Speech Perception in Directional, Adaptive Directional and Omnidirectional Microphones in Hearing Aids:
A Laboratory Measure

Register No: A0490007

A dissertation submitted in part fulfillment for the degree of
Master of Science (Audiology)
University of Mysore, Mysore

ALL INDIA INSTITUTE OF SPEECH & HEARING,
MANASAGANGOTHRI, MYSORE-570006
MAY 2006.

Dedicated to
the Almighty,
Preceptors,
Family &
Friends

Certificate

This is to certify that this dissertation entitled **"Speech Perception in Directional, Adaptive Directional and Omnidirectional Microphones in Hearing Aids: A Laboratory Measure"** is a bonafide work in part fulfillment for the degree of Master of Science (Audiology) of the student Registration No: A0490007. This has been carried under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any Diploma or Degree.

Mysore
May 2006

Prof. M. Jayaram
Director
All India Institute of Speech & Hearing,
Manasagangothri, Mysore-570006

Certificate

This is to certify that this dissertation entitled **"Speech Perception in Directional, Adaptive Directional and Omnidirectional Microphones in Hearing Aids: A Laboratory Measure"** has been prepared under my supervision & guidance. It is also certified that this dissertation has not been submitted earlier to any other University for the award of any Diploma or Degree.

Mysore
May 2006

Prof. M. Jayaram
Guide
Director,
All India Institute of Speech & Hearing,
Manasagangothri, Mysore-570 006

Declaration

I hereby declare that this master's dissertation entitled **"Speech Perception in Directional, Adaptive Directional and Omnidirectional Microphones in Hearing Aids: A Laboratory Measure"** is the result of my own study and has not been submitted earlier to any other University for the award of any Degree or Diploma.

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Chapter 1

Introduction

Difficulty in understanding speech in the presence of background noise is a common complaint of hearing aid users and a primary reason for dissatisfaction with hearing aids (Kochkin, 1993). Persons with impaired hearing require a more favorable signal-to-noise ratio than do persons with normal hearing (Dubno et al, 1984; Gelfand et al, 1988; Bronkhorst and Plomp, 1990). Many hearing aid manufacturers now offer different microphone options in wearable hearing aids. These include omnidirectional, fixed directional and the recent adaptive directional microphones.

The Omni Directional Microphone

The omnidirectional microphone is basically a closed box that is divided into two small volumes by a thin polymer diaphragm. Sound pressure enters the microphone through a small tube, and then travels to the region called the “front volume” of the microphone. In the front volume, the sound pressure creates a small motion of the diaphragm. On the other side of the diaphragm, the “back volume” contains a metal plate that is coated with an electret material. This electret material holds a permanent electrical signal that is amplified to become the electrical output signal of the microphone.

The Directional Microphone

The use of directional microphones in hearing aids has regained focus as a means to improve speech understanding in background noise. Many hearing aid manufacturers now offer directional microphones in both behind-the-ear (BTE) and in-the-ear (ITE) styles of hearing aids. The two designs that are currently implemented in hearing aids are the single-microphone and the two-microphone design. The three-microphone and array designs are in the initial stages of marketing.

The single-microphone design has sound inlets (front and back) leading to separate cavities, divided by a diaphragm. An acoustical time-delay network is used to ensure that the sound waves from both inlets reach the diaphragm at the same time, thus canceling out each other (Ricketts & Dittberner, 2002). The two microphone design uses two numbers of matched omnidirectional microphones placed inside a BTE or ITE hearing aid. An electric time delay is added to the output of the rear microphone. In other words, the operating principle of the two types of microphones is identical, only the implementation differs. A switch is often used to access the omnidirectional mode by disabling the rear microphone (Ricketts & Dittberner, 2002).

The directional response characteristics of both single- and two-microphone directional hearing aids are assessed in the same manner. The directionality of the hearing aid microphone is determined by calculating a Directivity Index (Beranek, 1954). The Directivity Index (DI) represents the ratio of the microphone output for signals arriving on-axis to those arriving off-axis. It has been presumed that higher the DI, the higher the predicted improvement in signal-to-noise ratio (SNR) and the greater the ease of communication in difficult listening environments (Ricketts & Dittberner, 2002). Recent research supports this presumption (Ricketts, Hornsby, & Henry, 2002).

Currently, directional microphone is one of the best options available in wearable hearing aids which facilitate better speech understanding in noise (Cord et al, 2004). Assuming that the listener is facing the signal source and that the background noise is not coming from the same direction (that is, the signal and the background noise are spatially separated in the listening environment), directional microphone technology has the potential for improving SNR at the listener's ear. Adaptive directional performance means smooth intuitive transition between listening environments. The automatic situation detection classifies the situation based on the analysis of an incoming signal.

The directional advantage is the improvement in speech recognition in noise obtained with directional microphones in comparison to omnidirectional microphones. It is often expressed as the decibel difference in SNRs. Valente et al (1995) reported a directional advantage of 7.6 dB (in SNR) for directional microphones over the omnidirectional condition in a group of hearing-impaired listeners. However, the directional advantage varied considerably across listeners, from 3.5 dB to 16.1 dB. This variability in directional advantage is particularly noteworthy because each dB improvement can bring in 8.5 percent or more improvement in speech recognition (Nilsson et al, 1994). In a similar study, Agnew and Block (1997) reported a mean directional advantage of 7.5 dB, with intersubject difference ranging from 2.3 to 14.6 dB.

Clearly, the directional advantage obtained by hearing-impaired persons in a laboratory condition can vary considerably even for the same hearing aid and test condition. Ricketts and Mueller (2000) reported no relationship between the slope of the audiometric configuration or degree of high frequency hearing loss, or the aided omni directional performance in a speech-in-noise intelligibility task and directional advantage. They concluded that the magnitude of directional advantage cannot be predicted from the audiometric variables evaluated. Jespersen and Olsen (2003) further examined the relationship between omni directional performance in noise and directional advantage the subjects were controlled for the slope of hearing loss. The effect of degree of hearing loss was also evaluated. They found that neither omni directional performance in noise nor degree of hearing loss could predict directional advantage.

The advantage obtained from directional microphones varies across patients in the test booth, and also in everyday living situation. Cord et al (2002) explored the perceived benefits of directional microphone technology in real world situations to patients who had been fitted with switchable omni directional/directional hearing aids. The latter hearing aids incorporate both directional and omni directional microphone modes into a single multi memory device, allowing the wearer to switch between the two microphone configurations depending on the listening situation. Telephone interviews and responses to questionnaires were used to assess perceived performance with each microphone type. Although the majority of patients reported that they used the directional microphone mode regularly and were generally satisfied with the performance of their hearing aids, a substantial number (23%) reported that they did not use the directional microphone feature. Many indicated that they had initially tried the directional mode in adverse listening situations after receiving their hearing aids, but had not noticed any improvement in their ability to understand speech. As a result, they simply left their hearing aids set in the default omni directional mode in all listening environments.

