Effect of Different Signal Enhancing Technologies on Speech Recognition in Noise

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Abstract

A major consequence of sensori neural hearing loss (SNHL) is communicative difficulty, especially in the presence of noise and /or reverberation. The purpose of this investigation was to compare three types of technologies that have been shown to improve the speech perception performance of individual with SNHL: directional microphones (DMic), digital noise reduction (DNR) and frequency modulation (FM) system. 23 adult subjects with moderate to moderately severe SNHL served as subjects. Speech identification scores and signal to noise ratio (SNR) measurements were used to understand the benefit of these technologies in the presence of noise. These measurements were carried out in four listening conditions such as unaided, DMic, DMic+DNR and FM.Results revealed that speech perception in noise was significantly better with FM technology than with the other two listening conditions (DMic and DMic+DNR) in both SNR and speech identification measurement. There was no significant difference in performance between DMic and DMic+DNR listening conditions in SNR measurement. Even though the statistical analysis showed significant difference in performance between DMic and DMic+DNR listening condition in speech identification there was only an average of 2-3% improvement in speech identification with DMic+DNR over DMic.

Introduction

With appropriate prescription and fitting, a hearing aid can significantly improve speech recognition scores for an individual with hearing impairment in quiet and non-reverberant listening environment. This benefit, however, is greatly reduced in presence of noise, especially for individuals with higher degrees of hearing loss (Killion and Niquette, 2000). Hence, one of the challenges in providing amplification for the hearing impaired population is to select the technology that will provide the maximum benefit in background noise or competing speech. The most effective ways to improve speech recognition in noise is to improve the signal to noise ratio (SNR). Frequency modulation (FM) systems and directional microphones (DMic) are two examples of such technological advances (Hawkins, 1984; Lewis, Crandell, Valente and Horn, 2004). Automatic noise reduction or automatic signal processing is also one of the technologies designed to potentially increase intelligibility in noise (Graup et al., 1986).

Directional microphones typically use a cardiod polar plot sensitivity pattern, it means that they reduce signals originating from the rear and the sides and only amplify signal arriving from the front-where the speaker will often be located. Numerous investigations have demonstrated that directional microphone technology can improve speech intelligibility in noise by as much as 3 to 8 dB (Valente, Fabry & Potts (1995); Kuk, Ludvigsen and Paludan-Muller (2002); Ricketts and Dhar, 1999; Valente, Schuchman, Potts, and Beck (2000).

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Personal FM system has also been shown to improve speech intelligibility in noise (Hawkins, 1984; Fabry 1994; Crandel and Smaldino, 2000). Past investigations have demonstrated that the utilization of FM technology can improve speech intelligibility in noise by as much as 20-25 dB (Crandel and Smaldino, 2000). With personal FM system, the speaker's voice is picked-up via FM wireless microphone located near speaker's mouth – where the effect of reverberation, distance, and noise are minimal. The FM system converts the acoustic signal to an electrical waveform at the microphone, and the signal is transmitted via FM signal, from the transmitter to the receiver. Both the transmitter and the receiver are tuned to the same transmitting and receiving frequency. At the receiver end, the electrical signal is amplified, converted back to an acoustical waveform and conveyed to the listener.

The term 'Digital noise reduction (DNR) will be used to describe processing from a digital hearing aid which aims to provide less amplification for noise than speech. DNR algorithm relies on difference in physical characteristics of a signal to distinguish speech from noise (Rickets and Hornsby 2005).

Studies on the efficacy of DNR algorithms are less frequent in literature, and their conclusions are often inconsistent. Although listeners often demonstrate a strong tendency for subjective preference for DNR algorithms (Boymans and Dreschler, 2000), actual improvement in speech perception in reportedly unreliable. An implementation of DNR processing is to at least provide improved sound quality for speech in noise, in the absence of improved speech recognition (Ricketts and Hornsby 2005).

Despite the documented enhancement in speech intelligibility with directional microphone and FM technologies, only a few investigations have attempted to directly compare these two. Hawkins (1984) evaluated the speech intelligibility of children utilizing these two types of technologies (FM technology and DMic). Results demonstrated that FM technology, FM only mode provided significantly better speech recognition in noise when compared to directional microphone technology.

Lewis, Crandell, Valente and Horn, (2004) studied the speech perception ability of adults with mild to severe sensory neural hearing loss in noisy background utilizing directional microphone and FM technology. Results from this investigation indicate that FM system provides significantly improved speech intelligibility over the omni directional microphone (22.74 dB) and directional microphone (19.3 dB) listening conditions.

