COMPARISON OF DIRECTIONAL MICROPHONE AND DIGITAL NOISE REDUCTION ALGORITHMS IN HEARING AID USERS

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Register Number: 15AUD005

A Dissertation Submitted in Part Fulfilment for the Degree of

Master of Science (Audiology)

University of Mysore, Mysuru

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MANASAGANGOTHRI, MYSURU-570006

MAY, 2017

CERTIFICATE

This is to certify that this dissertation entitled **"Comparison of directional microphone and digital noise reduction algorithms in hearing aid users"** is the bona fide work submitted in part fulfilment for the degree of Master of Science (Audiology) student with Registration Number 15AUD005. This has been carried out under the guidance of a faculty of this institution and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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This is to certify that this dissertation entitled **"Comparison of directional microphone and digital noise reduction algorithms in hearing aid users"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This dissertation entitled **"Comparison of directional microphone and digital noise reduction algorithms in hearing aid users"** is the result of my own study under the guidance of Dr. N. Devi, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru **Register Number: 15AUD005**

May, 2017

ACKNOWLEDGEMENT

"I can no other answer make but thanks, and thanks; and ever thanks" to my guide **Devi ma'am**, for her help, patience and encouragement during the study…

I would like to render my thanks to the director of AIISH, Dr. Savithri for permitting me to carry out the study.

I would like to express my thanks to HOD, Audiology Dr. Sandeep Maruthy sir, all teachers and staffs of AIISH for their support, motivation and timely helps throughout my life in AIISH.

Special thanks to Vikas sir, Hemanth sir, Nisha ma'am for guiding and helping me in localization unit for the study. Thanks to Jithin sir, Rama ma'am, Subramanya sir and Prashanth sir for their help.

Sincere thanks to Dr. Vasanthalakshmi ma'am for helping me in statistical analysis.

My best buddies Pavana, Lakshmi, Usha and Ammu… thank u guyz for all support.

My dearest friends in AIISH Sneha, Kirthi, Meenu, Sanjeev, Shanthu, Keerthi, Nayana, Naveen, jeena and all my classmates.

Big thanks to my seniors Sindhu, Shilpa, Rashmi, Tina, Ishu and juniors Sujan and Kavitha for their love and support during my AIISH life.

Lastly, thanks a lot my family amma, appa and my cute little sister (Shalu)… the word thank you is not enough for expressing my gratitude.

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.

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CHAPTER 1

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. To measure an ANL, listeners are asked to adjust running speech to their most comfortable listening level (MCL). Background noise is then introduced, and listeners are asked to adjust the noise to their maximum acceptable background noise level (BNL) while listening to and following the words of a story. The difference between the BNL and the MCL is the ANL. This procedure quantifies a listener's willingness to listen to speech in the presence of background noise. ANLs are not related to age (Nabelek et al., 1991; Freyaldenhoven & Smiley, 2006; Nabelek, Freyaldenhoven, Tampas, Burchfield & Muenchen, 2006), hearing sensitivity (Nabelek et al., 1991; Freyaldenhoven et al., 2006), type and preference of background sounds (Nabelek et al., 1991; Crowley and Nabelek, 1996), gender (Rogers et al., 2003), primary language of the listener (von Hapsburg & Bahng, 2006), presentation level (Freyaldenhoven et al., 2007; Recker & Edwards, 2013), acoustic reflex thresholds or contralateral suppression of otoacoustic emissions (Harkrider & Smith, 2005), middle ear characteristics (Harkrider & Smith, 2005), cochlear responses, efferent activity of the medial olivocochlear bundle pathway (Harkrider & Smith, 2005; Harkrider & Tampas, 2006), or speech perception in noise scores (Nabelek, Tampas & Burchfield, 2004). ANLs are reliable and normally distributed in individuals with both normal and impaired hearing (Freyaldenhoven et al., 2006; Nabelek et al., 2006).

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. It 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. (Lord Rayleigh, 1907; Mills, 1972; Kistler & Wightman, 1992). As high frequencies are often inaudible to individuals with a sensorineural hearing loss, they would have reduced access to ILD and spectral cues and therefore rely mostly on ITD cues. According to Blauert, (1983) interaural differences in time, phase and level (ITD, IPD and ILD respectively) are the major cues in localization. ITD and IPD occur coincidently and IPD vary systematically with source azimuth and wavelength. IPDs dominate in localizing the low frequency sounds (up to 1.5 kHz). ILDs are the most prominent cue in localizing high frequency sounds (above 1.5 kHz) and can result in up to 20 dB difference between the two ears at 6 kHz. These spectral cues help mainly for vertical localization of broadband high frequency sounds (4-12 kHz) (Moore, 1997).

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). The SNR 50 of individuals with hearing loss is 30 dB higher than that of individuals with normal hearing i.e. for a given background noise, the speech needs to be 30 dB higher to achieve the same level of understanding as individuals with normal hearing (Tillman et al., 1970; Dirks et al., 1982; Duquesnoy, 1983; Festen & Plomp, 1990; Baer & Moore, 1994; ; Plomp, 1994; Eisenberg et al., 1995; Killion, 1997a; Peters et al., 1998, Killion & Niquette, 2000; Soede, 2000). Individuals with sensorineural hearing loss require a SNR of up to +20 dB for optimal speech recognition scores (Ross et al., 1991). Due to the fact that a majority of real world listening conditions most commonly range from -10 to +5 dB SNR, the speech recognition ability of people with sensorineural hearing loss is often at a disadvantage (Ricketts & Hornsby, 2005). The most commonly used strategies to improve signal-to-noise ratio (SNR) in hearing aids are those that reduce the output of the "noise" in frequency ranges other than those important for speech intelligibility (Bentler et al., 1993). Several studies have reported significant improvement in speech intelligibility in noise with the use of directional microphones (Valente et al., 1995; Agnew & Block, 1997; Voss, 1997; Killion et al., 1998).

