Effect of directional hearing aids on speech perception in noise and localization

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CERTIFICATE

This is to certify that this masters dissertation entitled **Effect of Directional Hearing Aids on Speech Perception in Noise and Localization** is the bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student (Registration No. 11AUD016). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that the masters dissertation entitled **Effect of Directional Hearing Aids on Speech Perception in Noise and Localization** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any Diploma or Degree.

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DECLARATION

I declare that this masters dissertation, entitled **Effect of Directional Hearing Aids on Speech Perception in Noise and Localization** is the result of my own study and has not been submitted in any other University for award of any other Diploma or degree.

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CHAPTER 1

Introduction

Difficulty understanding speech in the presence of background noise is a common complaint of hearing aid users and is the primary reason for dissatisfaction with hearing aids (Kochkin, 1993). According to Moore (2008), individuals with hearing impairment have significant difficulty understanding speech in the presence of background noise due to poor spectral and temporal resolution of the damaged cochlea. For these listeners, an increase in the level of speech compared to unwanted noise results in an increase in speech recognition (Gelfand, 1998). The signal-to-noise ratio (SNR), in decibels (dB), is a commonly used measure that describes the level of the target acoustic signal relative to the background noise. Nabelek and Pickett (1974) found that listeners with normal hearing could achieve a 50% word understanding score even when the background noise is 9 dB louder than the target signal (i.e., -9 dB SNR). However, individuals with hearing impairment needed the signal to be 5 dB louder than the background noise (i.e., +5 dB SNR) in order to attain this same word understanding score.

Hearing aids have implemented strategies and circuitry schemes in order to improve understanding of speech in quiet and in noisy environments. These include strategies such as binaural amplification, reduction of low-frequency amplification, compression amplification, directional microphones, and digital noise reduction (Bentler, 2005). Each of these has got their own merits and demerits. According to Preves and Banerjee (2008), of all of the advances in hearing aid technology in the last several years, perhaps the greatest has been the performance of directional microphones. The use of

DSP in hearing aids has opened the door to many different types of algorithms used in directional microphones. Current hearing aids offer various forms of directional performance, from a classic front/back sound option, to adaptive directional, and to adaptive directional that focuses on the primary voice signal, regardless of direction (front, back, side, or variations in between).

The directional microphone technology has been found to be extremely useful in increasing the SNR for improved speech intelligibility in noise (Ricketts, 2000; Ricketts & Henry, 2002; Valente, Mispagel, Tchorz, & Fabry,2006; Valente & Mispagel, 2008). In general, directional microphone hearing aids provide attenuation to sounds arriving from angles other than in front of the listener. Hearing aid manufacturers now offer directional microphones in both behind-the-ear (BTE) and in-the-ear (ITE) styles of hearing aids.

Directional microphone has its own limitations - in certain instances where both speech and noise are from the same direction, use of directional microphone can be detrimental. It also poses limitations in reverberant and wind noise conditions (Valente & Mispagel, 2008).

There are certain parameters that describe the effective functioning of a directional microphone. The directionality of hearing aid can be measured by calculating Directivity Index or DI (Beranek, 1954). It is the ratio of the sound arriving from front axis to those coming from other axes. It has been assumed that higher directivity index brings about better signal to noise ratio (SNR). A directional microphone system can increase the SNR by 8 dB to attain 50% word recognition (Hawkins &Yacullo, 1984;

Valente, 1995). This leads to better speech perception in noise and ease of communication in noise or difficult listening situation (Ricketts & Dittberner, 2002)

The effectiveness of directional hearing aids can be evaluated using subjective and objective measures. The subjective measures include SNR-50 and localization; and the objective measure includes Front-to-Back Ratio (FBR) through real ear measurement. Though FBR can also be measured in test boxes, it may not be that accurate (Ricketts & Mueller, 1999).

The directional advantage is the improvement in speech recognition in noise obtained with directional microphones in comparison to omnidirectional microphones. And this advantage is often expressed in terms of decibel difference in SNRs obtained by directional microphone and omnidirectional microphone. Another measure of speech perception in noise is the SNR-50. The signal to noise ratio required for correct repetition of 50% of the words being presented is abbreviated as SNR-50. Hawkins and Yacullo (1984) found that directional microphones reduced the SNR by 3-4 dB needed for hearing aid wearers to achieve 50% word recognition.

A more appropriate and cost-effective method of verifying the status of directional hearing aid is the front-to-back ratio (FBR) measurement. This is obtained by subtracting the output of sounds received at 180 degrees azimuth from the output of sounds at 0 degrees azimuth. This measure differs from the DI in that the hearing aid output is only measured at two angles of acoustic inputs rather than at all angles surrounding the aid (Wu & Bentler, 2011). In the present study, the effectiveness of directional microphone will be investigated through front-to-back ratio which is an objective measure.

Although impaired localization is not often recognized by hearing aid users as a problem in everyday life, the importance of being able to correctly determine where the sounds are coming from in real-life situations should not be overlooked (Byrne & Noble, 1998). In particular, studies have demonstrated that directional microphones can affect horizontal plane localization performance relative to performance with an omnidirectional microphone (Van den Bogaert et al., 2006; Keidser et al., 2006).The present study investigates the effect of directional microphone on horizontal plane localization.

Need for the study

There are several studies which demonstrate the efficacy of directional microphones in improving the recognition of speech in noise (Lentz, 1972; Sung, Sung & Angelli, 1975; Madison & Hawkins, 1983; Hawkins &Yacullo, 1984). There are studies that report on speech perception in different SNRs. There is a dearth of studies which assess the effect of directional hearing aid on localization. Hence, there is a need to evaluate the effect of directional hearing aids on localization in persons with hearing impairment as directional hearing aids attenuate signals from back compared to signals from front.

Further, the polar pattern specified by hearing aid manufacturers is based on the measurement on a KEMAR or in anechoic chamber. This may vary with different individuals due to head shadow, body baffle effect and variability in ear canal resonance. This variability is not well documented in a polar plot. The change in the polar pattern might result in change in the performance of a particular microphone technology. Therefore, quantifying these differences will significantly help an audiologist in selecting an appropriate microphone in different situations. Therefore, it is necessary to assess the benefits of directional and omnidirectional microphones technology in identifying signal coming from 0 degree azimuth in relation to the sounds coming from back.

Therefore, the present study aims at assessing the benefit of directional microphone technology in hearing aids in identification speech in the presence of noise (using SNR-50) and localization. The study also intends to examine the relationship between the SNR-50 and FBR.

Aim of the study:

The aim of the study is to determine the effectiveness of directional hearing aid on objective and subjective measures.

Objectives:

The specific objectives include,

1. To evaluate the effect of directional hearing aid on speech perception in noise using SNR-50.
2. To measure the front-to-back ratio of directional hearing aid.
3. To study the relationship between FBR and SNR-50.
4. To evaluate the effect of directional hearing aid on localization.

CHAPTER 2

Review of literature

The major complaint of individuals with hearing impairment is difficulty understanding speech in the presence of background noise and this is the primary reason for dissatisfaction with hearing aids (Kochkin, 1993). According to Moore (2008), individuals with hearing impairment have significant difficulty understanding speech in the presence of background noise due to the poor spectral and temporal resolution of the damaged cochlea. For these listeners, an increase in the level of speech compared to unwanted noise is one of the strategies to improve speech recognition (Gelfand, 1998).