In practice DMic and DNR technologies are used in conjunction. Their interaction and resultant effect on speech perception in noise were studied by Nordrum and Dhar (2006). Results showed 50% of the participants performed better with both DMic and DNR activated in conjunction, while the other 50% performed better in the DMic only condition.

There are no studies which compare the effect of all the three technologies on signal enhancement in the presence of noise. Hence, main focus of the study was to compare the speech recognition in noise with DMic, DMic and DNR combined (DMic+DNR) and FM technology.

Aims of the Study:

The study aims to

1) Compare the speech identification scores in noise in following listening conditions,
   a) Monaural digital BTE in DMic mode (DMic).
   b) Monaural digital BTE in DMic + DNR condition (DMic+DNR).
   c) Monaural digital BTE utilized with one Microlink MLxS FM receiver in FM only mode (FM).

2) compare the Speech Recognition Threshold in noise in terms of SNR in the following conditions,
   a. Monaural digital BTE in DMic mode (DMic).
   b. Monaural digital BTE in DMic + DNR condition (DMic+DNR).
   c. Monaural digital BTE utilized with one Microlink MLxS FM receiver in FM only mode (FM).

Method

Subjects: Twenty three post-lingually hearing impaired subjects in the age range of 20 to 60 years (mean age of 51 years) served as the participants in the study. All subjects had bilateral gradually sloping moderate to moderately severe sensory neural hearing loss with a mean pure tone average of 65dBHL. Their speech identification score was greater than 60%. No indication of middle ear pathology as confirmed by tympanometry. They were native speakers of Kannada language and were experienced hearing aid users for more than 6 months.

Instrumentation: A calibrated dual channel diagnostic audiometer (Madsen orbiter 922) with TDH-39 head phone, bone vibrator B-71 and Martin (c115) speakers were used.

A Calibrated immittance meter (GSI-Tympstar) was used to rule out middle ear pathology.

Nonlinear digital BTE hearing aid which had options for directional microphone, digital noise reduction algorithm and FM compatibility (direct audio input) was used.

A Pentium IV computer with NOAH-3 software was used to program the hearing aid. Hi-pro was used to connect the hearing aid with computer.

A calibrated dual channel audiometer (Madsen orbiter 922) with two Martin (c115) speakers was used for the hearing aid testing. With input from a Pentium IV computer, the channel one of the audiometer was used to deliver the recorded speech material and the channel two of the audiometer was used to deliver speech babble.

Multifrequency FM transmitter and Microlink MLxS receiver was used in the study. The FM receiver was connected to the hearing aid with an appropriate audio shoe.

Stimulus: The phonetically balanced list in Kannada developed by Yathiraj and Vijayalakshmi (2005) was used in the study. The speech material consists of 4 phonetically balanced wordlist and each list has 25 words. The words were spoken in conversational style by a female native speaker of Kannada and were digitally recorded in acoustically treated room; on a data acquisition system using 44.1 kHz sampling frequency and 16 bit analogue to digital converter. Kannada speech babble developed by Anitha and Manjula (2005) was used as noise in the study.

The testing was done in sound treated double room. The ambient noise level inside the test room was within the permissible limits (re: ANSI S3.1 1991, as cited in Wilber 1994).

Procedure: The conditions used in the study were the following:

1) Monaural digital BTE hearing aid in directional mode (DMic).
2) Monaural digital BTE hearing aid in DMic with DNR.
3) Monaural digital BTE hearing aid connected to Micro link FM receiver in the FM only mode.

The hearing aid was programmed based on the audiometric thresholds using NAL-NL1 fitting formula. The participants were seated comfortably and were fitted with hearing aid on the test ear with appropriately sized ear tips. The hearing aid was fine tuned depending on the subject’s listening needs by manipulating the low cut, high cut gain and the cut-off frequency values. Two programs were stored in the hearing aid, in the first program DMic was activated, whereas in the second program both DMic and DNR were activated. Other parameters of the hearing aids were kept at default setting.

In the present study the test hearing aid used had a 16 channel modulation based digital noise reduction system and an adaptive Wiener filter in its DNR processing scheme. The DMic used in this study has a hyper cardiod polar pattern which suppresses noise coming from one direction (rear end) while retaining good sensitivity to sound arriving from the other direction (front end).