Directional microphones are used to preserve a desired signal coming from a certain direction while reducing noise and interferences from other directions. Directional microphones are preferred when the background noise is present to the side or the rear, or when the desired signal is near to the listener, and the reverberation is low. Background noise tends to decrease the speech intelligibility especially for people suffering from hearing loss (Edwards, 2000; Levitt, 2001). Several studies have shown that the directional microphone gives na improvement of about 3 dB in Speech recognition threshold in difficult listening conditions (Hawkins & Yacullo, 1984; Leeuw & Dreschler, 1991; Maj et al., 2004). The goal of Digital Noise Reduction algorithms (DNR) is to reduce the background noise and enhance the desired speech signal in complex acoustical environments in order to improve speech intelligibility and/or listening comfort by increasing the SNR without introducing any signal distortion (Chung, 2004).

The period that succeeds the fitting of hearing aids, when a progressive improvement of the hearing and speech recognition abilities is observed due to the new speech cues that are available to the hearing aid user is termed as "Acclimatization" (Arlinger et al., 1996). Several studies were done with the aim of evaluating acclimatization after a certain period of use of hearing aids (Humes et al, 2002; Philibert et al, 2002; Kuk, Poos et al, 2003; Munro Lutman, 2003, Humes Wilson, 2003; Flynn, Davis Pogash, 2004). The results revealed a perceptible improvement in the speech abilities or a subjective benefit after continuous use of sound amplification.

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.

AIM

The aim of current study is

- To compare the performance of directional microphone and digital noise reduction algorithms (DNR) in hearing aid users.

OBJECTIVES

- To assess the acceptable noise level using directional microphone and digital noise reduction algorithms (DNR) in naive hearing aid users.
- To assess the acceptable noise level using directional microphone and digital noise reduction algorithms (DNR) in experienced hearing aid users.

- To assess the speech perception in noise using directional microphone and digital noise reduction algorithms (DNR) in naive hearing aid users.
- To assess the speech perception in noise using directional microphone and digital noise reduction algorithms (DNR) in experienced hearing aid users.
- To assess the horizontal localization using directional microphone and digital noise reduction algorithms (DNR) in naive hearing aid users.
- To assess the horizontal localization using directional microphone and digital noise reduction algorithms (DNR) in experienced hearing aid users.
- To compare the acceptable noise level, speech perception in noise and horizontal localization between naive and experienced hearing aid users.

CHAPTER 2

REVIEW OF LITERATURE

2.1. Performance of directional microphones and digital noise reduction algorithms (DNR).

Directional Microphones rely on spatial separation of a signal of interest i.e., speech and an unwanted signal i.e., noise (Ricketts, 2001). Digital Noise Reduction Algorithms (DNR) on the other hand, rely on differences in physical characteristics of a signal to distinguish speech from noise (Boymans & Dreschler, 2000; Kuk, Ludvigsen, & Paludan Muller, 2002). Significant improvement in hearing in noise performance with the use of Directional Microphones and an improvement in comfort with the use of DNR algorithms are reported (Ricketts & Hornsby, 2005).

Boymans and Dreschler (2000) measured the effects of a digital hearing aid on speech recognition or reception in noise for two noise reduction concepts: active noise reduction and directional microphones, separately and in combination. Study was done on 16 experienced hearing aid users, using a single blind crossover design. The study had combined laboratory experiments with three consecutive field trials of 4 weeks each. Performance measurements (speech recognition tests in background noise), paired comparisons and self-report measurements (questionnaires) were done. The speech recognition tests were performed before and after each field trial, the paired comparisons were performed in weeks 4 and 12 and the questionnaires were administered after each field trial. Results were obtained for three different settings: no noise reduction, active noise reduction alone and directionality alone. The effects of directional microphone were clearly positive, especially for the speech reception threshold tests and for the paired comparisons. The effects of active noise reduction showed much smaller but significant benefits with respect to averseness and speech perception in noise for specific acoustical environments. There was no extra benefit from the combined effect of active noise reduction and directional microphones relative to directionality alone.

Dhar et al., (2006) compared directional microphones and digital noise reduction algorithms. The performance of hearing in noise test (HINT) was done on 16 (symmetric, moderate to severe sensorineural hearing loss) experienced adult hearing aid users. When each technology was activated independently and then simultaneously in 4 commercially available hearing aids. 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.

McCreery, Venediktov, Coleman and Leech (2012) conducted an evidence based review to evaluate the efficacy of digital noise reduction and directional microphones for outcome measures of audibility, speech recognition, speech and language and self or parent report in paediatric hearing aid users. Twenty six databases for experimental studies published after 1980 addressing one or more clinical questions and meeting all inclusion criteria were included. The studies for methodological quality and reported or calculated p values and effect sizes were evaluated. A systematic search of the literature resulted in the inclusion of 4 digital noise reduction and 7 directional microphone studies (in 9 journal articles) that addressed speech recognition, speech and language, and/or self or parent report outcomes. No digital noise reduction or directional microphone studies addressed audibility outcomes. It was found that, digital noise reduction did not improve or degrade speech understanding whereas, directional microphones resulted in improved speech recognition in controlled optimal settings.

2.2. Effect of microphone directionality on localization and speech perception in noise.

One of the methods to improve SNR is directional hearing aids that work based on the spatial location of the signal of interest relative to unwanted signals. Directional hearing aids can give approximately 3-6 dB improvement; hence can give improved speech recognition across a range of noisy environments when compared to omnidirectional amplification (Ricketts, 2001). In comparison to omnidirectional microphone technology, directional microphone technology has demonstrated significant improvements in speech recognition in difficult listening environments, especially in noise. This benefit has been found on the order of 3-4 dB (Hawkins and Yacullo, 1984) or as high as 7-8 dB (Valente et al., 1995).