Therefore, it may be useful to identify listener variables that could be measured during the initial hearing aid evaluation to determine whether a patient is likely to benefit from directional microphone technology. Not only would such information be useful in determining candidacy for directional microphones, it could considerably assist in the counseling of patients fitted with this technology to guide on the benefit that may be expected in everyday listening.

The Adaptive Directional Microphone

Adaptive directional hearing aids operate by automatically varying the physical directional properties until an attenuation pattern that results in the lowest output intensity from the directional microphone is obtained. The adaptation time in commercial hearing aids ranges from a few milliseconds to more than five seconds. While there is no data supporting either longer or shorter adaptation time constants, it is generally agreed that shorter time constants are necessary for the directional pattern to adapt to a changing noise source position. Adaptive directional circuitry is limited in hearing aids to avoid directional microphone parameters that result in directional patterns with nulls in the front hemisphere. In this way, it is ensured that important sounds that arrive from the front hemisphere are not attenuated either inadvertently or undesirably. With the front hemisphere attenuation limitation, an assumption is made that the lowest output from the directional microphone will correspond to the greatest noise attenuation. Theoretically, a hypercardoid type pattern is expected in a diffuse noise environment, whereas a dipole pattern is expected if competing noise sources are located directly to the side (90^0 azimuth). The effectiveness of adaptive directional hearing aids is especially of interest given that, once they are activated, the hearing aid wearer does not have specific control over the spatial attenuation pattern. In other words, in a noisy environment, adaptive instruments automatically shift polar patterns in an attempt to maximize signal-to-noise ratio in the presence of discrete-position noise sources.

While it appears that adaptive directional processing has the potential to improve speech recognition in noisy environments, its effectiveness in comparison to traditional fixed directional processing strategy is yet to be addressed. Advantage of adaptive over fixed directional hearing aids is expected to be environment specific. Since both systems sample sound at two locations, the theoretical limits of directivity for any single directional pattern should be identical. As a result, subjects' performance when fitted with an adaptive directional hearing aid in an environment for which a fixed directional hearing aid has been optimized is expected to be identical to that measured for the fixed system. However, an 'adaptive advantage' would be expected in environments for which the fixed directional hearing aid is not optimized.

The Problem

It is apparent that microphone type - directional, omni or adaptive directional - has a significant influence on the benefit derived by the hearing aid users in their speech perception.

Directional microphone has a significant advantage over omnidirectional microphone when speech is at 0^0 azimuth and noise arises from 180^0 azimuth (Valente et al, 1995). However, speech in real life situations may originate from different directions at any point of time. The directional benefit in such conditions may substantially vary depending on the direction from which the speech originates. Therefore, it is necessary to assess the benefits of directional and omnidirectional microphone technology in identifying speech coming from 0^0 azimuth in the presence of speech coming from other directions and vice versa.

Hearing aid users have difficulty in understanding speech originating from different directions other than 0^0 azimuth. The degree of difficulty in understanding speech originating from different directions is not well documented. Therefore, it is necessary to quantify the extent of the difficulty a hearing aid user faces in understanding speech originating from different directions other than 0^0 azimuth.

The polar pattern specified by the hearing aid manufactures is based on the measurements on a KEMAR or in an anechoic chamber. This may vary with different individuals due to head shadow, body baffle effect and variability in ear canal resonance. But, this variability is not well documented. The change in the polar pattern might result in changes in the performance of a particular microphone technology. Therefore, quantifying these differences will significantly help an audiologist in selecting an appropriate microphone technology based on individual specific information.

Therefore, the present study aims at assessing the benefits of directional, adaptive directional and omnidirectional microphone technology in identifying speech coming from different directions other than the direction of interest in laboratory conditions.

Objectives

The objectives of this study were to

a) quantify the difficulty a hearing aid user faces in understanding speech arising from different angles around the azimuth with different microphone technologies

b) assess the ability of hearing aid users to perceive speech through different microphone technologies in the presence of speech coming from a direction different from that of speech of interest, and

c) to identify the angle at which speech is best perceived in directional mode by measuring aided sound pressure level at the level of ear canal using probe microphone and hearing aid analyzer.

Chapter 2

Review of literature

Directional Benefits over Omnidirectional Microphone

Early studies on the relative effectiveness of directional and omnidirectional microphone, as implemented in a hearing aid, focused on the effects of reverberation time as well as unilateral and bilateral fittings (Hawkins & Yacullo, 1984). In general, these early investigations reported a 2-3dB advantage for the directional microphone in environments with short and moderate reverberation times (0.3 and 0.6 s).

Influence of Reverberation time

As most of the earlier studies on the relative benefits of directional and omnidirectional microphones were carried out in anechoic chambers or sound attenuating booths, the effect of reverberation was typically not considered. However, the findings of more recent studies emphasize the importance of considering reverberation time as part of the evaluation procedure. For example, Ricketts (2000) studied the effect of the configuration of multiple noise source(s) in two reverberant environments. The Hearing in Noise Test (HINT) (Nilsson et al, 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 (difference between the reception threshold for sentences for omnidirectional and directional conditions). Listeners 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 a reverberation time of 1.1 seconds. Four noise source configurations were studied, including a signal located in front and noise at (a)180^o (typical of earlier evaluation methods); (b) 90^o, 135^o, 180^o, 225^o, and 270^o, (typical of listening in the front of a class or in a theater); (c) 30^o, 105^o, 180^o, 225^o, and 330^o (typical of an environment with more diffuse noise); and (d) with 30^o, 105^o, 180^o, 225^o, and 330^o but with the 30^o and 330^o loudspeakers turned perpendicular to the listener (typical of a situation in which noise sources in the front are far away).

Both reverberation and noise configuration were found to influence directional benefit across hearing aids. In the living room environment, directional benefit ranged between 3.6 to 7.9 dB, depending on the noise source configuration. This directional benefit decreased to a range of 2 to 5.1 dB in the classroom setting. Directional benefit was significantly higher for the $0^o/180^o$ loudspeaker configuration in comparison with all others. Significantly less directional benefit was provided to listeners in the diffuse restaurant configuration (condition c) than classroom or restaurant configuration where the background noise at 30^o and 330^o was reduced by 5 dB (condition d). These results reveal that the 0^o/180^o test configuration commonly used in clinical evaluation may overestimate the benefit that will be obtained in more realistic environments having multiple noise sources. Second, an inverse relationship was noted between directional benefit/performance and reverberation time across different hearing aid brands, that is directional benefit/performance decreased as reverberation time increased. Although smaller in magnitude, this result is in agreement with previous investigations (Studebaker et al, 1980; Madison and Hawkins, 1983; Hawkins and Yacullo, 1984).

