Comparison of Directional Microphone and Digital Noise Reduction Algorithms in Hearing Aid Users

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Abstract

The hearing aid users often have difficulty understanding speech in the presence of background noise. With improved technology in hearing aids, directional microphones have demonstrated an improvement in speech perception in noisy situation. Whereas, digital noise reduction algorithms (DNR) provide more comfort but not significant assistance in improving speech perception in noise. With this focus the present study aimed to compare the performance of directional microphone and digital noise reduction algorithms (DNR), in hearing aid users. The study included two groups: 10 naive and 10 experienced hearing aid users. Acceptable noise level (ANL), speech perception in noise using SNR 50 and horizontal localization were evaluated. The participants of both groups were evaluated in directional microphone and digital noise reduction algorithms (DNR) conditions enabled independently and together. The results revealed that naive hearing aid users had poor performance compared to experienced hearing aid users. Both groups performed better in directional microphone + DNR on and directional microphone on condition compared to DNR alone condition.

Key words: *acceptable noise level (ANL), speech perception in noise (SNR 50), horizontal localization, hearing aids*

Introduction

The auditory system assimilates information from both ears and provides benefits in terms of loudness, localization, sound quality, noise suppression and listening in noise (Carhart, 1946; Keys, 1947; Hirsh, 1948; Koenig, 1950; Dillon, 2001). The auditory system has the potential to selectively attend to particular sound, is one of the most amazing and significant benefits of binaural hearing. Some individuals cannot benefit from hearing aids because of their inability to understand speech in the presence of background noise. Nabelek, Tucker and Letowski (1991) introduced a procedure for determining acceptable noise level (ANL) while listening to speech. This quantifies a listener's willingness to listen to speech in the presence of background noise. Auditory localization refers to the ability of a person to locate the sound source in space. It is very important in a daily life listening situations. It alerts a person for getting awareness about a potential danger and also helps in listening in noisy environment, by aiding to find out the signal source so the individual can give more attention to that source (Keidser et al., 2006; Devore et al., 2009). According to the 'duplex' theory, localization judgments in the frontal horizontal plane are primarily based on analysis of interaural time differences (ITD) cues at low frequencies and interaural level differences (ILD) and spectral shape cues at high frequencies. The comparison of noise and speech signals is commonly referred to as the signal to noise ratio (SNR) and is measured in decibels (dB). A quieter environment establishes a higher SNR, which indicates an easier listening condition. However, truly quiet conditions are rare and listening usually takes place in the presence of background sound which mixes with the target signal. The background sound might consist of multiple interferers in different locations and it tends to diffuse in nature. When a listener is physically further away from a talker, a lower SNR makes the desired message even more difficult to understand (Flexer, 2004).

NEED FOR THE STUDY

The common complaint of hearing aid users is difficulty understanding speech in the presence of background noise (Kochkin, 1993; 1994). With improved technology in hearing aids, directional microphones are considered as the method of improving signal to noise ratio, with demonstrated improvement in speech perception in noisy situation. On the other hand, digital noise reduction algorithms (DNR) are considered to provide more comfort but not significant assistance in improving speech perception in noise (Valente, 1999). However, there has been research to indicate that DNR, in combination with directional microphones, can provide significant improvement in the understanding of speech in noise relative to analog or DSP hearing aids using omnidirectional microphones (Valente, Sweetow, Potts & Bingea, 1999). Several studies have shown little evidence for acclimatization in the larger scale in experienced hearing aid users (Turner, Humes, Bentler & Cox, 1996; Humes et al., 2002; Humes & Wilson, 2003). There are various test procedures to measure the perception of speech in the presence of noise (SPIN), acceptance of noise as a background stimuli and localization of the speech. Reviewing the literature, there is dearth of research, reporting the results of these tests if individuals (naive and experienced) benefit from directional microphones and digital noise reduction algorithms (DNR) independently or in combination of the both.

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METHOD

Participants

Two groups of individuals in the age range of 18-50 years were taken for the study. Group I consisted of 10 adults (20 ears) using hearing aids for the first time (naive users). Group II consisted of 10 adults (20 ears) using hearing aids for more than 1 year (experienced users). All testing were carried out in a sound treated double room, with ambient noise levels within permissible limits as recommended by ANSI S3.1.1999. A dual channel clinical audiometer with sound field measurement facility was used for pure tone audiometry and speech audiometry testing. A calibrated diagnostic immittance meter (GSI tympstar) was used to assess the functioning of the middle ear system.