In the third condition, in addition to the hearing aid the subject was also fitted with Microlink MLXs FM receiver. The FM receiver was attached to the hearing aid directly with the audio shoe and the “FM only “mode was selected. Synchronization of the FM transmitter and receiver was made according to protocols specified by the manufacturer. The FM transmitter was placed on a stand located 7.5 cm from the loud speaker at a height of 0.5 meters to simulate ideal user position.

The testing was carried out in two phases: Speech identification in noise measurement and Speech recognition threshold in noise measurement. Among the 23 participants 11 subjects were randomly selected for speech identification measurement and 12 subjects for speech recognition testing.

Phase 1: speech identification in noise measurement.

The testing was done in a sound treated double room. The participant was seated at a distance of 1 meter from the loud speakers. Recorded speech material was presented from a loud speaker positioned at 0° azimuth and noise was presented at 180° azimuth. Speech identification score was measured in two signal-to-noise ratio's (SNR) 0 dB and +10 dB, the signal level was kept constant at 45 dB HL.

The order of listening conditions was randomized for each of the 11 participants tested. The participants were asked to repeat the words presented. The words correctly repeated were given a correct score of one; the words incorrectly repeated or missed out were not scored.

The speech identification measurements were done in the three listening conditions, namely

1) Monaural digital BTE hearing aid in directional mode (DMic).
2) Monaural digital BTE hearing aid in DMic with DNR.
3) Monaural digital BTE hearing aid connected to Micro link FM receiver in the FM only mode.

Phase 2: Speech Recognition Threshold in Noise in terms of Signal to Nose Ratio (SNR)

In this study, SNR is defined as the level at which the participant is able to repeat two out of three words (66.6% criterion) presented in noise. An adaptive procedure was utilized to establish the SNR. In this procedure, intensity of speech stimuli was held constant at 50 dB HL. The noise level was set 15 dB below the signal and systematically varied in 2 dB steps based on the participant's response. The noise level was varied until the subject repeats 2 words out of the three words presented. The noise level was subtracted from the speech level to find the SNR.

The performance was evaluated in three listening conditions, namely

1. Monaural digital BTE hearing aid in directional mode (DMic).
2. Monaural digital BTE hearing aid in DMic with DNR.
3. Monaural digital BTE hearing aid connected to Micro link FM receiver in the FM only mode

Results and Discussion

The present study was carried out to compare the benefit of various hearing aid technologies (DMic, DMic+DNR and FM) designed to improve speech understanding in noise. Speech identification scores and SNR measurements were used to understand the benefit of these technologies in the presence of noise. Speech identification testing was carried out in eleven subjects and SNR measurements were carried out in twelve subjects. All subjects had bilateral gradually sloping moderate to moderately severe sensory neural hearing loss with a mean pure tone average of 65dBHL. They were native speakers of Kannada language and all were experienced hearing aid users of more than 6 months. The data was appropriately tabulated and statistically analyzed using SPSS (15.0) version. Repeated measure ANOVA was used for statistical analysis.

Speech Identification Measurement

Speech identification measurement was carried out at two SNR's (0 and +10dB) in eleven subjects in three listening conditions namely DMic, DMic+DNR and FM. Mean and standard deviation for each of these conditions at two SNRs are depicted in Figure 1.

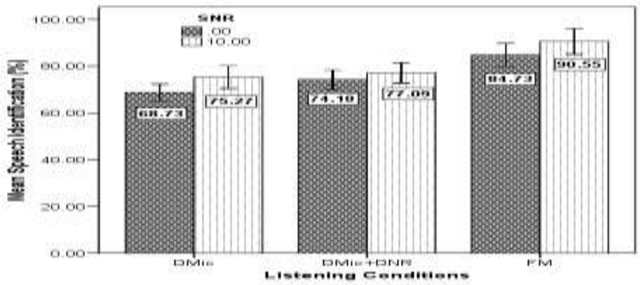

Figure: 1 Comparison of mean speech identification scores across the three listening conditions (DMic, DMic+ DNR and FM) in 0 and 10dB SNR

From figure1, it can be observed that mean speech identification performance is higher with FM compared to other two listening conditions (DMic and DMic + DNR). FM listening condition had an average of 10 to 14% greater improvement in speech identification at 0 dB and 10 dB SNR over DMic and DMic+DNR. Among DMic and DMic+DNR listening condition, the mean speech identification score was better in DMic + DNR by 2% at 0 dB SNR and 5% at 10dBSNR.