While Ricketts attempted to simulate real-world effects in the clinic, Killion and colleagues (1998) took a very different approach – they recorded evaluation materials in real-world environments. Test recordings were made in several different environments while subjects wore prototypes of binaural in-the-ear (ITE) hearing aids equipped with both omnidirectional and supercardioid microphones. Several pairs of ITE hearing aids were equipped with D-Mic^{TM} cartridges whose outputs were available through subminiature Microtronic four-pin connectors. One pin was connected to the omnidirectional microphone output while a second pin was attached to the directional microphone output. The directional microphone output was equalized to produce the same frequency response (flat) as the omnidirectional microphone. Cables were connected to permit each of the two stereo microphone outputs – directional and omnidirectional – to be connected to a hand-held digital analog tape (DAT) recorder. The individual, acting as a “recording dummy,” wore two custom ITE hearing aids attached to the recording instrumentation described above. Each DAT recorder was carried in a small belt pack. Outputs of the omnidirectional and directional microphones were recorded simultaneously permitting thereby later comparison of the two microphone outputs under identical conditions.

A sequence of sentence blocks modeled after the Speech in Noise Test (SIN) (Fikret-Pasa, 1993; Killion and Villchur, 1993) was recorded in various noisy real-world environments: a crowded street party (90-95 dBA), two restaurants (70-80 dBA and 60-65 dBA), and a museum party (80-85 dBA). It is difficult to compare the results of these two studies with those carried out in the past because of methodological differences. However these studies addressed the need for a test environment that approximates common real-world reverberation and noise conditions. A comparison of results from outdoor (street party) and indoor recordings showed that individuals with hearing loss obtained greater benefit (9 dB improvement) with the directional microphones in the outdoor situation. This is to be expected because the street party situation is a free field situation where the listener is in the direct sound path of the primary talker. In the other listening environments, the room reverberation and talker-listener distance made listening more difficult.

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- 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 0^0 relative to the participants, in this study which is an optimal arrangement for the cardioid pattern of the microphone under test.

Pumford et al. (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 placed. Although the improvement of 5.8 dB in SNR between the omnidirectional and directional mode 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.

Ricketts (2000b) evaluated the impact of head orientation and unilateral and bilateral fittings on the reception thresholds of hearing-impaired listeners wearing hearing aids in omni- and directional modes. The aided performance across these four fittings was evaluated for three different head and body angles in a moderately reverberant living room environment. Participants generally performed better in the directional mode and with bilaterally 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 (whether acoustic or electrical) were held constant. More recently, an adaptive directional design has been introduced into the wearable hearing aid. In this design, the characteristics of the polar pattern are under the control of the designed algorithm and continually adjusted according to the properties of environmental sounds. As such, only those hearing aids using a two microphone design can implement this adaptive option. The evolving polar pattern depends on the summed outputs of the separate microphone signals. The noise source is suppressed by the resultant low sensitivity of the microphone in its particular direction (Soede, Berkhout, & Bilsen, 1993). Although there is data to support the use of such a design in noise environments which have a single noise source (Ricketts & Henry, 2002), it is unclear whether any benefit can be achieved in environments with multiple noise sources wherein a primary noise source is randomly moving around the listener.

Determining Directional Benefits Using Self-assessment Procedures

While there are many studies which have examined directional benefit using speech recognition measures, studies using formalized self-assessment procedures have been quite rare (e.g., Preves et al., 1999; Valente, Fabry, & Potts, 1995; Walden, Surr, Cord, Edwards, & Olsen, 2000). Self assessment of directional benefit and its relationship to improvements in speech recognition measured in the laboratory are important because of the difficulty in quantifying generalizable directional hearing aid benefit through laboratory measures. This difficulty is due to the fact that hearing aid wearers listen to speech in a variety of different listening environments. Speech recognition scores through a directional hearing aid are influenced by the complex interaction between the spatial attenuation pattern of the particular directional hearing aid and the spatial distribution of the primary and competing signals in the listening environment. Stated differently, wearers of hearing aids have to communicate while listening to a variety of "auditory scenes" made up of one or more sound sources of interest and one or more competing sources. Factors related to listening environment such as source to listener distance, source to listener angle and room reverberation may differentially interact with the hearing aid to affect speech recognition. As factors like reverberation time, placement and number of competing noise sources have been shown to have a significant impact on directional benefit (Hawkins and

Yacullo, 1984; Ricketts and Dhar, 1999; Ricketts, 2000a). It is difficult to select a single test environment that reflects “average real world performance”.

The generalization of laboratory assessed directional benefit is further complicated by low-frequency effects. Specifically, the directional mode acts to reduce sensitivity to low-frequency sounds, and venting can reduce both low-frequency gain and directivity (Ricketts and Dittberner, 2002). Careful interpretation is therefore necessary to separate the effects of changes in low frequency audibility from the effects of directionality (Ricketts and Henry, 2002).

In addition to their rarity, formalized self-assessment studies of directional benefit have not been overwhelmingly supportive of directional technology. Valente et al. (1995) measured hearing aid benefit using the Profile of Hearing Aid Benefit (PHAB; Cox, Gilmore, & Alexander, 1991) and the Abbreviated Profile of Hearing Aid Benefit (APHAB; Cox and Alexander, 1995) for 50 listeners fitted with directional hearing aids at two different test sites. These data were then compared with normative data for linear amplification. The authors reported better PHAB scores for the directional hearing aids on the subscales for background noise and reduced cues at one site, and better APHAB scores on the subscales of background noise and aversiveness at another site. Additionally, the authors reported a general preference for the directional hearing aids in comparison to the participant’s current omnidirectional aids at one of the two experimental sites. These data appear to provide some support for directional hearing aid use; however, since normative data were used for comparison, the amount of benefit due strictly to the directional component is not available. Specifically, hearing aid brand, style, processing, and other factors are all known to influence subjective preferences.