Hearing aids

A digital BTE hearing aid which fitted moderate hearing loss and which had an option to select both directional microphone and digital noise reduction algorithms independently was taken.

Instrumentation and stimulus for assessing acceptable noise level (ANL) and Signal to noise ratio 50 (SNR-50):

A dual channel diagnostic audiometer (Inventis Piano) was used for testing acceptable noise level and Signal to noise ratio 50 (SNR-50). Three recorded standardized passage in Kannada (Savithri & Jayaram, 2005) were presented through the audiometer to the loud speaker located at one meter distance from the participant at ±45o azimuth. Personal laptop was used to play the recorded standardized passage to obtain ANL, the output routed through the auxiliary input of the dual channel audiometer and presented through speaker. 'Sentence identification test in Kannada' (Geetha et al., 2014) was used to find SNR 50. Four talker speech babble generated by Nayana, Keerthi and Geetha (2016) was used as back ground noise. The sentences were presented through the audiometer to the loud speaker located at one meter distance from the participant at ±45o azimuth. Personal laptop was used to play the recorded standardized sentences to obtain SNR 50, the output routed through the auxiliary input of the dual channel audiometer and presented through speaker.

Instrumentation and stimulus for assessing horizontal localization task:

Nine loud speakers were arranged in a circular array with a radius of 1 meter. The position of loud speakers were in 0o, 40o, 80o, 120o, 160o, 200o, 240o, 280o and 320o azimuth covering a range of 0o to 360o. Each speaker was mounted on Iso-PodTM (Isolation position/ decouplerTM) vibration insulating table stand. CuBase 6 software was used to prepare and present the signals. All loud speakers were connected to the personal computer. Train of white noise pulses with each train in the duration of 200 ms separated by 200 ms of silence was used as stimulus (Tyler et al., 2002). White noise stimulus was generated using Adobe Audition 3.0 loaded in personal computer and was routed through the speakers. The output of each loud speaker was calibrated according to the standards.

Procedure

Participant selection

The pure tone thresholds for air conduction at octave frequencies from 250 Hz to 8 kHz and bone conduction threshold from 250 Hz to 4 kHz were obtained. Speech identification scores (SIS) was obtained using the PB word lists in Kannada language developed by Yathiraj and Vijayalakshmi (2005). Tympanometry and acoustic reflex using 226 Hz probe tone at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were assessed.

Programming of hearing aid

A digital hearing aid was programmed based on the audiogram using NAL-NL2 formula. The hearing aid was programmed for three settings; once with directional microphone (condition 1) and digital noise reduction algorithms activated (condition 2) independently, another with both directional microphone and digital noise reduction algorithms activated together (condition 3).

Acceptable noise level (ANL)

The participants were instructed to adjust the level of the speech to a level that is "too loud" then "too soft" and then "most comfortable level" (MCL) was obtained. Next, background noise (multi talker babble) was added, and the participants were instructed to adjust its level to a level that is "too loud " then "soft enough for the speech to be very clear" and finally to the highest level the participant was "willing to put up with" while following the speech. The difference between the participant's most comfortable listening level (MCL) and maximum tolerated background noise level (BNL) gives ANL.

ANL = MCL - BNL.

Same procedure was followed to check the performance of acceptable noise level in condition 1, 2 and 3 for both group I and group II.

Speech identification in noise

Ten sentences embedded at different SNRs were randomized. Each sentences were presented at 55dBHL in aided condition. The participants were instructed to repeat the sentences heard. The SNR at which the testing started (L) and number of correctly recognized target words in each sentence was noted down. The total number of target words from all the sentences were added (T). Also the total number of words per decrement

(W) and SNR decrement step size in each sentences (d) were noted down. The obtained values were substituted to the given equation adapted by Spearman-Karber to obtain SNR 50 % (Finney, 1952). The below equation was used to calculate SNR 50.

SNR 50 = L+ (0.5*d)-d (T)/W

The above procedure was carried out to check the performance of speech in noise in condition 1, 2 and 3 for both group I and group II.