Repeated measure ANOVA was performed to assess the difference in speech identification scores across the three listening conditions (DMic, DMic+DNR and FM) at two SNR (0 dB SNR and 10 dB SNR), with listening conditions and SNR as within group factors.

Analysis revealed a significant main effect of listening conditions (DMic, DMic+DNR) ($F(2, 20) = 76.04$, $P<0.001$) and SNR ($F(1, 10) = 26.01$, $P<0.001$). Interaction analysis revealed that there is no significant interaction between listening conditions and SNR ($F(2, 20) = 3.01$, $P=0.072$). As there was significant difference between speech identification performance in the listening conditions multiple comparison using Bonniferronis test was performed for the three listening conditions, DMic, DMic+DNR and FM . Results showed that there was significant difference between DMic and DMic +DNR ($P<0.05$) listening conditions, DMic +DNR and FM ($P<0.001$) listening conditions, and DMic and FM ($P<0.001$) listening conditions.

Earlier research indicates significant improvement in hearing-in-noise performance with the use of DMic and FM. However, DNR has shown improvement in listening comfort rather than improvement in speech recognition in the presence of noise (Ricketts and Hornsby, 2005). In the present study there was significant difference in speech identification scores across DMic, DMic+DNR, and FM listening conditions. This finding is in contrast to the previous studies which have showed no significant improvement in speech perception in noise when using a DNR algorithm in isolation or in conjunction with directional microphone (Walden et al., 2000; Ricketts and Hornsby 2005).

It is difficult to compare across studies, because of the different procedures employed in estimating the benefit of these technologies in noise. Even though the statistical analysis showed significant difference in performance between DMic and DMic+DNR, there was only an average of 2-3% improvement in speech identification with DMic+DNR over DMic. Hence, this improvement cannot be considered as a drastic improvement in speech identification in the presence of noise.

Similarly, studies suggest that DNR algorithms may be effective in improving speech perception in noise when the speech and noise sources are not spatially separated (Bray et al 2002) or when the noise field is isotropic (Bray & Nilsson, 2001).

However, Ricketts and Hornsby (2005) studied the effect of digital noise reduction (DNR) processing on aided speech recognition and sound quality measures in a commercial hearing aid. The results revealed that the presence or absence of DNR processing did not impact speech recognition in noise (either positively or negatively). Paired comparisons of sound quality for the same speech in noise signals, however, revealed a strong preference for DNR processing. These data suggest that at least one implementation of DNR processing is capable of providing improved sound quality, for speech in noise, in the absence of improved speech recognition.

Hawkins (1984) demonstrated that the FM condition provided a significant improvement in speech identification scores in the presence of noise. Nelson, LaRue and Rourk (2004) fitted subjects monaurally with a unidirectional linearly programmed hearing aid and later coupled their hearing aid to a Phonak MLx FM receiver with DAI. It was found that the improvement in word identification scores were statistically significant for the FM condition when compared to the hearing aid alone condition.

To summarize, all the three conditions showed significant improvement in speech identification scores in the presence of noise. Though, the improvement with DMic and

DMic + DNR condition was statistically significant, the improvement in scores were minimal, this could be attributed to the difference in the speed and magnitude of gain reduction for the steady state signal across channels as well as the type of the competing signal (speech babble) used in this study. The improvement with FM was statistically significant over DMic and DMic + DNR conditions, this could be attributed to the improved signal-to-noise ratio provided with the FM system as it overcomes the effect of distance, reverberation and background noise.

(b) Speech Recognition Threshold in Noise in terms of Signal to Nose Ratio (SNR)

In this study, SNR is defined as the level at which the participant is able to repeat two out of three words (66.6% criterion) presented in noise. Repeated measures ANOVA were carried out to compare the SNR across various listening conditions namely unaided condition, DMic, DMic + DNR and FM conditions. Repeated measure ANOVA revealed that there is significant difference in SNR ($F (3, 33) = 329.086$, $p<0.001$) across the three listening conditions. Bonniferroni's multiple comparison test showed that there was no significant difference in SNR across DMic and DMic + DNR listening condition ($P>0.05$). However, there was significant difference between FM and each of the two other listening conditions (DMic, DMic+DNR).