Preves et al. (1999) examined subjective hearing aid benefit for compensated directional, noncompensated directional and omnidirectional modes of a single model of in-the-ear hearing aid fitted bilaterally. It is well known that directional microphones are less sensitive in the low frequencies than their omnidirectional counterparts for sounds arriving on-axis due to frequency-dependent differences in phase alignment (Thompson, 1999). Gain compensation is sometimes recommended to offset the low-frequency audibility that may result from this “directional roll-off” (Ricketts and Henry, 2002). Assessment of omnidirectional, compensated directional and non compensated directional modes was completed using the APHAB, paired comparison judgments, and interview data. This test battery was completed following a 3 to 6 week evaluation period with the hearing aids during which time the listener was allowed to freely switch between directional and omnidirectional modes. Listeners were instructed to try both hearing aid settings in a variety of listening environments. All listeners completed two numbers of 3 to 6 week trial periods. In the first trial period, frequency response in the directional mode was left uncompensated. In the second trial period, frequency response in the directional mode was compensated to provide a similar frequency response as in omnidirectional mode. Listeners were instructed to fill out APHAB following the trial period for both omnidirectional and directional microphone strategies.

Paired t-tests for comparison between omnidirectional and compensated directional modes indicated significantly greater hearing aid benefit for the directional condition as measured by reverberation (8.4%) and background noise (8.5%) subscales of APHAB. Similar results were noted for omnidirectional and uncompensated directional condition, but the difference did not reach statistical significance.

More recently, Walden et al. (2000) examined the performance of 40 adults with hearing loss fitted bilaterally with low-threshold compression digital signal processing (DSP) instruments in comparison with their own hearing aids, which were either linear hearing aids with input compression limiting (AGO-I) or 2-channel analog wide dynamic range compression (WDRC) Instruments. The DSP instruments included three user memories: 1) omnidirectional, 2) directional, and 3) noise reduction in combination with directional. Users were instructed to use all three memories in a variety of listening situations. The listener's own hearing aids were evaluated using the Connected Speech Test (CST), the PHAB and subjective ratings of speech understanding, listening comfort, and sound quality prior to fitting the test DSP instruments. The test instruments were evaluated a second time using the same test battery following a 6 to 9 wk evaluation period. Hearing aid benefit in each of the three modes of the DSP instruments were not evaluated separately using PHAB. Instead participants were instructed to fill out the PHAB for the test instruments based on the user memory that was considered optimal for the listening situation in question.

Significant directional benefit, as measured by the CST, was reported, Concomitant directional benefit in everyday listening situations, as measured by the PHAB, however, was not found. Walden et al. (2000) suggested several factors that may have contributed to the lack of subjective benefit observed, even in the presence of objective benefit. These factors included the possibility that objective laboratory measures overestimated directional benefit in the real world due to environmental factors (reverberation, number of competing noise sources, etc.), the fact that the PHAB was not independently administered for each hearing aid condition, and lack of appropriate acclimatization. The possibility of the factor of lack of real-world experience of some participants with the difficult SNR conditions of the test environment was also reported.

Directional Vs Omnidirectional Microphone Preference in Everyday Listening

The combined results of these studies (Preves et al., 1999; Valente, Fabry, & Potts, 1995; Walden, Surr, Cord, Edwards, & Olsen, 2000; Ricketts and Dittberner, 2002; Ricketts and Henry, 2002) do not provide definitive support for directional over omnidirectional hearing aid modes when listening in everyday environments. One conclusion from these data might be that directional benefit in real world listening situations is simply not present. A second, more plausible explanation is that current subjective instruments may be limited in their inclusion of, or categorization of, listening situations that are differentially affected by microphone type. In response to the directional studies that had been completed by Preves et al. (1999) and Walden et al. (2000) at the time, Jerger (2000) suggested that identifying the exact characteristics of everyday listening environments in which directional hearing aids are helpful might be necessary in order to fully understand the benefits of directional amplification. It may also be useful to attempt to identify specific listening situations for which directional amplification may prove to be detrimental. Identification of specific listening situations is also important given evidence that hearing aids generally reveal less benefit in noisy listening situations such as those for which directional hearing aids are recommended.

Although some of the experiments reviewed here support the use of directional technology, further studies are needed that examine “omnidirectional only” versus “directional only” modes. Such investigations are necessary if identification of specific listening environments for which the directional mode may have either a positive or negative impact is of interest.

Full-time use of directional amplification has generally not been supported by research. Listeners tend to prefer omnidirectional mode to directional mode when listening in quiet. Safety concerns in outside environments are also an argument against full time directional amplification. It has long been known that directional benefit is not present, or expected, in quiet, nonreverberant listening situations (Frank and Gooden, 1973). At least, one study (Lee, Lau, and Sullivan, 1998) has shown that, in comparison to an omnidirectional mode, a directional mode can reduce speech recognition in quiet when the speaker of interest is behind the listener. Surveys have generally shown either no preference (Mueller, Grimes, & Erdman, 1983) or preference for omnidirectional over directional strategies in quiet (Kuk, 1996, Wolf et al. 1999). In addition to these findings, one survey has also shown that most patients prefer to be able to switch between modes rather than full-time directional amplification (Wolf et al. 1999).

Rickets et al. (2003) systematically examined hearing aid benefit as measured by speech recognition and self-assessment methods across omnidirectional and directional hearing aid modes. These data were used to compare directional benefit as measured by speech recognition in the laboratory to hearing aid wearer's perceptions of benefit in everyday environments across full-time directional, full time omnidirectional, and user selectable directional fittings.

Results from tests on speech intelligibility in noise have indicated significantly more hearing aid benefit in directional modes than omnidirectional. PHAB results indicated more benefit on the background noise subscale in the user selectable directional fitting condition than in the full time omnidirectional condition. However, this directional advantage was not present for the full time directional condition.

Acknowledging these research findings, technologists have designed hearing aids to include both directional and omnidirectional microphone processing modes. Clinically, the use of omnidirectional mode is advocated for listening in quiet, whereas the directional mode is generally advocated as a way to improve the "effective signal-to-noise ratio" in noisy environments. The research of Preves et al. (1999) and Walden et al. (2000) clearly suggests that these simple recommendations may not be optimal. Appropriate use of microphone mode may depend on listening factors other than the presence or absence of noise. This hypothesis is also supported by studies of speech understanding in noise. Specifically, Kuk (1996) reported a preference for omnidirectional mode in at least one noisy environment (talkers of interest seated behind listeners in a car). It is clear that the perception of hearing aid benefit in noise will be reduced if the directional mode interacts with the environment in a detrimental way.