Speech recognition in fifty adults with mild to moderately severe sensorineural hearing loss was assessed by Valente, Fabry, and Potts (1995). All participants were using behind the ear hearing aids. Hearing in noise test (HINT) was done in two microphone modes with four programs. First, with a “basic” program in which the omnidirectional microphone and the hearing aids programmed so the real ear insertion response (REIR) matched the NAL-R prescriptive target. Second, with a “basic” program with the dual microphones activated. Third, with a “party” comfort program with only the omnidirectional microphone active. Fourth, with a “party” program with the dual microphone active. Comparison made across four conditions revealed a mean improvement of 7.4 to 7.8 dB in the “basic” program when the dual microphone was activated in comparison to omnidirectional performance. In addition, the dual-microphone “party” condition improved the performance by 7.7 and 8.5 dB relative to the basic omnidirectional condition. Finally, there was only a 0.3 to 0.7 dB improvement for the party dual-microphone condition in comparison to the “basic” dual-microphone condition. This difference was not statistically significant. Similar results were obtained in In The Ear (ITE) type of hearing aids in a study done by Valente, Schuchmant, Potts, and Beck (2000).

Gravel et al., (1999) studied the speech recognition in noise in 20 children with mild to moderate severe hearing loss. And also, two microphone conditions with binaural hearing aids was assessed. First, using Omni directional hearing aid and second, dual microphone hearing aid technology. The children were grouped in to 2 groups based on age, 4 to 6 years and 7 to 11 years. The test materials that was used were words and sentences from Paediatric speech intelligibility (PSI) developed by Jerger and Jerger in 1984. The background noise was a multitalker babble. Speech stimuli presented from 0° azimuth and the noise presented from a speaker placed one meter behind the subject at 180° azimuth. They found a significant difference between two microphone conditions, between the two age groups and the two stimuli types in terms of SNR that yielded 50% correct recognition both stimuli. There was a mean advantage of 4.7 dB SNR for dual microphone condition over Omni directional condition. Better SNRs were seen for older group of children irrespective of stimuli type and microphone conditions and for sentences irrespective of age group and microphone conditions.

Effect of microphone directionality on localization and speech intelligibility in 19 adults (mild to moderate sensorineural hearing loss) with bilateral and unilateral hearing aid users was assessed by Kobler and Rosenhall (2002). The horizontal localization task included an array of 8 loudspeakers in horizontal plane with 45°

difference between them. Number of correctly identified sources was taken as measure of localization performance. 50% scores were obtained in both unaided and bilateral aided condition whereas in unilateral aided condition the performance was very poor, on an average only10%. The results concludes that horizontal localization could not be improved by bilateral hearing aid fitting. However, bilateral hearing aid fitting had significant advantage on localization over unilateral hearing aid fitting. Speech in noise test with Swedish sentences (Hagerman, 1982) were used. It was measured as a percentage of correctly identified words. The poorest scores occurred in unaided condition. There was an improvement of 13% with unilateral aided condition and 18% with bilateral aided condition in speech intelligibility scores. The difference was statistically significant.

Lewis, Crandell, Valente and Horn (2004) compared the effect of directionality and FM system on speech perception in noise. Forty five subjects with mild to severe sensorineural hearing loss participated in the study. Hearing in Noise Test (Nilsson et al., 1994) was used for assessing speech perception in noise. Correlated speech shaped noise was used as noise which is of typical acoustic spectra of every day listening situations. The reception threshold for sentences (RTS) was obtained. The results revealed that there was improvement in mean RTS by approximately 5 dB in binaural hearing aid conditions with omnidirectional microphone mode compared to unaided condition. Also, the utilization of directional microphone gives an improvement of 1.2 dB in RTS over omnidirectional microphone mode. With FM system, there was significant improvement (of around 15.5 dB) in speech perception over any hearing aid conditions, even with the use of the directional microphone. Speech perception was even better by using two hearing aids in conjunction with two FM receivers rather than with just one FM receiver.

Van den Bogaert, Doclo, Wouters and Moonen (2008) studied the effect of multi microphone noise reduction systems on sound source localization by users of binaural hearing aids. Two noise reduction techniques for binaural hearing aids namely, the binaural multichannel Wiener filter (MWF) and the binaural multichannel Wiener filter with partial noise estimate (MWF-N), and a dual monaural adaptive directional microphone (ADM), which is a widely used noise reduction approach in commercial hearing aids were evaluated. Mean absolute error (MAE) was taken as a measure of localization performance. MAE is defined as the sum of difference of stimulus azimuth and response azimuth divided by the total number of presentations. MAE were measured in different stimulus conditions such as noise and speech component presented separately(S,N); speech and noise components were presented simultaneously which resembled more a steady-state real-life listening situation (S+N). From results it was concluded that localization is highly influenced by noise reduction algorithms of hearing aid. It was concluded that the localization cues were preserved for certain stimuli such as speech and certain location signals such as front direction. For e.g. the localization is better for signal from front when using ADM, in which strategy very less noise reduction happened for sounds from front direction..

Keidser et al., (2009) studied the effect of frequency dependent microphone directionality on horizontal localization in 21 adults. Comparison of the localization performance was done between subjects using hearing aid with that of the data obtained from 30 adults with normal hearing sensitivity. The spectral shape of signal was altered based on the location of sound source in frequency dependent microphone directionality system. Five different stimuli with different spectral features were presented through loudspeakers arranged in a circular array. The localization task was carried out in four conditions: without hearing aids, with hearing aids having no directionality, with hearing aids having partial (from 1 and 2 KHz) directionality and full directionality. It was concluded from the results that there was only a small positive effect seen for full directionality in front/back localization and negative effect seen for left/right localization. Partial directionality showed an improvement in front/back localization but no effect on left/right localization. The performance was very poor for unaided condition and aided with no directionality conditions.