Horizontal localization

The stimuli used for localization task was a train of white noise impulse of duration 200 millisecond. A set of 27 burst of noise were randomly assigned for different loudspeaker leading to have 3 stimulus per speaker. The participant's task was to orally indicate the source of stimulus from the array of speakers. The inter stimulus interval were changed according to each participants reaction time. Degree of error (DOE) was used to measure the accuracy of localization. The formula for calculating the root mean square DOE (Ching, Incerti & Hill, 2004) is given below.

$$rms\ DOE = \sqrt{\frac{(DOE)_1^{\,2} + (DOE)_2^{\,2} + (DOE)_3^{\,2} + \ldots + (DOE)9^2}{9}}$$

Where, DOE1-9 = Degree of error of the nine loud speakers; and

rms DOE = Root mean square degree of error.

Same procedure was followed to check the performance of horizontal localization in condition 1, 2 and 3 for both group I and group II.

RESULTS

The aim of current study was to compare the performance of directional microphone and digital noise reduction algorithms (DNR) in hearing aid users. Normality test was performed using Shapiro-Wilk test. Since, the data did not have normality ($p > 0.05$) hence non-parametric test was done. Further, Wilcoxon signed ranks test was done for comparison of data between right and left ear. No significant difference ($p > 0.05$) was found between scores of right and left ear. So, data of right and left ear were combined for both groups. Again normality test was re-performed with combined data of both ears. However, further analysis was done using non-parametric test as the data was not normally distributed.

1) Comparison of acceptable noise level (ANL) scores

Descriptive analyses of the data obtained from group I and II were analysed to obtain mean, median and standard deviation (SD) for ANL. Figure 1. shows the mean and standard deviation (SD) for ANL scores of both the groups of participants across three conditions.

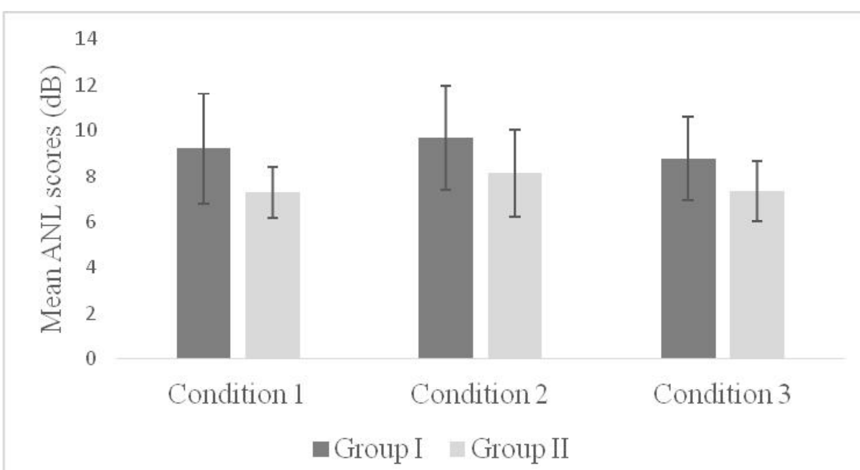

Figure 1: Mean and standard deviation (SD) of ANL scores of both the groups across three conditions

Lesser mean of ANL scores indicate better performance and larger mean of ANL scores indicate poorer performance. As shown in the figure 1, the mean for ANL is higher for group I compared to group II in all conditions. Which indicates that naive hearing aid user's performance is poorer for ANL compared to experienced hearing aid users.

Comparison of ANL scores across condition 1, 2 and 3 within group I.

The ANL data obtained across different conditions in group I was analysed using Friedman test. The results showed a significant difference across conditions [?2 (2) = 7.01, p <0.05]. Further, Wilcoxon signed rank test was conducted to determine which pair of condition had better performance.

Table 1: Pairwise comparison of ANL scores across condition 1, 2 and 3 within group I

Conditions	/Z/	Level of significance
ANL2 - ANL1	1.59	*P* >0.05
ANL3 - ANL1	1.34	*p* >0.05
ANL3 - ANL2	3.00	*p* <0.05

The results of Table 1, shows that the /Z/ value and level of significance obtained on pairwise comparison using Wilcoxon signed rank test across different conditions. Results of these analyses indicated that there was a significant difference between condition 2 and 3 (p < 0.05). However, there was no significant difference between scores of ANL in condition 1 and 2 and in condition 1 and 3 (p > 0.05).