In order to improve understanding of speech in quiet as well as in noisy environments, hearing devices have implemented various strategies. These include strategies such as binaural amplification, reduction of low-frequency amplification, compression amplification, directional microphones, frequency modulation (FM) and digital noise reduction (Bentler, 2005). Each of these has got their own merits and demerits. According to Preves and Banerjee (2008), performance of directional microphone has been the greatest of all of the advances in hearing aid technology in the last several years. The use of digital signal processing (DSP) in hearing aids has opened the door to many different types of algorithms used in directional microphones. Present hearing aids provides many forms of directional performance, from front/back sound option to, to adaptive directional, and to adaptive directional that focuses on the main voice signal, regardless of directiona (front, back, side, or variations in between).

Directional advantage over omnidirectional microphones

Omnidirectional hearing aids do not improve the SNR in comparison with the unaided ear, and in some cases the SNR can be worsened by amplification. Multiple microphones (or multiple ports) in directionl hearing aids improve SNR from front hemisphere relative to unwanted signals usually that occur from the rear hemisphere. Sounds arriving from the Frontal azimuths are provided with more gain for the SNR than for those arriving from rear azimuths. Improvement in SNR relative to omnidirectional hearing aid fittings have lead to improved speech intelligibility in noisy environment.

Hawkins and Yacullo (1984) found that directional microphones reduced the SNR by 3 to 4 dB needed for hearing aid wearers to achieve 50% word recognition. Valente, Fabry, and Potts (1995) reported a directional advantage of 7 to 8 dB (in SNR) for directional microphones over omnidirectional condition in a group of listeners with hearing impairment. However, the directional advantage varied considerably across the listeners, from 3.5 dB to 16.1 dB. This variability in directional advantage is particularly noteworthy because each dB contribute in speech recognition. In a similar study, Agnew and Block (1997) reported a mean directional advantage of 7.5 dB, with inter-subject difference ranging from 2.3 to 14.6 dB.

Cord, Surr, Walden and Olsen (2002)investigated the perceived benefits of directional microphone technology in real-world situations in individuals with hearing impairment who had been fitted with switchable omnidirectional/ directional hearing aids. Depending on the listening environment the individuals could switch between omnidirectional and directional modes which was incorporated into a single multimemory device. Performance on each microphone type was assessed through interviews and questionnaires. Majority of the individuals reported the use of directional microphone mode was used regularly and was satisfied with the performance of their hearing aids. 23% of them reported that they did not use the directional microphone feature. Directional mode was initially tried in adverse listening situations but many of them had not noticed any improvement in their ability to understand speech. Hence, individuals had simply left their hearing aids set in the default omnidirectional mode in all listening environments.

There are studies also done to find out the mean directional advantage of omnidirectional and directional hearing aids. In another study by Walden, Surr, Cord, and Dyrlund (2004) used testing procedures to find out the mean directional advantage. They obtained a mean directional advantage of 3.3 dB for participants approximately five weeks after they had been fitted with a switchable omnidirectional/directional hearing aid. The mean directional advantage obtained the mean directional advantage to be substantially leass than that reported by Valente, Fabry, and Potts (1995) and by Agnew and Block (1997) which revealed mean directional advantages of 7.6 dB and 7.5 dB respectively. The discripencies may be due to the differences in the methodology undertaken in their study.

Another study done by Jasperson and Olsen (2003) aimed at examining whether the outcome of an aided speech in noise intelligibility task using hearing aids in omnidirectional mode can help predict the amount of directional hearing aid benefit and result revealed that degree of hearing loss influences ominidirectional and directional performance but not directional benefit.

The slope of the unaided audiogram and the degree of high-frequency hearing loss can also influence directional benefit (Killion, Schulien, Christensen, Fabry, Revit, Niquette, & Chung, 1998). The authors proposed that hearing aid users with flat audiometric configuration should have less directional benefit than those with a sloping hearing loss. This was based on the directional characteristics of the hearing aid and the reduced ability of some users with more severe high-frequency hearing loss to utilize high-frequency speech information. The directivity index improvement for the directional hearing aid setting is predominantly in the low frequencies., as compared to the omnidirectional setting (Killion et al., 1998). This finding is typical of many ITE and BTE directional hearing aids. Since the improvement in directivity between directional and omnidirectional condition is greatest in the low frequencies, those hearing aid users who rely primarily on low frequency speech information i.e., those with sloping hearing loss will achieve greater directional benefit than those who are able to use speech information across the entire frequency range those with severe high-frequency hearing loss.

The SNR loss is the loss in ability to understand speech at the SNR used by individuals with normal hearing. Researchers like Killion et al.,(1998) have shown that hearing aid users with greater SNR loss appear to receive greater directional benefits. Although the difference in directional benefit measured by Killion et al.(1998) were later attributed to difference in threshold slope, it is still unclear whether the difference might be due to other unknown factors related to SNR loss.

Limitations of directional microphone:

Though directional hearing aids provide improvement in speech recognition in the presence of noise, there are several limitations.

One difficulty in implementing two-microphone directionality is that the microphones must be very closely matched at all frequencies to provide good SNR improvement at these frequencies (Thompson, 1999). The directionality is degraded if the frequency responses of the two microphones are not identical. . Directional hearing aids have been modified. Manufacturers "tune" the response of the directional microphone system in an attempt to provide maximum directivity across the frequencies.Consequently, directivity of modern hearing aids approaches theoretical limits.

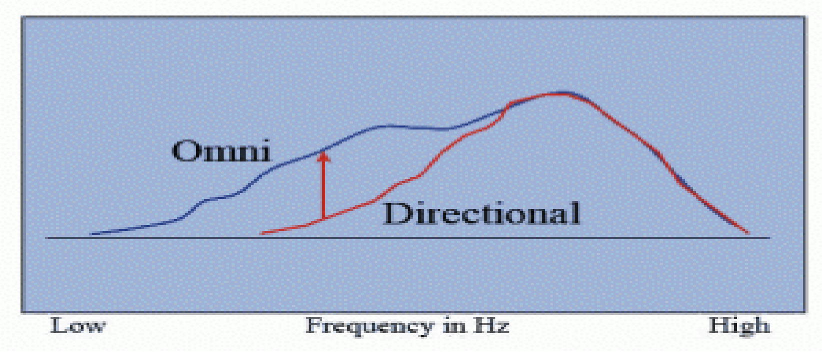

Figure 2.1.Effect of omnidirectional verses omnidirectional microphone in the frequency response of the hearing aid.

Limitations have been found with low frequency when the microphones used in a directional array are spaced close together. It has been said that frequencies above approximately 800 to 1,000 Hz will be activated by three-microphone array, with two microphones used to achieve directivity for the lower frequencies. Despite this limitation, use of the three-microphone array in high frequencies affords the possibility of slightly higher average directivity than is possible from two-microphone, or two-microphone-port, systems.

Low frequency roll off begins at the frequency which is predictable on the basis of the spacing between the microphone ports. Numerous smaller separation results in the reduction in sensitivity occurring at increasingly higher frequencies. Closer the microphone ports, the greater the potential for reduced audibility of low-frequency sounds. Regardless of port spacing, the magnitude of low frequency roll-off is relatively constant at approximately 6 dB per octave.

The directional microphone has an effect on the low frequency range of the hearing aid. Hence, this might also have an effect on the localization ability provided by a directional hearing aid. Perceptual evidence is required to ascertain this aspect.