2.3. Effect of digital noise reduction algorithms (DNR) on localization and speech perception in noise.

Keidser et al., (2006) studied the effect of directional microphones, wide dynamic range compression and noise reduction strategies (DNR) on horizontal localization. Participants were 12 adults with a median age 75 years and with a pure tone 3 frequency average 46 dB HL. Pink noise pulses with a duration of 750 ms were used as a stimulus for different conditions with omnidirectional, cardioid and figure eight microphone setups. 12 speakers were arranged in a circle with 18^{o} difference. Degree of error was obtained. From the results it was concluded that fitting a cardioid (directional) microphone on at least one ear could improve front/back discrimination. The reason could be accounted for the more amplification that happens to the signals from front source and suppression of signals from rear due to the cardioids (directional) microphone, whereas there is an equal amplification to signals from front and rear sources in Omni directional and figure eight microphone condition. The difference in amplification for front and back signal at least in one side may have an effect in front/back localization of sound.

Oliveira, Lopes and Alves (2010) studied speech perception through digital hearing aid using a digital noise reduction algorithm on 32 individuals with mild to moderate sensorineural hearing loss. The participants were tested for sentence recognition with an active and inactive noise reduction algorithm in the presence of competing noise. After a period of training, the subjects were re-tested and the results showed a significant advantage in sentence recognition in the presence of the noise reduction algorithm compared to when noise reduction algorithm was off. It was concluded that the noise reduction algorithms could be an option in individuals who find it difficult to understand in the presence of noise.

2.4. Effect of microphone directionality on acceptable noise level (ANL).

Binaural directional microphone processing allows hearing aid users to accept a greater amount of background noise (lower ANLs), which may in turn improve listener's hearing aid success (JaHee Kim et al., 2014). ANLs are the same for normal hearing and hearing impaired persons and, in general, range from around –2 dB to 30 dB, with a mean ANL of 10 to 11 dB. Both directional microphone technology and DNR can reduce the aided ANL (Nabelek, 2005).

Freyaldenhoven, Nabelek, Burchfield and Thelin (2005) compared acceptable noise level (ANL) for measuring hearing aid directional benefit with masked speech reception threshold (SRT) and front to back ratio (FBR) procedures. Forty adult subjects wearing binaural hearing aids were evaluated in omnidirectional and directional modes. The participants were fitted with a variety of hearing aids by clinical audiologists, independent of the study. For each procedure, speech and noise were presented through loudspeakers located at 0 degrees and 180 degrees azimuth, respectively. 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.

Peeters, Kuk, Lau and Keenan, (2009) measured the subjective and objective improvement of speech intelligibility in noise offered by a commercial hearing aid that uses a fully adaptive directional microphone and a noise reduction algorithm that optimizes the Speech Intelligibility Index (SII). Eighteen participants with varying configurations of sensorineural hearing loss were evaluated using Hearing in Noise Test (HINT) and the Acceptable Noise Level (ANL). It was found that both the directional microphone and the noise reduction algorithm improved the speech in noise performance of the participants. The benefits reported were higher for the directional microphone than the noise reduction algorithm. A moderate correlation was noted between the benefits measured on the HINT and the ANL for the directional microphone condition, the noise reduction condition, and the directional microphone plus noise reduction conditions.

Kim and Bryan (2011) studied the effects of asymmetric directional microphone fittings (i.e., an omnidirectional microphone on one ear and a directional microphone on the other) on speech understanding in noise and acceptance of background noise (ANL). Fifteen full-time hearing aid users were fitted binaurally with four directional microphone conditions (i.e., binaural omnidirectional, right asymmetric directional, left asymmetric directional and binaural directional microphones). Speech understanding in noise was assessed using the Hearing in Noise Test (HINT) and acceptance of background noise (ANL) was assessed using the Acceptable Noise Level procedure. Speech was presented from 0° while noise was presented from 180° azimuth. The results revealed that speech understanding in noise improved when using asymmetric directional microphones compared to binaural omnidirectional microphone fittings and was not significantly hindered compared to binaural directional microphone fittings and listeners accepted more background noise when fitted with asymmetric directional microphones as compared to binaural omnidirectional microphones. It was also found that the acceptance of noise was further increased for the binaural directional microphones when compared to the asymmetric directional microphones.

JaHee Kim et al., (2014) studied the effect of Acceptable Noise Levels (ANLs) in binaural listening and in monaural listening condition and also the effect of meaningful background speech noise on ANL for directional microphone hearing aid users. Fourteen hearing aid users in the age range of 32-84 years participated in the study. Seven young normal hearing listeners in the age range of 24-29 years were taken for pilot testing. The ANLs were compared across 5 types of competing speech noises, consisting of 1-8 talker background speech maskers. The results showed that directional hearing aid users accepted more noise (lower ANLs) with binaural amplification than with monaural amplification, regardless of the type of competing speech. When the background speech noise became more meaningful, hearing impaired listeners accepted less amount of noise (higher ANLs), suggesting that ANL is dependent on the intelligibility of the competing speech.

2.5. Effect of digital noise reduction algorithms (DNR) on acceptable noise level (ANL).

Muller et al., (2006) studied the effect of Digital Noise Reduction on ANL. Twenty two adults fitted with 16 channel wide dynamic range compression hearing aids containing DNR processing were evaluated. Both speech intelligibility and acceptable noise level (ANL) were assessed using the Hearing in Noise Test (HINT) with DNR on and DNR off. The ANL was also assessed without hearing aids. A significant mean improvement for the ANL (4.2 dB) in DNR on condition was seen compared to DNR off condition. There was no significant mean improvement for the HINT for the DNR on condition, and on an individual basis, the HINT score did not significantly correlate with either aided ANL (DNR on or DNR off) suggesting that, at least within the constraints of the DNR algorithms it can significantly improve the clinically measured ANL, which results in improved ease of listening for speech in noise situations.