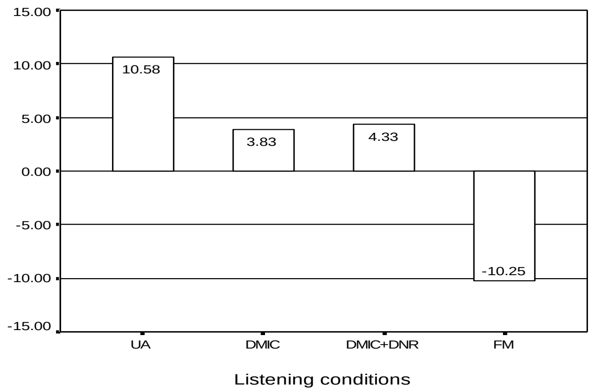

Figure-2 Comparison of mean SNR across different listening conditions (DMic, DMic + DNR and FM).

From the figure 2, it can be noted that the speech recognition performance (better SNR) was better with FM condition than with other listening conditions (DMic and DMic+DNR). In DMic listening condition, the subjects required an average SNR of 3.83 dB, while subjects required an average SNR of 4.33 dB in DMic+DNR condition. It can also be inferred from the figure that use of DMic resulted in an improvement of 6.75 dB over the unaided condition, while use of DMic+DNR resulted in an improvement of 6.25 dB over the unaided condition. Hence, it can be concluded that the use of DMic +DNR resulted in increment in SNR of only 0.5 dB over DMic listening condition, however this improvement in SNR was not statistically significant. In the FM condition subjects required SNR of -10.25; hence the use of the FM resulted in an improvement in SNR of

14.58 over DMic+DNR condition and 14.08 over DMic condition. This improvement in SNR with FM was statistically significant over the other two conditions.

In general, individuals with hearing impairment require the speech signal to be 4 to 18 dB higher than extraneous background noise in order to obtain speech recognition scores similar to individuals with normal hearing (Killion 1997a; Moore 1997). Similarly Killion (1997b), suggests that individuals with pure-tone averages of 65dB (PTA of individuals in present study) require an average SNR of 7-9 dB in order to obtain 50% correct on the Speech-In-Noise (SIN) test when the signal is presented at 70 dB HL. The subjects in this study required a SNR of approximately 10.58 in the unaided listening condition, which is in accordance with the results of Killion (1997).

In DMic condition there was an improvement of 6.75 dB over unaided condition. This finding is in accordance with the study by Lurquin and Rafthy (1996), where they obtained a statistically significant difference in SNR of 6.8 dB between unaided and directional microphone condition in similar experimental set up as in the present study.

In DMic+DNR condition there was only 6.25 dB advantage over the unaided condition. However, there was no significant difference in speech recognition threshold between DMic and DMic+DNR conditions. These finding are in agreement with the past researches (Walden et al 2000, Ricketts and Hornsby 2005), where it was concluded that there was no significant difference in the speech recognition in noise threshold between DMic and DMic+DNR conditions.

The best speech identification scores and better speech recognition in noise threshold (SNR) was found when subject fitted with FM than DMic or DMic+DNR. FM provided an improvement in SNR of 20.83 dB over unaided and 14.08 over DMic condition.

The results are similar to the conclusions derived from these studies:

Hawkins (1984) concluded that the FM only condition provided a significant improvement over DMic and DMic+DNR conditions (15.3 dB).

Similarly, Lewis and Crandall (2006) reported that monaural FM resulted in an improvement of SNR of 14.2 dB over directional microphone. In these studies, the proximity of the FM transmitter to the desired signal reduces the effects of noise, distance, and reverberation in a better way than hearing aids. This could be the reason for the improved speech recognition with FM technology.

To summarize, for the assessment of benefit from the three technologies (DMic, DMic + DNR and FM conditions) two methods were employed:

1) Speech identification scores
2) SNR measurement.

In the present study, an improvement of 14.08 dB was observed with FM technology over DMic in SNR measurement, whereas only 15% improvement was observed in the speech identification measurement with FM technology over DMic. This difference in the benefits across these methods could be attributed to the variability in the measurement procedures. One other reason for this difference in benefit could be the ceiling effect observed with speech identification (1^{st} method) scores due to which the advantage of FM system could not be completely assessed.

Overall, from the results of this investigation it can be concluded that FM technology significantly improves the speech intelligibility scores over the hearing aid conditions (DMic and DMic+DNR conditions) in the presence of noise. This data suggests that FM technology will offer significantly better communicative performance in adverse listening situations than any type of hearing aid microphone configuration or microphone with digital noise reduction configuration. Speech recognition in the presence of noise does not improve across DMic and DMic+DNR condition, this could be attributed to the DNR technology (modulation detection based noise reduction) used in the hearing aid and the type of noise used in this study.

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