Influence of reverberation time

Earlier studies on the relative benefits of directional and omnidirectional microphones were carried out in anechoic chamber, the effect of reverberation was typically ignored. However, the findings of later studies emphasized the importance of considering reverberation time as part of the evaluation procedure. Ricketts (2000) studied the effect of configuration of multiple noise sources in two reverberant environments. The hearing in noise test (HINT) (Nilsson,soli & Sullivan, 1994) was used to determine the absolute binaural reception threshold for sentences for three pairs of different directional hearing aids as well as the directional benefit. The directional benefit was considered as the difference between the reception threshold for sentences for omnidirectional and directional conditions. Individuals with sensorineural hearing loss were tested in two listening environments: (1) a 'living room' with a reverberation time of 0.6 seconds, and (2) a 'classroom', with reverberation time of 1.1 seconds. Four noise source configurations were studied, including a signal located in front and noise at (a) 180 degree (b) 90, 135, 180, 225, and 270 degrees; (c) 30, 105, 80, 225, and 330 degrees but with more diffuse noise); and (d) with 30, 105, 180, 225, and 330 degrees but with 30 and 330 loudspeaker turned perpendicular to the listener.

Reverberation and noise configuration were found to influence directional benefits across hearing aids. In the living room environment, directional benefit ranged between 3.6 to 7.9 dB, depending on the noise source configuration. In the classroom setting The directional benefit decreased from 2 to 5.1 dB. Directional benefit was significantly higher for the 0/180 loudspeaker configuration in comparison with all others. Significantly less directional benefit was provided to listeners in the diffuse restaurant configuration than classroom or restaurant where the background noise at 30 and 330 was reduced by 5 dB. The results revealed that the 0/180 test configuration commonly used in clinical evaluation may overestimate the benefit that will be obtained in more realistic environments having multiple noise sources. An inverse relationship was noted between directional benefit/performance and reverberation time across different hearing aid brands, that is directional performance decreased as reverberation time increased.

Omnidirectional vs. two microphone design directional hearing aids

Valente et al. (1995) assessed the advantages of a two microphone design directional hearing aid. They noted a 7.4 to 8.5 dB improvement in SNR for the two-microphone design over an omnidirectional design for participants tested in a sound treated room. A single speaker was situated at 0 degree relative to the participants, which is an optimal arrangement for the cardioids pattern of the microphone under test.

Pumford, Seewald, Scollie, and Jenstad (2000) compared speech recognition scores of ITE and BTE dual microphone hearing aids to assess the effect of the hearing aid style in which the microphone had been replaced. Although the improvement of 5.8 d B in SNR between the omnidirectional and directional modes of the BTE hearing aid appears to be larger than the improvement of 3.3 dB for the ITE hearing aid, the omnidirectional performance of the BTE was poorer by an equivalent amount.

Rickets (2000) evaluated the impact of head orientation and unilateral and binauaral fittings on the reception thresholds of listeners with hearing impairment wearing hearing aids in omnidirection modes. The aided performance across these four fittings was evaluated for three different head and body angles in a moderately reverberant living room environment. The participants generally performed better in the directional mode and with binaural fitments.

It is apparent that performance (and benefit) measured in laboratory settings with directional microphone hearing aids is dependent on a number of factors including the location of the competing noise source(s), reverberation effects, head and microphone port orientation, and vent size. All these studies have considered the fixed one- or two- – microphone designs; that is; the polar patterns achieved by the microphone characteristics, spacing, and delay element were held constant.

Front to back ratio:

A front-to-back ratio (FBR) measurement in an anechoic chamber was used to express the amount of directionality for the first directional hearing aids about 25 years ago. This measurement was contrived by hearing aid manufacturers expressly for directional hearing aids with cardioids. Such a measurement on a coupler shows a cardioids microphone at its best because there is maximum sensitivity for sounds from the front and minimum sensitivity in the null of the cardioids for sounds from 180 degrees. The front to back ratio is not a very good measurement for hearing aids with supercardioid or hypercardioid polar patterns, both of which have lobes at 180 degrees, but a higher DI than cardioids (Valente, Dunn &Roeser, 2008).

The goal of directional hearing aids is for the output to be greater if the signal is presented in front while in the directional setting and less (at least by 3 dB) when the signal is behind. When this type of measurement is completed with a probe microphone in the patient’s ear and the loud speaker is moved from front to backof the individual, it is called a front to back ratio (Valente et al., 2008).

It has been documented that in most of the hearing aids, it is difficult to measure FBR with precision in test boxes but it can be assessed rather easily in the clinic with probe microphone equipment, using the differences between the real ear aided response (REAR) taken from 0 degree and 180 degree Azimuth (Mueller & Hawkins, 1992).

Laboratory can also be utilized to estimate FBR using a Zwislocki coupler mounted on the KEMAR (Hawkins &Yacullo. 1984; Madison & Hawkins, 1983). Any of these methods can be utilized to estimate hearing aid directionality.

Of the methods reported in literature, it is considered appropriate for verifying the status of directional hearing aid using the front-to-back ratio (FBR) measurement, where in the output of sound received at 180 degrees Azimuth is subtracted from the output of sound received at 0 degrees Azimuth. This measure differs from the DI in that hearing aid output is only measured at two angles of acoustic inputs rather than at all angles surrounding the aid (Wu &Bentler, 2011). As it is easier to calculate FBR, clinically available hearing aid analyzers can be used to measure the FBR or provide data for the clinician to compute it (EtymoticDesign, Inc., 2011; Frye Electronics, Inc., 2012). Through a correlation between the measures it can be inferred that FBR can approximate the directional microphone benefit enough to supervise any changes in directionality in a hearing aid, but FBR does not measure directivity like the DI does. (Dittberner&Bentler, 2007)

Caution must be exercised, however, when comparing the results from FBR across hearing aids. Specifically, a hearing aid with a single narrow null in the polar pattern (present at 180° azimuth) could appear to have excellent directionality, as measured by the FBR, even though there may be little attenuation for other angles. The directional advantage provided by such a hearing aid in the real world (when the listener is surrounded by noise sources) would typically be poorer than a directional hearing aid that had a smaller FBR but provided increased directionality across a wider range of azimuths. For example, compare the polar plots of the cardioid and hypercardioid patterns. Although the hypercardioid pattern clearly has better overall directivity, the cardioid pattern is superior at 180°.

It has been reported that the FBR ranges from 10 to 30 dB for directional hearing aids (Agnew & Block, 1997; Hawkins &Yacullo, 1984; Mueller & Johnson, 1979). Obviously, these measures can vary substantially given both the polar pattern of the hearing aid tested and the test conditions, such as the reverberation time of the environment. To understand this, an example which can be given is, if the FBR is calculated using probe microphone testing in a typical hearing aid fitting room, the distance between patient and loudspeaker will affect the outcome. That is, the farther away the listener is from the loudspeaker, the lower the FBR, because the impact of reflections arriving from directions where the microphone is more sensitive increases (Mueller & Hawkins, 1992).

The effects of various FBRs on the performance of directional microphone hearing aids were conducted by Mueller, Gustav, Johnson, and Robert (1979).They evaluated twenty four adults with sensorineural hearing impairment. Four directional microphone hearing aids differing only in front-to-back ratios were utilized. The speech material used was the Synthetic Sentence Identification Message Competition Ratios of 0, -10, and -20 db. The target signal was presented from a 0 degree azimuth with the competing message presented from a direct overhead location. Results revealed a systematic improvement in speech understanding as the size of the FBR increased. This relationship was not significantly affected by the difficulty of the listening situation.