Wu and Stangl (2013) studied the effect of WDRC and its combined effect with digital noise reduction (DNR) and directional processing (DIR), on ANL. They also studied, whether the hearing aid output SNR could predict aided ANL across different combinations of hearing aid signal processing schemes. Twenty-five adults with sensorineural hearing loss were evaluated. ANL was measured monaurally in two unaided and seven aided conditions, in which the status of the hearing aid processing schemes (enabled or disabled) and the location of noise (front or rear) were manipulated. The hearing aid output SNR was measured for each listener in each condition using a phase inversion technique. The aided ANL was predicted by unaided ANL and hearing aid output SNR, under the assumption that the lowest acceptable SNR at the listener's eardrum is a constant across different ANL test conditions. Results revealed that, on average, WDRC increased (worsened) ANL by 1.5 dB, while DNR and DIR decreased (improved) ANL by 1.1 and 2.8 dB, respectively. Because the effects of WDRC and DNR on ANL were opposite in direction but similar in magnitude, the ANL of linear/DNR-off was not significantly different from that of WDRC/DNR-on. The results further indicated that the pattern of ANL change across different aided conditions was consistent with the pattern of hearing aid output SNR change created by processing schemes.

2.6. Comparison of performance between experienced and naive hearing aid users.

Nabelek et al., (1991) measured ANLs for three groups of elderly listeners (≥ 65 years) fitted with hearing aids: full time users, part-time users, and rejecters. Each group consisted of 15 subjects. The ANLs were collected under earphones for five different types of background noise (speech babble, speech spectrum, pneumatic drill, traffic noise, and elevator music). The results revealed no significant difference between different types of noises. The data indicated that ANLs were related to the use of hearing aids. 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). Thus, it was concluded that full time hearing aid users accepted more background noise than did either part time users or individuals who stopped using their hearing aids. The ANLs for part time users and rejecters are not significantly different.

Cox and Alexander (1992) studied speech recognition thresholds (SRT) in 8 new hearing aid users and 4 experienced hearing aid users. Speech recognition was measured using the Connected Speech Test (CST) at the time of fitting and 10 weeks later. There was no significant change in mean benefit (aided minus unaided) performance in noisy or reverberant listening conditions in both new and experienced users. However, in a low noise background there was a statistically significant increase in mean benefit over time of 5–6% in experienced users.

Gatehouse (1992) used the Four Alternative Auditory Feature (FAAF) test to track performance over a 12 weeks post fitting period in 4 new hearing aid users fitted monaurally. Benefit increased from 5% at the time of fitting to greater than 15% at 12 weeks post fitting. The improvement commenced at around 6 weeks post fitting and was due to both an increase in the aided condition and a decrease in the unaided condition. No improvement in benefit was observed in the not fitted control ear of these monaurally aided subjects. In a subsequent experiment, Gatehouse (1993) refitted 36 experienced hearing aid users with a new aid that provided greater high frequency amplification than their previous one. Aided performance was measured on the FAAF test at 0, 8, and 16 weeks after the new fitting. It was seen that, mean scores with the old and new hearing aids were similar initially but increased significantly by 2.3% at 8 weeks and 4.4% at 16 weeks respectively.

Cox et al., (1996) studied the benefit of Connected Speech Test (CST). Experienced hearing aid users were taken as a control group. The experimental group of 22 new hearing aid users were fitted monaurally and tested at the time of fitting and 12 weeks later. The results showed an increased mean benefit on CST from 4% at the time of fitting to 8%, 12 weeks later. There was no improvement seen in the control group. The change in benefit was due to an increase in aided performance with no change in unaided performance.

Horwitz and Turner (1997) compared 13 new hearing aid users fitted monaurally with 13 experienced hearing instrument users as the controls. Speech recognition was measured over 18 weeks using the Nonsense Syllable Test (NST) with the hearing aid at a fixed initial gain setting and at the participant's daily adjusted gain setting. The results showed a gradual increase in mean benefit from around 6% at the time of fitting to around 14% at 18 weeks for the fixed gain setting in the new users. This was due to increases in aided performance rather than reductions in the unaided performance.

Humes and Wilson (2003) studied the changes in hearing aid performance and benefit in 9 elderly hearing aid wearers over a 3 year period following the hearing aid fitting. Objective measures of hearing aid performance included 3 measures of speech recognition: (a) the Nonsense Syllable Test (NST) presented at 65 dB SPL and a +8 dB signal-to-noise ratio (SNR), (b) the Connected Speech Test (CST) presented at 50 dB SPL in quiet, and (c) the CST presented at 65 dB SPL and a +8 dB SNR. Subjective, self-report measures of hearing-aid benefit included the Hearing Aid Performance Inventory (HAPI) and the Hearing Handicap Inventory for the Elderly (HHIE). Performance and benefit measures were obtained at post fit intervals of 1 month, 6 months, 1 year, 2 years and 3 years using a standardized measurement protocol. Results showed a little evidence of acclimatization in either objective or subjective measures of hearing aid performance and benefit in hearing aid wearers followed over a 3 year period. For both objective and subjective types of measurements considered in this study, there were just as many, if not more, significant declines in aided performance over time as there were improvements.

Nabelek, Tucker and Burchfield (2004) compared the effect of speech perception in background noise with Acceptance of Background Noise in Aided and Unaided Conditions. ANL and SPIN were measured in 41 full time users and 9 part time users. Results revealed that for both good and occasional hearing aid users, the ANL is comparable in reliability to the SPIN test and that both measures do not change with acclimatization. The ANLs and SPIN scores are unrelated. Although the SPIN scores improve with amplification, the ANLs are unaffected by amplification.