Comparison of ANL scores across condition 1, 2 and 3 within group II.

The data obtained across different conditions in group II was analysed using Friedman test. It was found that there was a significant difference across conditions [?2 (2) = 8.27, p <0.05]. Wilcoxon signed rank test was conducted to determine which pair of condition are significantly better. Table 2, shows the /Z/ value and level of significance obtained on Wilcoxon signed rank test between different conditions.

Table 2: Pairwise comparison of ANL scores across condition 1, 2 and 3 within group II

Conditions	/Z/	Level of significance
ANL2 - ANL1	2.70	*p* <0.05
ANL3 - ANL1	0.28	*p* >0.05
ANL3 - ANL2	2.76	*p* <0.05

Results of Table 2 revealed that there was a significant difference between condition 2 and 3 (p <0.05) and in condition 1 and 2 (p <0.05). However, there was no significant difference seen between condition 1 and 3 (p >0.05).

Comparison of ANL scores between group I and group II

Non-parametric test Mann-Whitney U test was carried out to check if there are any statistical differences between groups.

Table 3: Comparison of ANL scores between groups and across different conditions

Conditions	/Z/	Level of significance
ANL 1	2.82	*p* < 0.05
ANL 2	1.74	*p* > 0.05
ANL 3	2.59	*p* < 0.05

Table 3, shows the /Z/ value and level of significance obtained on Mann-Whitney U test between group I and group II. The results revealed a statistically significant difference between condition 1 and 3 (p < 0.05), except in condition 2 (p >0.05).

2) Comparison of SNR 50 scores

Descriptive analyses of the data obtained from group I and II were done to obtain mean, median and standard deviation (SD) for SNR50 in different conditions. Mean and standard deviation (SD) of SNR 50 are shown in figure 2.

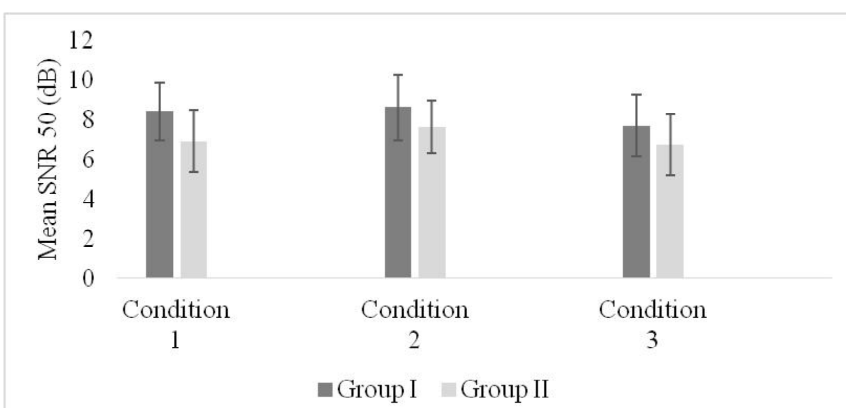

Figure 2: Mean and standard deviation (SD) of SNR 50 scores between two groups across conditions

Lesser mean of the SNR 50 indicate better performance and larger mean indicate poor performance. From figure 2 it can be seen that the mean for SNR 50 is higher for group I compared to group II. Which indicates that experienced hearing aid user's performed better in noisy situation compared to naive hearing aid users.

Comparison of SNR 50 scores across condition 1, 2 and 3 within group I

Friedman test was used to analyse the SNR50 data obtained across 3 different conditions. The data showed a significant difference across conditions [?2 (2) = 10.99, p <0.05]. Further, Wilcoxon signed rank test was conducted to determine which pair condition had better performance.

Table 4: Pairwise comparison of SNR 50 scores across condition 1, 2 and 3 within group I

Conditions	/Z/	Level of significance
SNR 2 - SNR 1	0.75	p >0.05
SNR 3 - SNR 1	2.50	p <0.05
SNR 3 - SNR 2	3.02	p <0.05

Table 4, shows the /Z/ value and level of significance obtained on Wilcoxon signed rank test between different conditions. The results of Table 4 revealed that there was a significant difference between condition 2 and 3 (p < 0.05) and condition 1 and 3 (p < 0.05). However, there was no significant difference seen between condition 1 and 2 (p > 0.05).