Directional Benefit in Test Booth Vs Field Data

Walden et al (2000) conducted a clinical trial of a digital hearing aid with the omnidirectional/directional option that illustrated the disparity between test booth and field data. Test booth speech recognition scores in noise showed highly significant directional advantages, but subjective ratings in daily use showed minimal directional benefit. Walden et al suggested a number of possible explanations for the discrepancy between directional microphone benefit observed in an audiometric suite and in everyday use including the likelihood that most real-life listening situations may not closely match the acoustics of the test booth.

Although a variety of factors may contribute to a directional advantage, it appears that the benefit obtained from either microphone type is particularly dependent on the physical characteristics of the listening environment. From this perspective, only when a specific set of environmental conditions exists in everyday listening will one or the other microphone mode provide superior performance.

Two recent studies (Cord et al, 2002; Surr et al, 2002) explored issues surrounding the use of dual-microphone hearing aids in everyday listening. Cord et al explored the benefits of directional microphone technology in real-world situations experienced by successful users of switchable omnidirectional/directional hearing aids. Telephone interviews and written questionnaires were used to assess perceived benefit with each microphone mode. The results suggested that the benefit of directional microphones in everyday listening is highly dependent on the specific characteristics of the listening situations encountered. Participants perceived that the directional microphone mode was superior to the omnidirectional microphone mode in situations where (a) background noise was present, (b) the signal source located in front of the listener was spatially separated from the source of the background noise, (c) there was low reverberation and (d) where the talker was close to the listener. Surr et al fitted 11 experienced hearing aid users with digital hearing aids featuring switchable omnidirectional and adaptive-directional modes. The subjects were asked to identify and describe at least one listening situation each day in which one microphone mode performed better than the other using a checklist daily journal format. This was to be done over a 6 week period. Although all participants reported difficulty in identifying situations where they perceived a difference between the two microphone modes, descriptions favoring the directional mode outnumbered those for the omnidirectional mode. The results indicated that location of the primary talker, presence or absence as well as type of background noise, and characteristics of space in which communication occurred influenced microphone preference.

Taken together, the studies of Cord et al. (2002) and Surr et al. (2002) suggest that the following characteristics of a listening environment serve as major determinants in defining the success of omnidirectional as well as directional hearing aid microphones: (a) presence/absence of background noise, (b) location of the signal source, (c) distance of the listener from the signal source, (d) amount of reverberation present, and (e) location of noise source in relation to that of signal. Neither study was definitive in the sense that they could not determine the superiority of one microphone mode over the other in everyday listening situations, or how frequently specific situations favoring one mode or the other occurred. However, results from Cord et al suggested that situations favoring the omnidirectional mode might occur significantly more frequently in everyday life than situations favoring the directional mode.

Cord et al. (2004) examined whether persons who were successful users of directional microphone hearing aids in everyday living tended to obtain a larger directional advantage in the test booth than persons who were unsuccessful users. Results revealed that the mean directional advantage did not differ significantly between patients who used the directional mode regularly and those who reported little or no benefit from directional microphones in daily living and, therefore, tended to leave their hearing aids set in the default omnidirectional mode.

Directional Benefits across Various Simulation of Noisy Environment

Single Noise Source

In many studies, simulation of a noisy listening environment has been accomplished by placing a single noise source directly behind the listener, that is, at 180^0 azimuth (Lentz, 1972; Mueller and Johnson, 1979; Madison et al, 1983; Hawkins et al, 1984; Valente et al, 1995; Lurquin and Rafhay, 1996). While there might, be occasions where a listener would encounter a single noise source directly behind, this test condition is not typical of listening conditions that people come across. In addition, an evaluation method that utilizes a signal in front of the listener and noise directly behind the listener will show maximum benefit for microphones with maximum attenuation (null) at 180^0 (i.e., a cardioid pattern of directivity) as compared to modern day supercardioid and hypercardioid microphones whose polar patterns are characterized by rear lobes. In some early studies, multiple noise sources were used (e.g., Nielsen, 1973; Compton, 1974; Preves, 1975; Rumoshosky, 1976; Lentz, 1977), but in most of these cases the noises were correlated (waveforms from each loudspeaker were similar). Correlated noise is not typical of most listening situations.

Multiple Noise Sources

The use of multiple noise sources is necessary because modern directional hearing aids contain microphones having varying polar patterns and degrees of directivity. In real-world environments, such as a restaurant or a cocktail party, noise may arise from all directions. Therefore, in order to assess improvement in SNR achieved by directional hearing aids, it would be advantageous to have noise arising from multiple directions in the evaluation environment.

Of concern is the issue of location and number of interfering noise sources. While earlier studies focused on 0/180 degree placement of primary/competing signals (e.g., Hawkins and Yacullo, 1984; Valente et al, 1995; Nielsen and Ludvigsen, 1998), it is now well understood that placement of a small number of speakers will have significant impact on the outcome, if those noise sources fall within the nulls of the particular polar response patterns (i.e., cardioid, hypercardioid, supercardioid). Pumford et al (2000) circumvented this design bias, by creating a “more diffuse” field using four interference speakers and one primary signal speaker. Sentence recognition thresholds were measured with subjects wearing in-the-ear (ITE) and behind-the-ear (BTE) style directional microphone hearing aids. For the BTE hearing aid condition, the authors reported a difference of 5.77 dB SNR between the omnidirectional and directional modes. A difference of 3.27 dB was reported for the ITE hearing aid. As the investigators noted, however, the ITE omnidirectional condition provided better

SNR performance than the BTE omnidirectional condition due to the placement of the microphone in the concha in ITE. Consequently, the actual performance with the two microphone modes was similar, although the benefit seemed to favor the BTE style.

Rickets and Dhar (1999) compared the benefits across three commercially available directional microphone hearing aids using a more diffuse field to evaluate the performance of these hearing aids in an anechoic chamber and a “typical living room” listening environment. The environment was created with six speakers (one of which was the primary-signal speaker). The authors reported a 2-3dB directional advantage in the anechoic chamber over the reverberant environment (Ricketts & Dhar, 1999).

It is clear that the benefit received is directly related to the location of the interfering noise. Each polar response pattern will have at least one (first-order cardioid) and as many as three (second-order hypercardioid) nulls, or angles at which the microphone has reduced sensitivity to any background interference (Dittberner et al, 2001).

Various configurations of noise sources have been reported (Hawkins and Yacullo, 1984; Valente et al, 1995; Nielsen and Ludvigsen, 1998; Ricketts and Dhar, 1999; Pumford et al, 2000), but while more complex sound fields may better represent the environments encountered in real-world listening situations, complex sound fields are very difficult to replicate in clinical settings.