CHAPTER 3

METHOD

The purpose of current study was to compare the performance of directional microphone and digital noise reduction algorithms in hearing aid users.

Hypothesis

The present study tested the null hypothesis which states that 'there is no significant difference in the performance of directional microphone and digital noise reduction algorithms in hearing aid users'. To test the hypothesis, acceptable noise level (ANL), SNR 50 and horizontal localization were measured in naive and experienced hearing aid users. The following method was used in the study to test the hypothesis.

3.1. Selection of participants

Two groups of individuals were taken for the study.

Group I: Ten adults (20 ears) in the age range of 18-50 years using hearing aids for the first time (naive users).

Group II: Ten adults (20 ears) in the age range of 18-50 years using hearing aids for more than 1 year (experienced users).

3.1.1. Inclusion criterion: The participants who fulfilled the following criterion were included in the study

- Adults with acquired moderate sensory neural hearing loss.
- Hearing threshold between 41 dB – 55 dB HL for frequency range of 250 Hz to 8000 Hz bilaterally (during the time of identification as well as testing).
- Difference between air conduction threshold and bone conduction threshold less than 10 dB HL.

- Fitted with digital BTE hearing aids.
- Non progressive hearing loss.
- Normal speech, language and cognitive skills.
- No otological or neurological problems.

A written consent from the all individuals regarding their willingness as a participant for the study was taken.

3.2. Instrumentation

3.2.1. Testing environment

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.

3.2.2. Clinical audiometer and Immittance audiometer

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.

3.3.3. 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. Hearing aids were programmed using NoaH 4 instrument with appropriate programming software in a personal computer. Appropriate cable and audio shoe were used. The hearing aids were connected to the programming interface with Hi-Pro.

3.3.4. Instrumentation for assessing acceptable noise level (ANL)

A dual channel diagnostic audiometer (Inventis Piano) was used for testing acceptable noise level. 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 ±45^{o} 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.

3.3.5. Instrumentation for assessing speech in noise performance

A dual channel diagnostic audiometer (Inventis Piano) was used for testing performance of speech in noise test. Signal to noise ratio 50 (SNR-50) was used to measure the speech identification in noise performance. 'Sentence identification test in Kannada' developed by Geetha et al., (2014) was used to find SNR 50. The sentences were presented through the audiometer to the loud speaker located at one meter distance from the participant at ±45^{o} 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.

3.3.6. Instrumentation 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 0^{o}, 40^{o}, 80^{o}, 120^{o}, 160^{o}, 200^{o}, 240^{o}, 280^{o} and 320^{o} azimuth covering a range of 0^{o} to 360^{o}. Each speaker was mounted on Iso-Pod^{TM} $^{(}$Isolation position/decoupler^{TM}) vibration insulating table stand. CuBase 6 software was used to prepare and present the signals. All loud speakers were connected to the personal computer.

3.4. Stimulus

3.4.1. Acceptable noise level (ANL)

The participants were seated in a sound treated room and speech was presented through speakers at ±45^{o} azimuth. Three recorded standardized passage in Kannada (Savithri & Jayaram, 2005) were used for determining ANL. Kannada speech babble (Nayana, Keerthi & Geetha, 2016) was used as the background competing stimulus for ANL. Personal laptop was used to play the recorded standardized passage to obtain ANL, the output routed through the auxiliary input of the double channel audiometer and presented through speaker.

3.4.2. Stimulus preparation for signal to noise ratio (SNR 50)

Signal to noise ratio-50 (SNR-50) was used to measure the speech identification in noise performance. 'Sentence identification test in Kannada' developed by 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. Each sentence in the list comprised of 4 target words. For each sentence root mean square was identified and then speech babble was added at desired SNR. Mixing was accomplished using Adobe Audition version 3. The first lists of ten sentences were mixed with speech babble at different SNR ranging from +20 to -1 dB SNR in 3 dB step size. Similarly next two list of sentences were mixed with speech babble at different SNR using similar procedure as specified earlier.

3.4.3. Horizontal localization

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.

3.5. Procedure

3.5.1. Participant selection

The pure tone thresholds for air conduction at octave frequencies from 250 Hz to 8 kHz were obtained using +10 and -5 dB procedure using Modified Hughson and Westlake procedure (Carhart & Jerger, 1959). The bone conduction threshold from 250 Hz to 4 kHz was identified using similar procedure. 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 by varying the intensity in 5 dB steps to notice a minimum change in the compliance of tympanic membrane.

3.5.2. 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).

3.5.3. 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.

3.5.4. 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.

3.5.5. 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.

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

Where, $DOE_{1\text{-}9}$ = 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.

3.6. Statistical analyses

The data obtained was analysed using Statistical Package for Social Sciences (SPSS, version 20.0). Descriptive statistics was applied to find out mean, median and standard deviation for each group. The tabulated data were analysed for normal distribution using Shiparo-Wilk test. Further, analyses were done using non-parametric test to compare across conditions and between groups.

CHAPTER 4

RESULTS

The aim of current study was to compare the performance of directional microphone and digital noise reduction algorithms (DNR) in hearing aid users. 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) and group II consisted of 10 adults (20 ears) who were using hearing aids for past 1 year (experienced users). Horizontal localization, acceptable noise level and speech perception in noise using SNR50 were assessed for both groups.