Comparison of SNR 50 scores across condition 1, 2 and 3 within group II

Friedman test which was used to analyse the SNR50 scores across 3 different conditions showed a significant difference across conditions [?2 (2) = 10.43, p <0.05]. Further, Wilcoxon signed rank test was conducted to determine which pair condition had better performance. Table 5, shows the /Z/ value and level of significance obtained on Wilcoxon signed rank test between different conditions.

Table 5: Pairwise comparison of SNR50 scores across condition 1, 2 and 3 within group II

Conditions	/Z/	Level of significance
SNR 2 – SNR 1	2.45	p <0.05
SNR 3 - SNR 1	1.07	p >0.05
SNR 3 - SNR 2	2.89	p <0.05

From the results of Table 5 it was found that there was a significant difference between condition 2 and 3 (p <0.05) and condition 1 and 2 (p <0.05). However, there was no significant difference seen between scores of SNR 50 for condition 1 and 3 (p >0.05).

Comparison of SNR 50 scores between group I and group II.

Non-parametric test Mann-Whitney U test was carried out to check statistical significance between groups.

Table 6: Comparison of SNR 50 scores of both the groups across three conditions

Conditions	/Z/	Level of significance
SNR 1	2.83	p < 0.05
SNR 2	1.86	p >0.05
SNR 3	1.79	p >0.05

The results showed that there was a significant difference in condition 1 (p < 0.05), except in condition 2 and 3 (p >0.05). Table 6, shows the /Z/ value and level of significance obtained on Mann-Whitney U test between group I and group II.

3) Comparison of horizontal localization scores

Descriptive analyses of the data obtained from group I and II were done to see the mean, median and standard deviation (SD) of rms DOE in localization. Figure 3, shows the mean and standard deviation (SD) of rms DOE in localization.

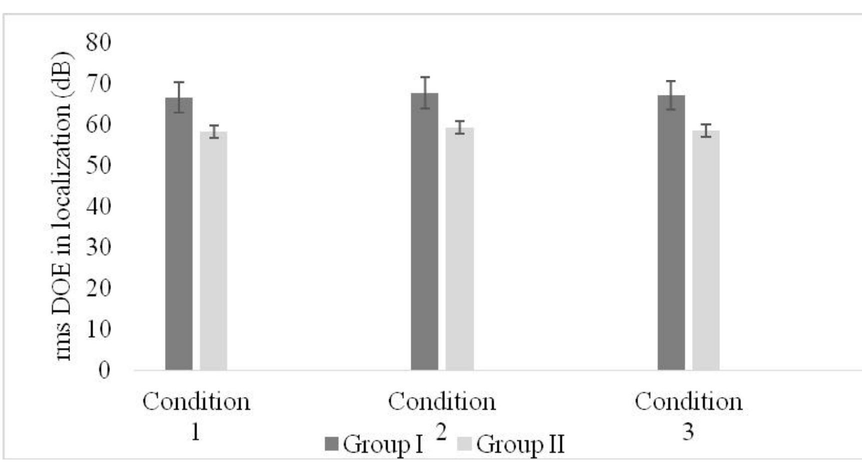

Figure 3: Mean and standard deviation (SD) of rms DOE in localization between two groups and across conditions

Lesser mean values of rms DOE represents less degree of error which indicate better performance in localization. Results showed that the mean for rms DOE of group II is lower than that of group I. Which indicates that experienced hearing aid user's less degree of errors compared to naive hearing aid users.

Comparison of horizontal localization across condition 1, 2 and 3 within group I

Localization data obtained across 3 different conditions using paired comparison was analysed using Friedman test. The data showed a significant difference across conditions [?2 (2) =22.79, $p < 0.05$]. Further, Wilcoxon signed rank test was conducted to determine which pair condition had better performance.

Table 7: Pairwise comparison of localization across condition 1, 2 and 3 within group I

Conditions	/Z/	Level of significance
loc2 - loc1	3.85	$p < 0.05$
loc3 - loc1	3.06	$p < 0.05$
loc3 – loc2	2.05	$p < 0.05$

Results of the analyses indicated that there was a significant difference between condition 1, 2 and 3 ($p < 0.05$). Table 7, shows the /Z/ value and level of significance obtained on Wilcoxon signed rank test between different conditions.