Localization

Individuals with hearing impairment have their highest priority in communicating in the presence of noise. Hearing is important in allowing the listener to sense their environment for safety and security. Evidences by Eriksson-Mangold, Hallberg, Ringdahl, and Erlandsson(1992) have indicated that localizing is important for hearing impaired individuals too. A study by Noble, Ter-Horst, and Byrne (1995) revealed that self –assessed disability associated with a decreased ability to localize was significantly associated with feelings of confusion and loss of concentration. Localization is not only important for understanding hearing impairment in general but also for understanding how individuals with hearing impairment are affected through the listenng environment with use of various types of amplification technology. Noble and Byrne (1990), Byrne, Noble and Lepage (1992) and Noble,Sinclair, and Byrne (1998) have indicated that hearing aids can disturb sound localization. The properties of directional microphone technology that enhances performance in noise may create problems in the individual's ability to localize. Individuals use time and intensity differences in sounds arriving at their two ears to localize the source of the sound (Zwislocki& Feldman , 1956; Tonning, 1975; Wightman & Kistler,1992). Timing differences in directional microphones are used to determine which sounds come from the front of the listener verses which sounds come from other angles of incidence. Microphones are usually are more sensitive to sounds coming from the front than sounds from other angles of incidence to the listener. Hence, the listener may have difficulty to detect signals from complex- real world acoustic environment and may not beable to use naturally occurring intensity cues for localization.

There are cues which help in localization and improve the directionality and it is widely accepted that interaural time and level differences are dominating cues for left/right discrimination in the horizontal plane, whereas monaural spectral differences are predominant for front/back discrimination (Middlebrooks & Green, 1991).

For localization of speech which comprises of both both low and high frequencies, and if directionality is limited to only high frequency, then it has several advantages. High frequency directionality has been found to be of greater importance than low frequency directionality when visual or speech-reading cues are absent (Grant & Walden, 1996; Grant, 2005; Grant et al., 2007).

Directional microphones can affect horizontal plane localization performance relative to performance with an omnidirectional microphone (Van den Bogaert, Klasen, Moonen, Van Deun, and Wouters. (2006) and Keidser, Rohrseitz, Dillon, Hamacher, and Carter,(2006). Both the studies, data were analyzed independently in the left/right and front/back dimension which revealed directional microphones had the most significant effect on horizontal localization performance. Left/right errors increased when different microphones were fitted to left and right ears and Front/back confusions were generally observed to be prominent. Van den Bogaert et al., (2006) study revealed good performance in the most frontal area of the horizontal plane and this finding was reported in subjects with normal hearing and individuals with hearing impairment.s

In terms of azimuth effect, there was significance with the fixed directional microphones(Kuk, Keenan, Lau, and Ludvigsen .,2005). Performance of omnidirectional, fixed directional, and adaptive directional microphone to signals presented from various azimuths were studied. the signal-to-noise ratio advantage of a directional microphone was achieved by reducing the sensitivity of the microphone to sounds from the sides and back. A fully adaptive directional microphone that is one that automatically switches between an omnidirectional mode and various directional modes may allow the achievement of signal-to-noise ratio improvement with minimal loss on audibility to sounds that originate from the sides and back. Hence, . to demonstrate such possibilities Kuk et. al, compared the performance of sound field aided thresholds, speech in quiet at different input levels, and speech in noise among seventeen individuals with hearing impairment under three microphone modes that is omnidirectional, fixed hypercardioid, and fully [or automatic] adaptive with the stimuli presented from 0° to 180° in 45° intervals. The results showed a significant azimuth effect only with the fixed directional microphone.

According to literature, directional microphone has shown better performance than omnidirectional microphone in the presence of noise in different listening environments. Studies related to front-to-back ratio have revealed that the performance was better with directional microphones than omnidirectional microphones. (Valente et al, 2008) Studies on localization have also indicated that front to back localization has been found to be better with directional microphone but there is not much difference seen in right /left localization (van den Bogaert et al., (2006). There is a dearth in literature regarding the effect of directional microphone on speech perception in noise and localization. Hence, the present study aims at investigating the effect of directional microphone on speech perception and localization in the individuals with hearing impairment.

CHAPTER 3

Method

The aim of the present study was to determine the effect of directional hearing aid on the speech perception in noise and localization.

Participants

Individuals having post-lingually acquired sensorineural hearing impairment satisfying the following criteria were included in the study. Participants with the age range from 15 to 55 years with flat, moderate to moderately severe sensorineural hearing loss, aided thresholds within speech spectrum, aided speech identification scores greater than 70%. They were native speakers of Kannada language. There was no complaint of cognition and psychological problems.

Stimulus

For speech perception in noise: The Phonemically Balance (PB) bi-syllabic Kannada word list (Yathiraj & Vijayalakshmi, 2005) was used. It has 4 lists and each list consists of 25 words.

For localization: Three 20 ms bursts of white noise with 20 ms of interval in between.

Test environment

All the tests were carried out in acoustically treated air-conditioned single or double room situation in which the ambient noise level were within permissible limits.

Instrumentation used

A calibrated diagnostic audiometer for estimation of unaided and aided performance; and a calibrated middle ear analyzer to rule out middle ear problem; were used for the purpose of the study. Two non-linear digital BTE hearing aids of the same model were used. The hearing aid was suitable for individuals moderate to moderately severe loss. It was a programmable instrument with fully digital 4-channels, Omnidirectional / Directional microphone, and noise reduction algorithm (disabled). A personal computer (with NOAH and hearing aid fitting softwares) and HiPro were used for programming digital behind-the-ear hearing aids. Fonix 7000 hearing aid analyzer was used to measure the FBR.

Procedure

Routine audiological evaluation was done for all the participants in order to select the participants for the study. This included pure tone audiometery, speech audiometery and immittance evaluation after performing otoscopic examination. Air-conduction thresholds were estimated by pure tone audiometry between 250 Hz to 8 kHz. Further, the bone-conduction thresholds were estimated between 250 Hz to 4 kHz. The modified Hughson-Westlake method (Carhart & Jerger, 1959) was used to estimate both air- and bone- conduction thresholds.

Speech audiometry was administered to measure speech reception threshold (SRT), speech identification score (SIS) and uncomfortable level. Immittance testing was done in order to rule out presence of any middle ear pathology.

After routine audiological evaluation, the data were collected from those fulfilling the inclusion criteria. The participant was fitted binaurally with the programmable digital BTE hearing aids coupled with snugly fitting eartips. The hearing aids were programmed using the auditory thresholds and NAL-NL1 prescriptive procedure (acclimatization level – 2). The rationale of this formula is to maximize speech intelligibility and loudness normalization. Optimization of paramenters was done for audibility for Ling six sounds. The hearing aids were programmed with omnidirectional mode in Pprogram 1 and with directional mode in Program 2.

The data were collected with hearing aid in Program 1 and Program 2 in two phases. Phase I comprised of measurement of speech perception in noise using SNR-50 measure and front-to-back ratio (FBR). In Phase II, localization for eight different locations of the loud speakers was evaluated.

Phase I: Measurement of speech perception in noise using SNR-50 measure and front-to-back ratio (FBR).

In Phase I, the performance of the participant on speech perception in noise (SNR-50) and front to back ratio were measured using the following procedure. This was done with the test hearing aid programmed in directional and omnidirectional modes. The following measures were obtained with hearing aid in Program 1 and Program 2. The subjects were asked whether the speech sounded too loud, too soft or just sufficient, when spoken with normal vocal effort from 4 to 5 feet distance. The gain was adjusted for comfortable loudness.