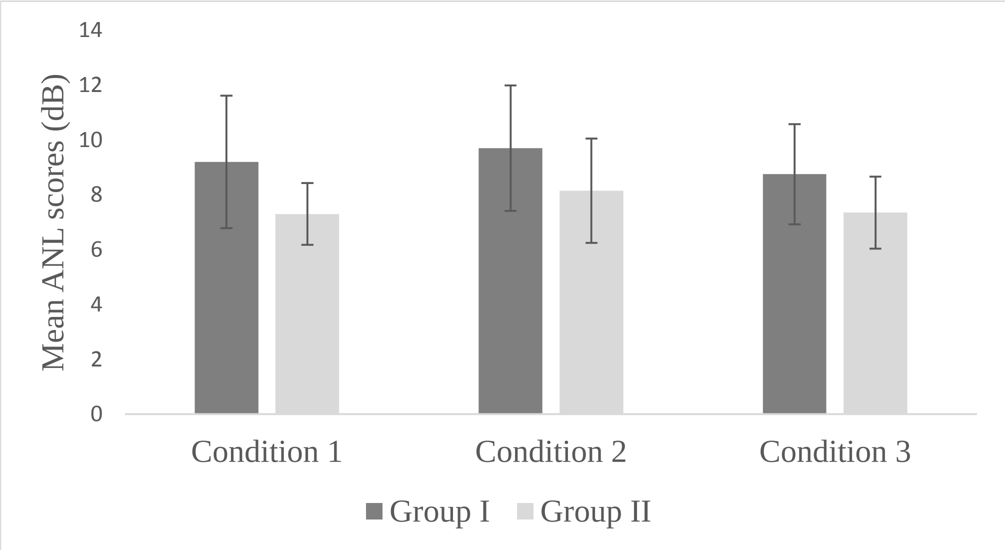
Normality test was performed using Shapiro-Wilk test. Since, the data did not have normality (p >0.05) hence non-parametric test was done. Further, Wilcoxon signed ranks test was done for comparison of data between right and left ear. No significant difference (p > 0.05) was found between scores of right 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.

4.1. 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 4.1. shows the mean and standard deviation (SD) for ANL scores of both the groups of participants across three conditions.

Figure 4.1.

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 4.1, 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 are poorer for ANL compared to experienced hearing aid users.

4.1.1. 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 [$\chi 2$ (2) = 7.01, p <0.05]. Further, Wilcoxon signed rank test was conducted to determine which pair of condition had better performance.

Table 4.1.

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 4.1, 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 ($p > 0.05$).

4.1.2. 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 [$\chi2$ (2) = 8.27, p <0.05]. Wilcoxon signed rank test was conducted to determine which pair of condition are significantly better. Table 4.2, shows the /Z/ value and level of significance obtained on Wilcoxon signed rank test between different conditions.

Table 4.2.

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

Conditions	/Z/	Level of significance
ANL 2 - ANL 1	2.70	*p* <0.05
ANL 3 - ANL 1	0.28	*p* >0.05
ANL 3 - ANL 2	2.76	*p* <0.05

Results of Table 4.2. 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 ($p > 0.05$).

4.1.3. 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 4.3.

Comparison of ANL scores between groups and across different conditions

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

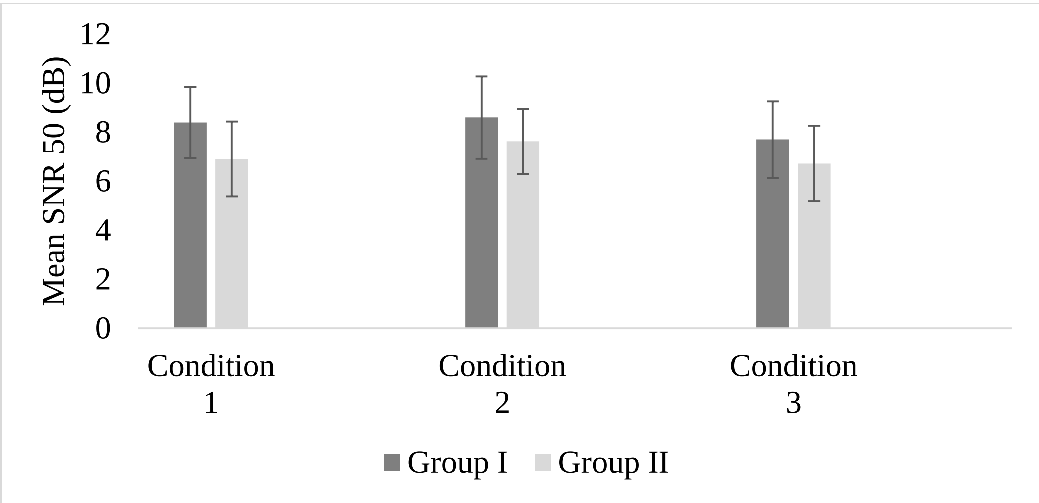
Table 4.3, shows the /Z/ value and level of significance obtained on Mann-Whitney U test between group I and group II. The results revealed a statistically significant difference between condition 1 and 3 ($p < 0.05$), except in condition 2 ($p > 0.05$).

4.2. 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 4.2.

Figure 4.2.

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 4.2 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.

4.2.1. 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 [$\chi 2$ (2) = 10.99, p <0.05]. Further, Wilcoxon signed rank test was conducted to determine which pair condition had better performance.

Table 4.4.

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 4.4, shows the /Z/ value and level of significance obtained on Wilcoxon signed rank test between different conditions. The results of Table 4.4 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 ($p > 0.05$).

4.2.2. 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 [$\chi 2\ (2) = 10.43$, $p < 0.05$]. Further, Wilcoxon signed rank test was conducted to determine which pair condition had better performance. Table 4.5, shows the /Z/ value and level of significance obtained on Wilcoxon signed rank test between different conditions.

Table 4.5.

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 4.5 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).

4.2.3. 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 4.6.