Directional Vs Adaptive Directional Benefits Using Multiple Noise Sources

Bentler et al. (2004) compared the benefit of fixed and adaptive directional microphone in an anechoic chamber and a moderately reverberant classroom. In both the anechoic and reverberant spaces, a 5-speaker arrangement was made to create the competing, panning noise sources (five loudspeakers were angled towards the participant at 110^0, 150^0, 180^0, 210^0, and 250^0 azimuth). The target signals (i.e., the talker's voice) were routed from a CD player through an audiometer and to the front main loudspeaker.

Subject's ability to perceive speech on HINT and Connected Speech Test (CST) was assessed. The subject's were also asked to fill out self-report questionnaires like The Localization Abilities in Typical Environments (LOCATE), International Outcome Items for Hearing Aids (IOI –HA), and PHAB. Competing signals (CST, multitalker babble signal and the HINT spectrally matched noise) were digitally manipulated and routed to the five loudspeakers. The test results indicated that the adaptive polar response provided no additional efficiency or effectiveness beyond the fixed polar response, at least when the hearing aid was programmed to the manufacturer’s default settings.

Ricketts & Henry (2002) studied the effectiveness of adaptive directional processing for improvement of speech recognition in comparison to non-adaptive directional and omnidirectional processing across four listening environments intended to stimulate those found in the real world. The test environment was a single, moderately reverberant room with four loudspeaker configurations: three with fixed discrete noise source positions and one with a single panning noise source. Sentence materials from the HINT and CST were used. Results indicated improved speech recognition performance with adaptive and non adaptive directional processing over that measured with omnidirectional processing across all the four listening conditions. While the magnitudes of directional benefit provided to subjects listening in adaptive and fixed directional modes were similar in some listening environments, a significant speech recognition advantage was seen for the adaptive mode in specific conditions. The advantage of adaptive over fixed directional processing was most prominent when a competing noise was presented from the listener’s sides (both fixed and panning noise conditions), and was partially predictable from electroacoustically measured directional pattern data.

Chapter 3

Method

The aim of this study was to quantify the difficulty listeners may have in perceiving speech arising from different angles around 0^0 azimuth. This was carried out as a function of different microphone modes, namely, directional, omnidirectional and adaptive directional technology. A second aim of the study was to study the angle(s) from which speech is best perceived in the fixed directional microphone mode.

Subjects and Selection Criteria

Ten post-lingually hearing impaired subjects satisfying the following criteria were included in the study.

- Bilateral flat or gently slopping moderate to moderately severe sensorineural hearing loss.
- Aided thresholds within the speech spectrum.
- Aided speech recognition scores greater than 80%.
- No middle ear pathology.

- Naive hearing aid users were selected because acclimatization for hearing aid usage influences their performance on the tasks focused in this study.
- Subjects in the age range of 50 to 70 years

Ten normal hearing subjects whose pure tone audiometric thresholds were <15dB for both air (250Hz to 8 kHz) and bone conduction (250Hz to 4 kHz) were also selected for the study. Subjects had to be in the age range of 50 to 70 years.

Stimulus

The PB bi-syllabic Kannada word lists of Yathiraj and Vijayalakshmi, (2005) were used. The original word list consisted of four lists with twenty-five words in each list. These words were randomly selected and made into dichotic word lists with a 90 msec gap between the two words in each pair. The dichotic stimuli were made using Cool Edit Pro 2 software (downloadable trial version). A total of sixty dichotic stimuli with 90 msec gap between the two channels were prepared for the study. The word lists are given in Appendix 1.

Hearing Aid Description

Two similar non-linear digital behind-the-ear hearing aids with the following features were used. The hearing aid was suitable for individuals with severe degree hearing loss.

- Compact power
- Programmable instrument with fully digital 16-channel amplifier with speech comfort system
- 2nd order adaptive automatic directional microphone (TriMic system)
- Automatic Situation Detection
- Highly effective noise suppression algorithm
- Four individual hearing programs for microphone and telecoil mode
- Automatic feedback suppression
- Instruments in left and right version
- Professional fitting with CONNEXX software

Prescriptive Formula

NAL-NL1 prescriptive formula was used to fit hearing aids. The rationale of this formula is to maximize speech intelligibility and loudness normalization.

Test Environment

All tests were conducted and measurements made, including programming of hearing aid, in a sound treated room in which the ambient noise levels were within permissible limits (re: ANSI S3.1-1991, cited in Wilber, 1994).

Instrumentation

A Pentium IV computer along with NOAH-2, CONNEXX (Sifit V5.0a) software, and HI-PRO (for connecting the hearing aid with the computer) was used for programming the hearing aid. A Pentium III computer connected to a calibrated diagnostic audiometer (AD 229e) was used to present stimuli. Four column speakers (Ahuja ASC – 20T PA) calibrated to emit output that would result in equal SPL at the microphone were used.

The speakers were calibrated using with 1/2” free field sensitive microphone (Larson – Davis system 824, Model No. 2540) and preamplifier (PRM 902). The speakers were calibrated by placing the microphone of the sound level meter at the level of subject’s head assuming that the subject would be sitting in that given position.

A toggle switch was used to route the signal of one channel to any of the three speakers kept at 90^0, 180^0, or 270^0 azimuth. Figure 1 shows a block diagram of the test setup for presenting stimulus. A calibrated hearing aid analyzer system (FP 40) was used to measure the sound pressure level at the ear canal of the subject.

Procedure

Audiological Examination

All subjects were administered pure tone audiometric test, both air conduction (at octave frequencies of 250 Hz – 8 kHz) and bone conduction (at octave frequencies of 250 Hz – 4 kHz) on a 2-channel audiometer (Orbiter 922). Speech recognition scores were obtained at most comfortable loudness level. Tympanogram and acoustic reflex thresholds was obtained (GSI Tympstar) to rule out any middle ear pathology.

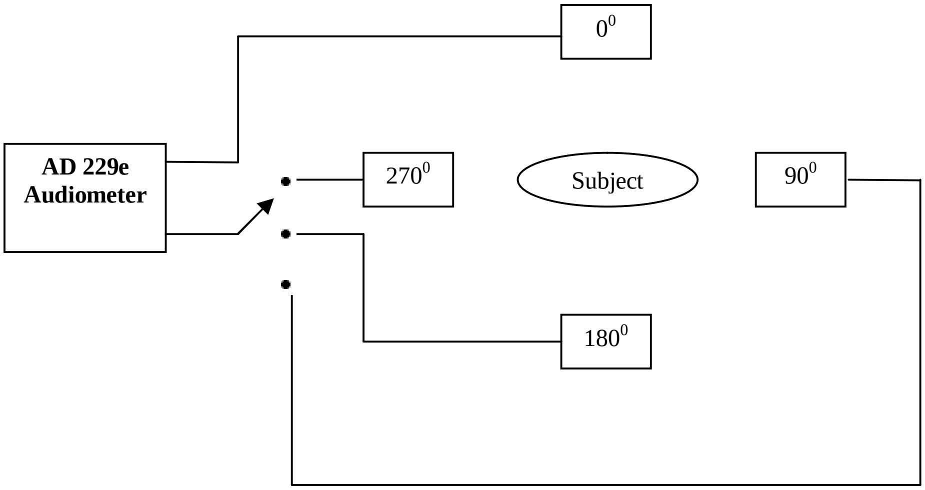

Figure 1: Block diagram of the test set up.