Speech perception in noise (SNR-50): The SNR-50 was measured using PB word list in Kannada (Yathiraj & Vijayalakshmi, 2005). The live speech material was routed through the audiometer to a loudspeaker at 0^0 Azimuth located at a distance of 1 metre away from the participant. The speech material was presented at a constant level of 45 dB HL. The speech noise was routed through the audiometer to a loudspeaker at 180^0 Azimuth placed 1 meter away from the participant. The presentation level of speech noise was varied. Initially, the presentation level of noise was kept at level 15 dB lower than the level of speech signal (i.e., 30 dBHL) and was varied in 5 dB steps (later in 2 dB steps) to measure the SNR-50. The participant was instructed to repeat back the words presented in the presence of competing noise. At each noise level, a set of three words was presented. If the participant was able to repeat back at least two of them correctly, then the speech noise was increased in 2 dB-steps. If the participant failed to repeat back at least two out of three words being presented, the speech noise was decreased in 4 dB steps. This was continued till a lowest level at which the participant repeated two out of three words correctly. At this point, the difference between intensity of speech signal and speech noise in dB, was considered as SNR- 50.

Measurement of FBR using real ear measurement: Real ear measurement was carried out using a calibrated Fonix 7000 hearing aid analyzer. The participant was seated on a chair at 0 °s azimuth and one foot distance from the loud speaker of the hearing aid analyzer. Leveling of the system was done with the reference microphone located on the pinna of the test ear using the integrated ear hook to ensure the validity of probe tube microphone measurement. The audiometric thresholds of the test ear of the participant were entered into the system. After selecting the insertion gain measurement mode in the system, NAL-NL1 was selected as target prescriptive procedure.

The probe tube of the hearing aid analyzer was inserted in the ear canal. To ensure correct length of insertion of the probe tube during measurements, the probe tube was marked was marked prior to the measurement. For this, the probe tube was detached from the microphone and laid on a flat surface next to the ear tip of the hearing aid, with the tip of the probe tube extending 5 mm from end of ear tip of the hearing aid, then at this point a marker pen was used to mark the length of the tube. It was ensured that this mark was at the entrance of the ear canal during probe tube measurements. This marking was used as the insertion depth and was kept constant during all the real ear measurements.

The marked probe tube with the microphone set-up was again inserted to the ear canal of the participant’s test ear. The programmed hearing aid was placed behind the ear of the patient with the eartip appropriately placed in the canal. For measurement of FBR, the real ear aided gain (REAG) was measured from 0° and 180°, with the hearing aid in omnidirectional and directional modes. To find out FBR of the hearing aid, the participant with the hearing aid was made to sit on the chair at a fixed distance (1 foot) in front (0° Azimuth) of the loudspeaker of Fonix 7000 system. The reference microphone was disabled. The protocol used for measurement of FBR is given in Table 3.1

Table 3.1

Protocol for measuring REUG, REAG, REIG.

Type of stimuli	Composite signal
Stimulus level	65 dB SPL
Reference microphone	Disabled
Prescriptive formula	NAL NL-1
Output limiting	120 dBSPL
Test type	Insertion Gain

The real ear aided gain (REAG) of the hearing aid was measured in the ear canal using the probe tube microphone. This was done with the participant wearing the test hearing aid programmed for omnidirectional mode in front of the loud speaker (i.e., 0° Azimuth) of Fonix 7000. This measurement was saved as REAG 1. The measurement was repeated with the hearing aid set to directional mode (saved as REAG 2). The REAG was again measured by turning the back of the participant towards the loud speaker of Fonix 7000 (i.e., 180° Azimuth). This measurement was done with the hearing aid set at omnidirectional (saved as REAG 3) and directional modes (saved as REAG 4).

In the omnidirectional mode, the FBR was computed by the hearing aid analyzer by subtracting the real ear aided measurement at 180° from the real ear aided measurement done at 0°. In the directional mode also, the FBR was computed by the hearing aid analyzer by subtracting the real ear aided measurement at 180° from the real ear aided measurement done at 0°. The values of REAG 1, REAG 2, REAG 3 and REAG 4 were noted at 200 Hz, 500 Hz, 800 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz, and 8000 Hz frequencies from the data table displayed for each test ear of each participant.

Phase II: Localization for eight different locations of the loud speakers

The participant was made to sit on a chair in the centre of the localization set-up. Horizontal plane localization was measured for eight loudspeakers which were located at 0, 45, 90, 135, 180, 225, 270, and 315 degrees.

Horizontal sound localization set-up

Horizontal sound localization was determined by using eight Genelec 8020B speakers mounted on Iso-Pod^{TM}(Isolation position/decoupler^{T}) vibration insulated table stand. These speakers were arranged in a circular array with one meter radial diameter from the centre. All the speakers were placed at 45^0 apart from each other covering 0^0 to 360^0 with eight speakers.

The white noise was calibrated using an sound level meter (SLM) The white noise stimulus generated using Adobe Audition 3.0 on the computer was routed through these speakers and the output of each loudspeaker was calibrated using a Larson-Davis SLM system (model 2540). The SLM was placed at centre with a ½ inch free-field microphone. The microphone of the sound level meter with preamplifier was placed at a position corresponding to the centre of the head and at a height of one meter from the ground. The level of white noise was adjusted in the CuBase 6 program such that reading on the SLM was 60 dBSPL from each of the eight loud speakers.

Horizontal plane localization task

The participant wearing the programmed binaural digital BTE hearing aids was seated in the centre of surrounded by eight loudspeakers. A train of three white noise bursts for each loud speaker were routed in random order. The train of white noise was presented randomly in such a way that there were three presentations through any single loud speaker. The stimuli were presented at 60 dBSPL. During the test, the participants were instructed to maintain the designated position and orientation of the head. The order of presentation of eight set of stimuli was randomized.

The participants were instructed that he/she would be hearing a train of noise stimuli from any one of the eight speakers at a time. Each time, he or she had to report the loudspeaker from which the stimulus was heard. The response mode from the participant was through a pointing task**.** The location of the loudspeaker to which participants pointed was noted down in terms of azimuth. The loud speaker through which the burst was presented and the loud speaker pointed out by the participant were both noted for every presentation in order to compute the degree of error in localization.

For the purpose of the study, Degree of Error (DOE) was measured for the localization task. The DOE corresponds to the difference in degrees between the degrees of azimuth of the loudspeaker of actual presentation of the stimuli, to the degree of azimuth of the loudspeaker identified as the source of the stimulus by the participant. For example, if the stimulus was presented from a loudspeaker at 45^0 azimuth and the participant reported the sound to be arriving from loudspeaker at 135^0, then the DOE would be 90^0 i.e., $45^0-(135^0) = 90^0$. This DOE was obtained for four trials at each angle in each aided condition and averaged. Thus, in each test condition, there were eight DOE. In order to avoid the minus/plus values and to get only the positive values, the root mean square DOE was computed using the procedure given by Ching, Incerti, and Hill (2004) for the purpose of the study.

A single representation of degree of errors in each aided condition was done by the calculation of root mean square degree of error (rms DOE). The rms DOE is defined as the square root of the average of squared degrees of errors in each set. Thus, each participant had two rms DOEs, representing the localization abilities of the participant in the omnidirectional condition and directional aided conditions. The formula used for calculating the rms DOE for localization (Ching, Incerti, & Hill, 2004) is

$$\text{rms DOE} = \sqrt{\frac{(DOE_1)^2 + (DOE_2)^2 + (DOE_3)^2 + \ldots + (DOE_8)^2}{8}}$$

Where, DOE_8= Degree of Error of the 8th presentation in a set; and rms DOE = Root mean square degree of error.