Comparison of horizontal localization across condition 1, 2 and 3 within group II

Friedman test was used to analyse the localization data obtained across 3 different conditions. The data showed a significant difference across conditions [?2 (2) =20.58, $p < 0.05$]. Further, Wilcoxon signed rank test which was conducted to check for condition that had better performance.

Table 8: Pairwise comparison of horizontal localization across condition 1, 2 and 3 within group II

Conditions	/Z/	Level of significance
loc2 - loc1	3.10	$p < 0.05$
loc3 - loc1	1.87	$p < 0.05$
loc3 – loc2	3.10	$p < 0.05$

Results of the analyses indicated that there was a significant difference between condition 1, 2 and 3 ($p < 0.05$). Table 8, shows the /Z/ value and level of significance obtained on Wilcoxon signed rank test across different conditions.

Comparison of horizontal localization between group I and group II.

To compare the results of rms DOE in localization between group I and group II, non-parametric test Mann-Whitney U test was carried out.

Table 9: Pairwise comparison of horizontal localization scores of both the groups across three

Conditions	/Z/	Level of significance
rms DOE	5.41	$p < 0.05$
rms DOE	5.41	$p < 0.05$
rms DOE	5.41	$p < 0.05$

conditions

Table 9, shows the /Z/ value and level of significance obtained on Mann-Whitney U test between group I and group II. The results showed that there was a significant difference between condition 1, 2 and 3 ($p > 0.05$).

DISCUSSION

1) Comparison of acceptable noise level (ANL) scores

Acceptable noise level (ANL) scores across different conditions were evaluated for both naive and experienced hearing aid users.

Comparison of ANL scores across condition 1, 2 and 3 within and between groups

Results of the ANL scores across different conditions within group I showed that, naive hearing aid users had better performance in directional microphone + DNR on condition compared to other conditions. Similar results were reported by Kim et al., (2014). The study investigated the effect of meaningful background speech noise on ANL for directional microphone hearing aid users. The results showed that directional hearing aid users accepted more noise (lower ANLs) when the background speech noise became more meaningful, and hearing impaired listeners accepted less amount of noise (higher ANLs), suggesting that ANL is dependent on the intelligibility of the competing speech. However, the study did not measure the effect of background on ANL for noise reduction algorithms.

Results of the ANL scores across different conditions within group II showed that, experienced hearing aid users had similar speech perception in noise performance in directional microphone on and directional microphone + DNR on condition. Freyaldenhoven, Nabelek, Burchfield and Thelin (2005) also found similar results where ANL for measuring hearing aid directional benefit was compared with masked speech reception threshold (SRT) and front to back ratio (FBR) procedures in 40 experienced hearing aids users in omnidirectional and directional modes. Results showed that mean ANL (3.5 dB), SRT (3.7 dB), and FBR (2.9 dB) directional benefits were not significantly different. The ANL and masked SRT benefits were significantly correlated. However, the study did not measure hearing aid benefit in noise reduction algorithms.

The present study was also taken to compare the results of ANL scores between groups and the results indicated that, experienced hearing aid users performed better compared to naive hearing aid users. Nabelek et al., (1991) also reported similar results in elderly listeners (? 65 years) fitted with hearing aids: full time users, part-time users, and rejecters. The results showed that the mean overall ANL (averaged across all of the background noises) for a group of full time hearing aid users was significantly smaller (7.5 dB) than the corresponding ANLs for part time hearing aid users (14 dB) or for individuals who stopped using their hearing aids (14.5 dB).

2) Comparison of SNR 50 scores

Speech in noise perception using SNR 50 scores across different conditions were evaluated for both naive and experienced hearing aid users.

Comparison of SNR 50 scores across condition 1, 2 and 3 within and between groups

Results of the SNR 50 scores across different conditions within group I indicated that directional microphone + DNR on condition improved speech perception in noise performance compared to other conditions. Several studies have reported similar findings (Peeters, Kuk, Lau & Keenan, 2009; Oliveira, Lopes & Alves, 2010). Peeters, Kuk, Lau and Keenan, (2009) measured speech intelligibility in noise offered by adaptive directional microphone and a noise reduction algorithms in hearing aids. Results of the study revealed that both the directional microphone and the noise reduction algorithm improved the speech in noise performance. The benefits reported were higher for the directional microphone than the noise reduction algorithm.