Hearing Aid Fitment

After the audiological evaluation, those subjects fulfilling the stated criteria were included in the study. The hearing impaired individuals were fitted with hearing aids, following established procedures.

- The subject was fitted bilaterally with Siemens Triano 3P digital hearing aids which have the option of directional, adaptive directional and omnidirectional microphone in it. Appropriately sized ear tips were also given.
- The hearing aid was connected to the HI-PRO that was in turn connected to a computer with the programming software

- The hearing aid was detected by the CONNEXX (Sifit V5.0a) software after switching the hearing aid ‘ON’
- The following general settings were selected for first fit
    - Test ear (Right and Left ear)
    - Acclimatization level: Two (as all the subjects were naïve hearing aid users)
    - Prescriptive formula: NAL-NL1
    - Acoustical and other parameters were set to default setting
- Frequency shaping option was selected for fine tuning
    - The first fit target curve was set by the software
    - Then, depending on the subjects’ need, the low-cut and high-cut gain values were manipulated during fine tuning.
- Opinion of the subjects regarding amplification was obtained. 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 hearing aid’s microphone option will be altered from omnidirectional to directional equalized and then finally to directional adaptive for each of the three trial in experiment 3.

Experiment 1: Speech Recognition with Different Microphone Mode Settings

Each normal hearing subject was seated in the center of the room with four speakers placed at 0^0, 90^0, 180^0 and 270^0 azimuth. Speakers were calibrated to emit speech at equal sound pressure level at the level of subject's head. The speech stimuli were PB words in Kannada in the form of 60 pairs of dichotic stimuli with a gap of 90 msecs between the two words of the same pair. One stimulus in each pair was presented through the speaker at 0^0. The second stimulus in the same pair was presented through any one of the speakers kept at 90^0 (condition 1), 180^0 (condition 2) and 270^0 (condition 3). The description of each condition is given in Table 1. A total of 120 words were presented- 60 through the speaker kept at 0^0 azimuth and the other 60 through other speakers, speaker selection being random. The subjects were instructed to repeat whatever they heard from any of the four directions.

A similar procedure was repeated with subjects fitted binaurally with Siemens Triano 3P digital (BTE) hearing aids. Speech testing was done for three modes of microphone settings, namely, omnidirectional, directional equalized and directional adaptive. A similar procedure was followed for all the three modes.

S.No	Condition	Description
1.	1	0^0 & 90^0
2.	2	0^0 & 180^0
3.	3	0^0 & 270^0

Table 1: Speaker combinations.

Experiment 2: SPL at the Ear Canal

Sound pressure level in the ear canal in response to output from speakers located at different angles was measured. Figure 2 is a block diagram of the experimental setting. SPL was measured with the help of a probe microphone and hearing aid analyzer (FP 40) for a DIGI Speech ANSI of 70 dB SPL. SPLs were measured for speaker outputs at 8 different locations - 0^0, 45^0, 90^0, 135^0, 180^0, 215^0, 270^0 & 315^0 – aided and unaided, and for each ear separately (unilateral fitting). The scores were compared across frequencies and angles.

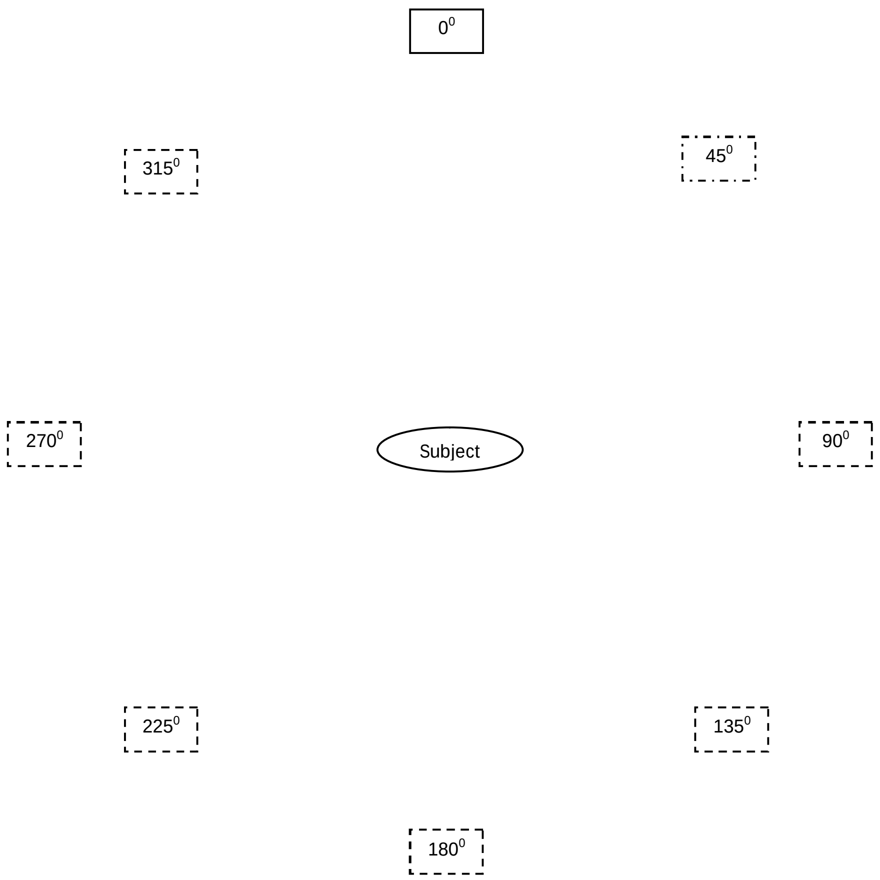

Figure 2: A block diagram of the experimental setting.