Thus for each aided condition, the degree of error (in omnidirectional and directional) for each loud speaker location was tabulated. Later, the DOE was calculated for right speakers (located at 45°, 90° and 135°), left speakers (located 225°, 270° and 315°), front speakers (located at 0°, 45° and 315°) and back speakers (located at 135°, 180° and 225°) and tabulated for each aided condition (omnidirectional and directional) for each participant.

. Thus, the data on SNR-50, FBR and localization in omnidirectional and directional modes were collected and tabulated for each participant. The tabulated data were subjected to statistical analyses.

CHAPTER 4

Results & Discussion

The present study aimed at evaluating the effects of omnidirectional and directional hearing aids in monaural and binaural modes. The parameters evaluated were speech perception in noise (using SNR-50), front-to-back ratio (FBR) and localization.

The data were collected from nine participants for speech perception in noise, ten participants for FBR, and from nine participants for localization. The data were tabulated and subjected to statistical analysis using SPSS (Statistical Package for the Social Sciences, version 20). The SNR-50 was done in both monaural and binaural conditions with omnidirectional and directional modes. The FBR was done in the monoaural mode alone. Localization was evaluated in binaural mode. The results are discussed under the following headings:

4.1. SNR-50

4.2. FBR

4.3 Localization

4.1 **SNR-50**

The data collected from ten participants for speech perception in noise were tabulated and subjected to statistical analysis using SPSS (Statistical Package for the Social Sciences, version 20). The SNR-50 was obtained in omnidirectional and directional conditions in both monaural and binaural modes. The mean and standard deviation (SD) of the SNR-50 with omnidirectional and directional conditions, in both monaural and binaural modes, are provided in Table 4.1.

Table 4.1

Mean, standard deviation and range of SNR-50 in different aided conditions.

Aided condition (N= 10)		*SNR-50 in dB*			
		Mean	*Std. Deviation*	*Range*	
				Minimum	*Maximum*
Monoaural	Omnidirectional	-3.70	3.89	-9.00	5.00
	Directional	-5.90	5.47	-11.00	7.00
Binaural	Omnidirectional	-4.10	4.72	-9.00	5.00
	Directional	-6.70	5.33	-11.00	5.00

In both monoaural and binaural conditions, the mean SNR-50 value for directional mode is higher than in omnidirectional mode. From Table 4.1, it can be observed that the mean SNR-50 value was better in the binaural condition irrespective of the microphones used in the hearing aids. In order to see if this difference was significant, Friedman Test was performed. This indicated that there was a significant difference in the SNR-50 among the aided conditions [$x^2(3)=13.33, p=0.004)$]. To examine the aided conditions in which significant differences existed, Wilcoxon's signed ranks test was performed. Though the performance was better in binaural mode than the monoaural, the Wilcoxon's signed ranks test indicated that there was no significant difference between the monaural and binaural SNR-50 values (Z=-1.23, p=0.219 for directional mode; Z=-1.01, p=0.314 for omnidirectional mode). Further, the test also indicated that there was a significant difference between the omnidirectional and directional microphone modes, in both monaural and binaural conditions. The performance was significantly better in directional compared to omnidirectional mode.

Table 4.2

Wilcoxon's signed ranks test performed to obtain the significant difference between omnidirectional (OD) and directional (D) modes.

Aided Condition	*SNR 50*			
	Monoaural		*Binaural*	
	Z	*P*	*Z*	*P*
OD – D	-233	0.02	-2.59	0.01

In the present study, the SNR-50 reduced by 2 to 3 dB in directional mode compared to omndirectional mode, implying a better performance in directional mode. This finding conforms to that reported in literature. Hawkins and Yacullo (1984) found that directional microphones reduced the SNR by 3-4 dB needed for hearing aid wearers to achieve 50% word recognition. In another study, Valente et al. (1995) reported a directional advantage of 7 to 8 dB (in SNR) for directional microphones over omnidirectional condition in a group of listeners with hearing impairment.

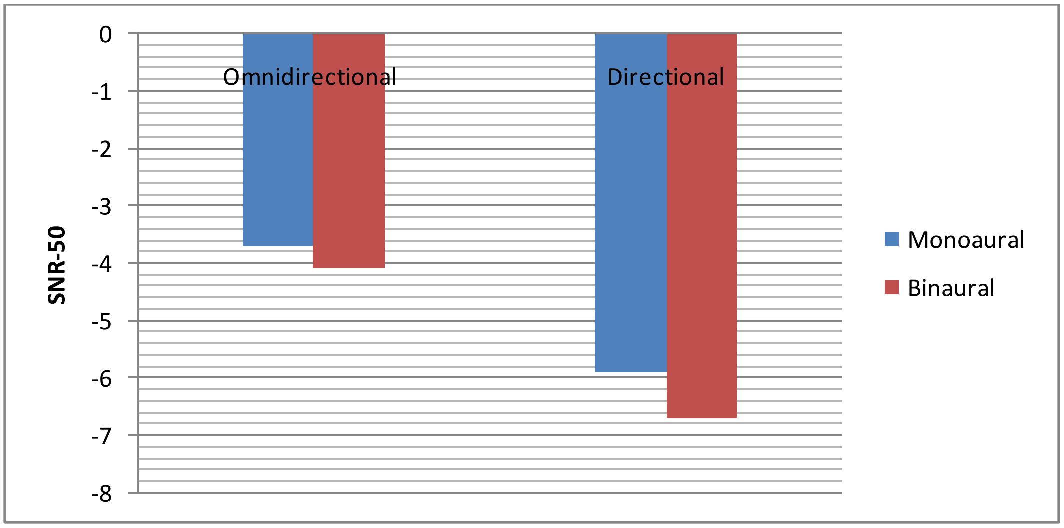

Figure 4.1. Mean and standard deviation of SNR-50 in different aided conditions.

4.2. Front-to-Back Ratio (FBR)

The FBR was measured in the monoaural mode with the hearing aid in omnidirectional and directional modes, on ten participants. The FBR is a ratio. Hence, if the values are positive, then the SPL measured from front is higher than from back. If the FBR values are negative, then the SPL measured from front is lower than from back.

Table 4.3

Mean front-to-back ratio at different frequencies in ominidirectional and directional modes in the monoaural aided condition

		FBR									
Aided condition (N=9)		*Overall RMS*	*200 Hz*	*500 Hz*	*800 Hz*	*1k Hz*	*1.5k Hz*	*2k Hz*	*3k Hz*	*4k Hz*	*6k Hz*
Omnidirectional	Mean	2.66	-1.02	2.77	1.22	-0.09	2.26	4.08	2.71	-0.58	4.05
	SD	3.62	7.07	6.02	3.39	4.79	2.88	4.25	4.76	5.15	9.24
Directional	Mean	5.45	-2.63	4.29	3.42	0.85	7.08	6.08	6.57	6.48	5.46
	SD	3.94	5.83	3.79	4.16	6.45	5.83	4.92	7.73	6.19	6.69