The results of SNR 50 scores across different conditions within group II indicated that experienced hearing aid users had similar speech perception in noise performance in both directional microphone on and directional microphone + DNR on condition. Similar results were reported by Dhar et al., (2006). The study compared directional microphones and digital noise reduction algorithms in 16 experienced adult hearing aid users. The results reaveled that thresholds for directional microphone alone and directional microphone + DNR conditions were significantly better than omnidirectional and DNR alone conditions. However, differences in thresholds between directional microphone and directional microphone + DNR as well as between omnidirectional and DNR conditions were not significant. In contrast to present study, Boymans and Dreschler (2000) found no benefit from the combined effect of active noise reduction and directional microphones relative to directionality alone.

The present study also compared the scores of SNR 50 between group I and group II and the results showed that, speech perception in noise was better in experienced hearing aid users compared to naive hearing aid users. Several studies have also reported similar results (Cox & Alexander, 1992; Gatehouse, 1993). Cox and Alexander (1992) studied speech recognition thresholds (SRT) in 8 new hearing aid users and 4 experienced hearing aid users. The results revealed no significant change or benefit in noisy/reverberant listening conditions in both new and experienced hearing aid users. However, in a low noise background experienced hearing aid users showed a statistically significant increase in mean benefit over time of 5-6%.

Comparison of horizontal localization scores

Horizontal localization scores across different conditions were evaluated for both naive and experienced hearing aid users

Comparison of horizontal localization across condition 1, 2 and 3 within and between groups

Results of the horizontal localization across different conditions within group I indicated that naive hearing aid users performed better when directional microphone + DNR condition is enabled. There are studies wherein it has been suggested that directional microphone can affect horizontal localization performance (Van den Bogaert et al., 2006; Keidser et al., 2006). Kobler and Rosenhall (2002) measured the effect of microphone directionality on localization and speech intelligibility in 19 adults with bilateral and unilateral hearing aid users. The results showed that microphone directionality did not improve horizontal localization in bilateral hearing aid user. However, the study did not measure localization in noise reduction algorithms.

Results of horizontal localization across different conditions within group II indicates that experienced hearing aid users performed similarly in directional microphone on and directional microphone + DNR on condition. Van den Bogaert, Doclo, Wouters and Moonen (2008) studied the effect of noise reduction systems on sound source localization in binaural hearing aid users. Results revealed that localization is highly influenced by noise reduction algorithms of hearing aid and could be an option to improve localization in hearing aid users.

The present study was also taken to compare the scores of horizontal localization between groups and the results indicated less rms DOE in localization for experienced hearing aid users compared to naive hearing aid users. Earlier studies have shown that sound localization is affected by hearing impairment (Hausler et al, 1983; Noble et al, 1994; Slattery & Middlebrooks, 1994; Rakerd et al, 1998). Byrne et al, (1992) studied localization in experienced users and reported that individuals with unilateral amplification might localize at least as well as users of bilateral amplification. However, the study did not measure localization in directional microphone/noise reduction algorithms.

SUMMARY AND CONCLUSION

The main objectives of the study were to compare the performance of directional microphone and digital noise reduction algorithms (DNR) in hearing aid users. The hearing performance was assessed using acceptable noise level (ANL), speech perception in noise (SNR50) and horizontal localization for both naive and experienced hearing aid users.

Acceptable noise level (ANL), SNR50 used to measure the speech identification in noise and rms degrees of error (DOE) were calculated to measure the horizontal localization performance. The evaluations were done for both naive and experienced hearing aid users in directional microphone and digital noise reduction algorithms (DNR) conditions. The scores of ANL, SNR50 and rms DOE in localization were tabulated and analysed using Statistical Package for Social Sciences version 20.0 (SPSS). Descriptive statistics, Mann-Whitney U test, Friedman test and Wilcoxon sign rank test were used for the analyses of data. The results revealed that Naive hearing aid users had better performance in directional microphone + DNR on condition compared to other conditions. Whereas, experienced hearing aid users performed similarly in directional microphone on and directional microphone + DNR on condition.

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