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

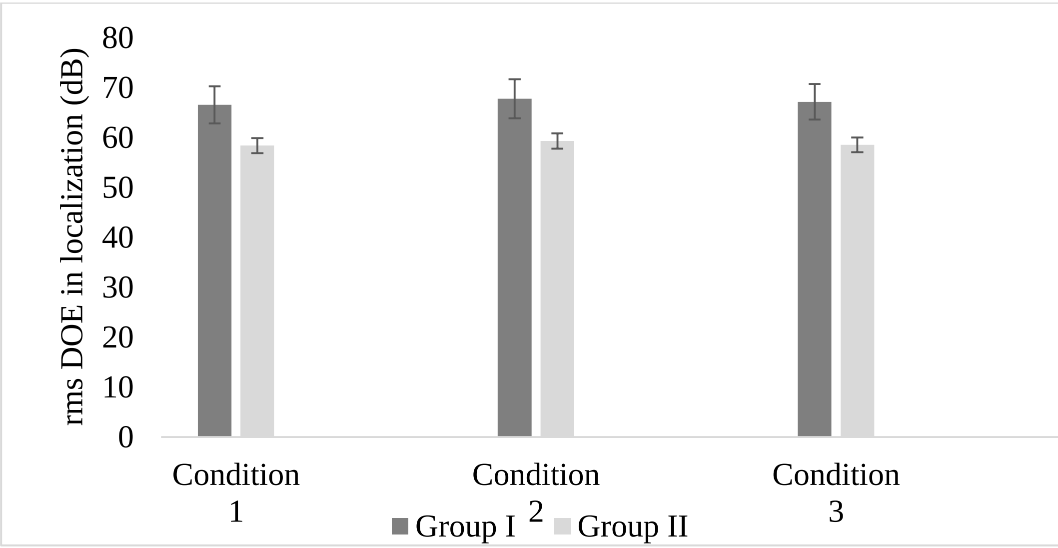
The results showed that there was a significant difference in condition 1 ($p < 0.05$), except in condition 2 and 3 ($p > 0.05$). Table 4.6, shows the /Z/ value and level of significance obtained on Mann-Whitney U test between group I and group II.

4.3. 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 4.3, shows the mean and standard deviation (SD) of rms DOE in localization.

Figure 4.3.

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.

4.3.1. 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 [$\chi 2$ (2) =22.79, p <0.05]. Further, Wilcoxon signed rank test was conducted to determine which pair condition had better performance.

Table 4.7.

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 4.7, shows the /Z/ value and level of significance obtained on Wilcoxon signed rank test between different conditions.

4.3.2. 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 [$\chi 2$ (2) =20.58, p <0.05]. Further, Wilcoxon signed rank test which was conducted to check for condition that had better performance.

Table 4.8.

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 4.8, shows the /Z/ value and level of significance obtained on Wilcoxon signed rank test across different conditions.

4.3.3. 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 4.9.

Pairwise comparison of horizontal localization scores of both the groups across three conditions

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

Table 4.9, 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 ($p > 0.05$).

CHAPTER 4

DISCUSSION

5.1. 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.

5.1.1. 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 JaHee 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).

5.2. 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.

5.2.1. 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. Oliveira, Lopes and Alves (2010) studied speech perception through digital hearing aids using a digital noise reduction algorithm on 32 individuals and found that the noise reduction algorithms improved the speech in noise performance. In contrast, Mc Creery, Venediktov, Coleman and Leech (2012) found that, digital noise reduction did not improve or degrade speech understanding. Whereas, directional microphones resulted in improved speech recognition.

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. Speech recognition or reception in noise was measured for active noise reduction and directional microphones, separately and in combination in 16 experienced hearing aid users. Results obtained for three different settings: no noise reduction, active noise reduction alone and directionality alone showed that, the effects of directional microphone were clearly positive. Whereas, the effects of active noise reduction showed much smaller but significant benefit with respect to speech perception in noise. There was no extra 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%. Gatehouse (1993) refitted 36 experienced hearing aid users with a new hearing aid that provided greater high frequency amplification than their previous one. Results showed that, mean scores with the old and new hearing aids were similar initially but increased significantly by 2.3% at 8 weeks and 4.4% at 16 weeks respectively. In contrast to present study Cox et al., (1996) found improved speech in noise performance in new hearing aid users. Whereas, no significant improvement was seen in the experienced hearing aid users.

5.3. Comparison of horizontal localization scores

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

5.3.1. 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. Keidser et al., (2006) compared the effect of directional microphones, wide dynamic range compression and noise reduction strategies (DNR) on horizontal localization. The results indicated that fitting a directional microphone could improve front/back discrimination that is seen 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.

CHAPTER 6

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 poor ANL scores (accept more noise) 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.
- Naive hearing aid users had high ANL scores (accept less noise) compared to experienced hearing aid users.
- Naive hearing aid users had better performance in directional microphone + DNR on condition compared to other conditions. Whereas, experienced hearing aid users had

similar speech perception in noise scores in directional microphone on and directional microphone + DNR on condition.

- Speech perception in noise is better in experienced hearing aid users compared to naive hearing aid users.
- Naive hearing aid users had less DOE in localization when directional microphone + DNR condition was enabled. Whereas, experienced hearing aid users performed similarly in directional microphone on and directional microphone + DNR on condition.
- Better performance in localization (less DOE) is seen in experienced hearing aid users compared to naive users.

Implications of the study

Direction microphone and directional microphone + DNR algorithms conditions improves hearing performance in individuals with hearing loss compared to DNR alone in both naive and experienced hearing aid users. Hence, during programming and counselling the results of the present study would provide insight for appropriate options that need to be selected. Training for localization also need to be included in auditory training for individuals with hearing loss as well those fitted with hearing aid.

Future directions for research

1. This study can be further extended to find out the effect of microphone directionality and digital noise reduction algorithms in different degree of hearing loss and in unilateral/asymmetric hearing loss.
2. Acceptable noise level (ANL), speech in noise and horizontal localization can be compared between adults and children with similar degree of hearing loss and the effect of hearing aid features on them.

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