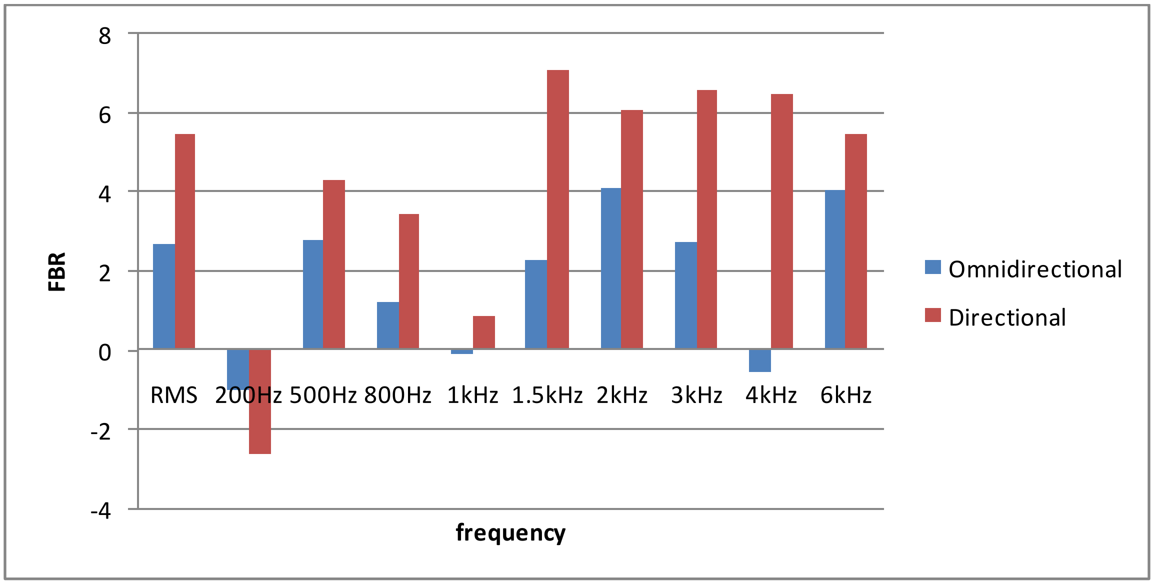

Figure 4.2. Mean values for front-to-back ratio in both the monaural aided condition

From Table 4.3 and Figure 4.2, it can be seen that most of the FBR values are positive indicating that the signal from front has more SPL than signal from back. The FBR for directional mode is more than in the omnidirectional mode by about 3 dB. This indicates that as expected, the intensity of signals arriving from front were higher than the signals from back. This pattern was noted in FBR at majority of the frequencies tested.

In order to examine if the difference in FBR in ominidirectional and directional modes was significant, Friedman's test was done. This revealed that the measured intensity of signal from front was significantly higher than from back in the directional mode compared to the omnidirectional mode [$x^2(19) = 50.49$, $p = 0.00$)]. To examine the frequencies at which significant differences existed, Wilcoxon's signed ranks test was performed. It was found that, there was a significant difference between omnidirectional and directional only at 1000 Hz ($p<0.05$).

Table 4.4

Wilcoxon's signed rank test to obtain significant difference of front-to-back ratio between the two aided conditions.

FBR in OD vs. FBR in D At different frequency (Hz)	*Z*	*p*
200	-0.05	0.96
500	-0.42	0.68
800	-1.48	0.14
1000	-2.39	0.02

1500	-1.48	0.14
2000	-.612	0.54
3000	-1.12	0.26
4000	-1.68	0.09
6000	-0.66	0.51

The results of this study conforms to the observation reported by Valente, Dunn, and Roeser (2008). In their opinion, it had been documented that to verify the functioning of directional microphone, it is important that output of the signal presented from front be greater than from behind, in the directional mode.

The directionality in a hearing aid affects the performance in noise and front-to-back-ratio. Hence, it would be interesting to know if there is any correlation between these two parameters. Pearson’s product-moment correlation was performed between SNR-50 and FBR.

Table 4.5

Pearson’s correlation between SNR-50 and front-to-back ratio.

Monaural Aided condition	*SNR-50 - FBR*	
	r	*p*
OD	+0.43	0.218
D	-0.53	0.114

From Table 4.5, it can be noted that there was a moderate correlation between the monaural SNR-50 and FBR, in both monidirectional and directional modes. This correlation was not significant. In omnidirectional mode, the correlation was positive implying that as the SNR-50 values reduced (indicating better performance in noise), the FBR also reduced (lesser difference between the SPL measured from front and back). In the directional mode, the correlation was negative implying that as the SNR-50 reduced (indicating better performance in noise) the FBR increased (greater differene between tne SPLs measured from front and back).

4.3 Localization

The performance on localization (in terms of rmsDOE) of eight different locations of the loud speakers for nine participants wearing binaural hearing aids was tabulated and subjected to statistical analysis. Participant attrition was present for one participant, hence the N was 9. Table 4.3 provides the mean and standard deviation (SD) values of the root mean square degree of error (rmsDOE) in localization.

Table 4.6

Mean and standard deviation (SD) values of the rms degree of error (rmsDOE) in localization.

Location of loud speakers	*rms DOE in Localization (N=9)*			
	Mean	*Std. Deviation*	*Minimum*	*Maximum*
Overall (OD)	14.99	9.62	0.00	36.74
Overall (D)	54.84	22.84	0.00	72.13
0° (OD)	.00	.00	0.00	.00
0° (D)	4.50	7.25	0.00	15.00
45° (OD)	37.50	71.50	0.00	225.00
45° (D)	.00	.00	0.00	.00
90° (OD)	7.50	12.75	0.00	30.00
90° (D)	10.50	15.89	0.00	45.00
135° (OD)	7.50	10.61	0.00	30.00
135° (D)	28.50	25.93	0.00	75.00
180° (OD)	.00	.00	0.00	.00
180° (D)	135.00	60.00	0.00	180.00
225° (OD)	16.50	16.51	0.00	45.00
225° (D)	52.50	36.91	0.00	90.00
270° (OD)	4.50	14.23	0.00	45.00
270° (D)	4.50	7.25	0.00	15.00
315° (OD)	12.00	17.03	0.00	45.00
315° (D)	.00	.00	0.00	.00

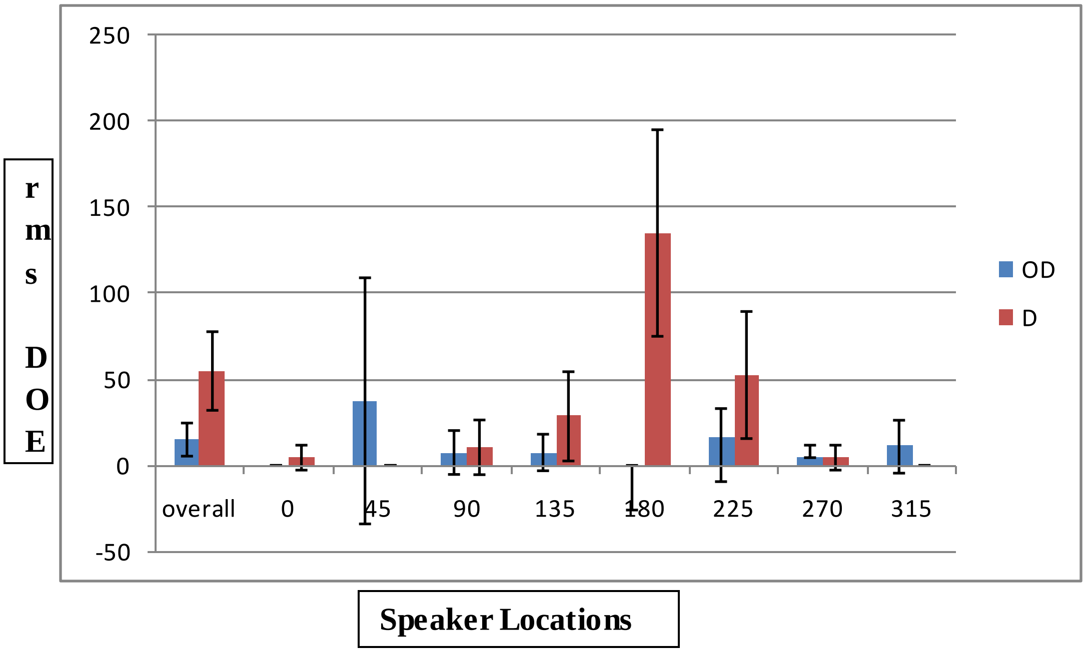

Figure 4.3. Mean and standard deviation (SD) values of the rms degree of error (rms DOE) in localization

