 20-60 years participated in the study. ANL and SNR were measured for all the participants. Both ANL and SNR were better with the use of FM system followed by the use of directional microphone. In addition, both ANL and SNR were dependent on the noise characteristics. Temporal and spectral characteristics of various noise affected speech recognition and ANL differently. Hence, the result should be interpreted differently for different noises. Further it was observed that ANL and SNR procedures were not different. Hence it can be concluded that ANL procedure can be used as an alternative measure to SNR procedure.

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). 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. 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. 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 in the hearing aids improve the Signal to noise ratio (SNR) by taking the advantage of spatial differences between speech and noise. 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). An FM system delivers desired sound

* Lecturer in Audiology, All India Institute of Speech and Hearing, Mysore, India
email: mamms_20@rediffmail.com

directly to the ear by reducing the background noise. FM system enhances the speech to noise ratio (SNR) at the listener's ear and thereby facilitates speech recognition.

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. Poor correlation have been found between speech perception scores in noise (SNR) and hearing aid benefit, satisfaction, or its use (Humes, Halling, & Coughlin, 1996). 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, 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.

Environmental noise such as cafeteria noise and speech babble are the common background interfering noise which many people encounter in real life environment. So there is a need to measure the speech recognition ability of an individual in different environmental noises. Benefits provided by the directional microphone and FM system in various environmental noise needs to be investigated.

Hearing aid fitting procedure 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 Speech 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.

Method: 28 participants (21 male & 7 female) in the age range of 20-60 years with bilateral moderate to moderately severe sensorineural hearing loss were included in the study. All participants were naïve hearing aid users with Speech identification scores (SIS) of ≥ 80%.

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).

Instrumentation: A calibrated dual channel diagnostic audiometer (Madson orbiter 922) with TDH-39 headphone and two Martin (c115) free field speakers was used. A non linear 4 channel digital behind the ear hearing aid with the fitting range from mild to severe degree of hearing loss was used. 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 had a hyper cardioid polar pattern.

Material: The speech material used for the purpose of determining the ANL included five different passages in Kannada. The passages were spoken in conversation style by a male native speaker of Kannada and were digitally recorded in an 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. The speech material used for determining the SNR included phonetically balanced word list in Kannada developed by Yathiraj and Vijayalakshmi (2005). The speech material were spoken in conversation style by a female native speaker of Kannada.

Background competing stimuli: Two types of background competing stimuli were used. Kannada speech babble 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.

Both speech and competing stimuli were recorded and stored on to a personal computer (PC) and was routed through the auxiliary input of the double channel audiometer. The speech materials were presented through one channel of the audiometer at 0^0 azimuth and the two background competing stimuli were presented through the other channel of the audiometer at 180^0 azimuth from the loud speaker.

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). Speech recognition scores were obtained using "The Common Speech Discrimination Test for Indians" developed by Maya Devi (1974) and Speech identification scores were obtained using "Phonetically Balanced Word List" developed by Vandana (1998).

Hearing aid fitting and FM fitting: The hearing aid was programmed either for the right/left ear depending on the SIS scores. 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, the 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. 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.

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 for determining the SNR, in which the 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 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.

To account for possible order effects, the presentation of the type of background noise was randomized in different aided conditions.

Results and Discussion

Analysis: SPSS version 16 was used to make statistical calculations. Descriptive statistics, One way repeated measure Analysis of Variance (ANOVA), Two way repeated measure ANOVA, Bonferroni multiple comparisons and Paired sample t test was used for analysis of the data.

Table 1. Mean and Standard Deviation (SD) of MCL, BNL and ANL (in dB HL) Obtained Using Cafeteria noise (CN) and Speech-Babble (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.

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.

Results of the repeated measure ANOVA 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 ($p < 0.001$).

In the present study the MCL was significantly lower for the FM system compared to aided condition with and without directional microphone. 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). 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.

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

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. 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.

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. Results revealed 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 ($p < 0.001$). To find the difference in BNL between the two background competing stimuli 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 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). 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 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.

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

From the Table 1 and Figure 1 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 for all the three aided conditions.