On observation of the Table 4.6, it is evident that the localization was poorer in directional mode compared to omnidirectional mode, as expected. To see whether this difference was significant, Friedman test was performed. Friedman test revealed that there was a significant difference between the directional and omnidirectional modes [$x^2(17)=96.23$, $p=0.000$)]. In order to know the locations (angles) of the loud speakers in which the omnidirectional was significantly better than the directional mode, post-hoc Wilcoxon signed-rank test was performed.

Table 4.7

Wilcoxon signed-rank test was performed to obtain significant difference.

Loud speaker location angles	*Z*	*P*
0°	-1.73	0.08
45° *	-2.03	0.04
90°	-1.41	0.16
135°	-2.27	0.23
180° **	-2.72	.01
225° **	-2.54	.01
270°	0.00	1.00
315°	-1.84	0.67

Note: * : Sig. diff. at p<0.05; ** : Sig. diff. at p<0.01

Wilcoxon signed ranks test revealed that there was a significant difference between omnidirectional and directional condition at only 45°, 180° and 225°. At other locations, the localization with OD was better though not significant.

Table 4.8

Mean of the degree of error across angles in omnidirectionl and directional mode.

Loud speaker locations	*Mean rms DOE in localization (N=9)*	
	Omnidirectional mode	*Directional mode*
Front	18.32	0.56
Back	10.53	79.97
Right	18.3	14.4
Left	12.2	21.16

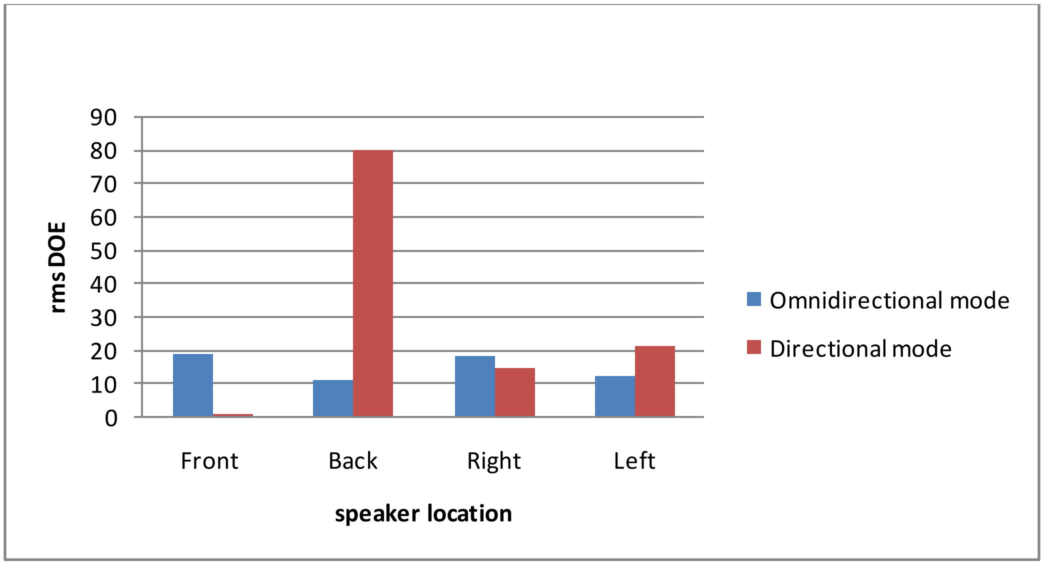

Figure 4.4. Mean of the rms degree of error across angles in omnidirectional and directional modes.

The rms degree of error for directional mode was high for the back angles at 135°, 180° & 225 (79.97°) compared to the front angles at 315 ° , 0 ° , and 45 ° (0.56°). No such pattern was observed in the omnidirectional mode implying that omnidirectional mode is equally good for localization of all directions.

There are studies wherein it has been suggested that the directional microphones can affect horizontal localization performance relative to performance with an omnidirectional microphone (Van den Bogaert et al., 2006; Keidser et al., 2006). In both the studies data were analyzed independently in the left/right and front/back dimensions. It was reported that directional microphones had the most significant effect on horizontal localization performance. Specifically, a cardioids/directional microphone could increase the left/right errors when different microphones were fitted to left and right ears. In addition, front/back confusions were generally prominent. In the result reported by of Van den Bogaert et al, 2006, subjects with normal hearing and hearing impairment showed good performance in the most frontal area of the horizontal plane.

CHAPTER 5

Summary and conclusions

There has been abundant research examining the perception of speech in the presence of background noise. But there is a dearth of studies on front-to-back ratio and localization with directional hearing aids. The present study aimed at determining the effect of directional microphone on speech perception in noise (SNR-50), FBR and localization.

The data were collected from nine participants with flat moderate to moderatively severe sensorineural hearing loss. The individual with hearing impairment were fitted with digital BTE hearing aids. Hearing aids programming was done with NAL- NL1 and fine tuned for audibility of ling sounds. The hearing aid was set with omnidirectional microphone in Prog 1 and directional microphone in Program 2 hearing aid.

Phase I of the study aimed at evaluating speech perception in noise using SNR-50 in two aided conditions, omnidirectional and directional. FBR was also established in these two aided conditions. Phase II involved measurement of localization for eight angles (0°, 45°, 90°, 135°, 180°, 225°, 270° and 315°) in omnidirectional and directional modes. The performance on localization was measured by root mean square degree of error (rmsDOE). The data collected were tabulated and subjected to statistical analyses.

The findings in the study were as follows:

1. The speech perception in noise was significantly higher in the directional mode compared to the omnidiectional mode.

2. Directional microphone was better than omnidirectional microphone in both monoaural and binaural conditions.
3. Front-to-back ratio was significantly higher for directional mode than omnidirectioanl mode.
4. There was a moderate correlation between the SNR-50 and FBR (p>0.05).
5. Localization was better with omnidirectional microphone compared to directional microphone.
6. In omnidirectonal mode, the degree of error for localization of front/back and right/left sides was lesser than directional mode. Within directional microphone, rmsDOE was lesser for sounds from front compared to sounds from behind.

Implication of the study

The study increases the knowledge on effect of directional microphone and omnidirectional microphone on speech identification in noise, FBR and localization. This information helps an audiologist during the selection of directional/omnidirectioal hearing aid for differet situations.

Future directions for research

The present study revealed the effect of directional hearing aids on speech perception in noise and localization. The speech perception in noise was evaluated when noise and speech are produced from a fixed position, but it has not thrown any light on speech perception when noise and speech are moving. It would be interesting to know the effect of adaptive directional hearing aid on speech perception in noise and localization.

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