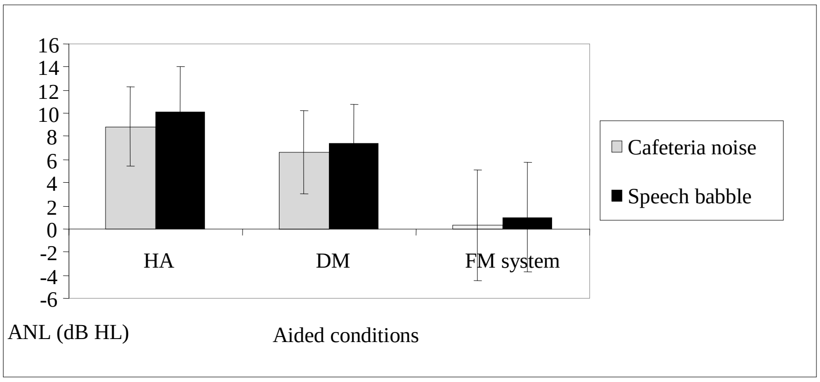

Figure 1. Mean ANL and standard deviation (S.D) for hearing aid with and without directional microphone and FM system obtained for cafeteria noise and speech babble.

Results of the two-way repeated measure ANOVA 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. Results revealed 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 ($p < 0.001$). 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 has been 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.

The findings of the present study with regard to the effect of directional microphone on ANL in agreement with the study done by Freyaldenhoven et al (2005). They too had reported a mean directional benefit of 3.5 dB for ANL. 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.

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 with the aided condition without any noise reduction technology. These results support the findings of Lytle (1994). 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 were approximately 2dB lower than the mean ANLs obtained using speech spectrum noise.

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.

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

Table 2. 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 2 it can be observed that the mean SNR was minimum for the FM condition and maximum for Hearing aid without directional microphone.

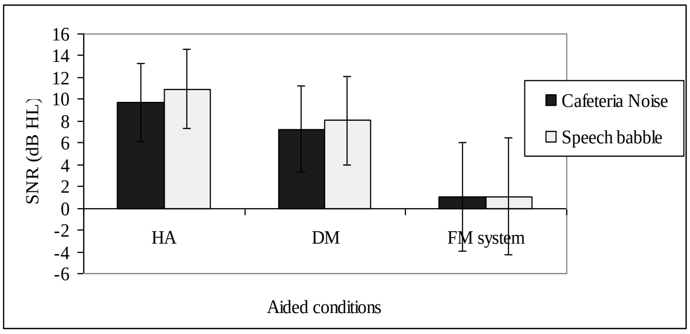

Figure 2. Mean SNR and standard deviation (S.D) for hearing aid with and without directional microphone and FM system obtained for cafeteria noise and speech babble.

From the Figure 2 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. Results revealed 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 ($p < 0.001$).

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.

Lesser SNR in FM system was obtained in the present study in comparison to the directional microphone. These results are in agreement with the study done by Lewis et al., (2004). 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.

The results of the present study are in fair agreement with the study done by Valente et al., 1995 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. The benefit of directional microphone in the present study may be due to the specific characteristics of the listening situations 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 (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).

The effect of different noises on SNR was similar to the findings of the past investigator (Sperry et al., 1997). The possible reason for getting higher SNR (poor performance) for speech babble than cafeteria noise in the present 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.

Thus it can be concluded from these findings that SNR was better with the use of FM system followed by the 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.

To know significant difference between ANL and SNR among three different aided conditions for two background competing stimuli, paired t test was done.

Table 3. Paired t test for (ANL) and (SNR) across two background competing Stimuli in three aided conditions.

Different aided Conditions with noises	t (27)	Significance level
(ANLHA)CN-(SNR)HACN	1.77	0.08
(ANLHA)SB-(SNR)HASB	1.27	0.21
(ANL)DMCN(SNR)DMCN	1.02	0.31
(ANL)DMSB-(SNR)DMSB	1.11	0.27
(ANL)FMCN-(SNR)FMCN	1.19	0.24
(ANL)FMSB-(SNR)FMSB	0.13	0.89

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 3 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 et al., (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. The possible reasons that could be attributed to the similar SNR and ANL obtained in the present study are,

1) Co oper & Cutts (1971) 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. 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.

2) Patients with lower ANL are likely to become successful, full time hearing aid users, patients with midrange ANLs may either be successful or unsuccessful users and patients with high ANLs 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.

Conclusion

From the results of the present study it can be concluded that 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. 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.

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