Chapter 4

Results

Data obtained from two groups of subjects (normal and hearing impaired) were analyzed to investigate the effect of microphone modes on speech recognition scores for stimuli coming from different angles around the azimuth. Statistical Package for Social Sciences (SPSS Version 10) for Windows was used to analyze the following:

a) Speech recognition scores of normal subjects under different test conditions (see Table 1) and, a comparison of those data with those from hearing impaired.

b) Speech recognition scores of hearing impaired under different test conditions and as a function of microphone strategies (directional, omni-directional and adaptive directional).

c) Comparison of aided sound pressure levels measured in the ear canal for a composite signal from eight different speakers at four different frequencies in the directional microphone mode.

Test used to analyze the data were:

a) Two way repeated measure ANOVA for the comparison of microphones and conditions.

b) One way repeated measure ANOVA for the comparison of speech recognition scores from different angles and at several frequencies.

1. Effect of Different Test Conditions on Speech Recognition Scores in Normal Subjects.

	Speech output from speakers placed at					
	0^0 & 90^0 (Condition 1)		0^0 & 180^0 (Condition 2)		0^0 & 270^0 (Condition 3)	
	Mean	S.D	Mean	S.D	Mean	S.D
Normals	91.00	2.42	82.75	2.19	89.75	2.19

Table 2: Mean and standard deviation (SD) of speech recognition scores in normal subjects in the 3 test conditions

2. Effect of Different Test Conditions on Speech Recognition Scores in Hearing Impaired Subjects Using Different Microphone Modes.

Microphone	Condition 1		Condition 2		Condition 3	
	Mean	S.D	Mean	S.D	Mean	S.D
Omnidirectional	66.50	2.42	64.50	4.53	65.25	3.99
Fixed directional	68.50	3.57	60.75	2.90	67.50	2.89
Adaptive directional	81.25	2.95	76.00	4.89	79.50	3.29

Table 3: Mean and standard deviation (SD) of speech recognition scores in hearing impaired subjects in the 3 test conditions and microphone modes

It is evident from Tables 2 and 3 that normal subjects have significantly higher speech recognition scores in comparison with hearing impaired subjects in all the three testing conditions irrespective of the microphone technologies that the later groups are using. In normal subjects, there was no significant difference in the mean speech recognition scores between conditions 1 and 3. Normal had significantly lower speech recognition scores for speech coming from 0^0 and 180^0(Condition 2).

Two-way repeated measure ANOVA was carried out to analyze the effect of conditions, microphone modes and their interaction effect in hearing impaired subjects. The results revealed a significant main effect of microphones [$F(2, 18) = 124.369$, $p < 0.001$] as well as test conditions [$F(2, 18) = 34.568$, $p < 0.001$]. There was also a significant interaction effect between microphones and conditions [$F(4, 36) = 5.673$, $p < 0.05$]. Therefore, Bonferroni's pairwise comparisons were made for deeper analysis of the interaction between microphones and conditions. There was no significant difference in the mean speech recognition scores between omni and fixed directional microphone modes, in any of the three test conditions while adaptive directional mode yielded significantly higher speech recognition score in comparison with omni and fixed directional modes. In the omnidirectional mode, there was no significant difference between the test conditions. However, in the fixed and adaptive directional modes, the difference between conditions 1 and 3 was not statistically significant. Figure 3 is a graphical representation of these findings.

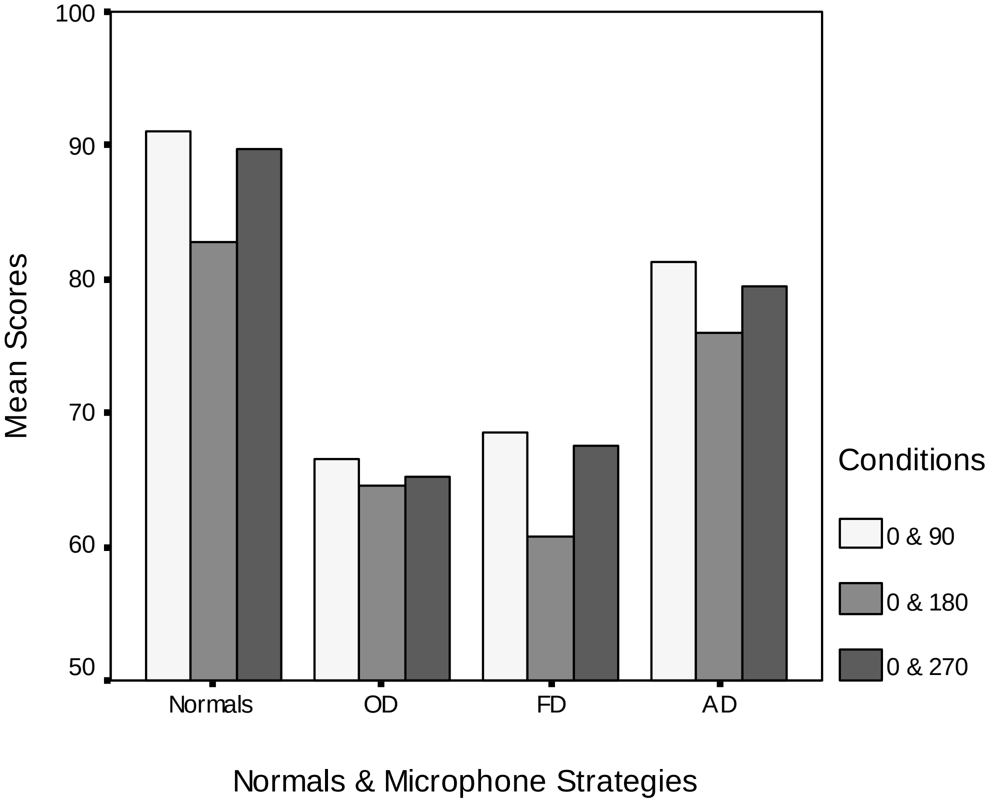

Figure 3: Mean speech recognition scores of normal and hearing impaired subjects. Hearing impaired subjects were fitted bilaterally with hearing aid having Omni Directional (OM), Fixed Directional (FD) and Adaptive Directional (AD) microphone strategies.

3. Effect of Different Angles on Sound Pressure Levels Measured at the Level of Ear Canal at Different Frequencies.

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Angle	Frequency							
	500 Hz		1000 Hz		2000 Hz		4000 Hz	
	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
0^0	29.30	1.32	37.48	0.69	50.22	0.90	19.47	0.57
45^0	29.82	0.65	37.11	0.73	49.33	1.85	18.99	0.70
90^0	20.64	1.06	28.87	0.58	39.84	0.85	9.01	0.57
135^0	20.67	1.20	27.86	2.89	40.33	3.44	9.14	0.53
180^0	27.43	0.86	38.17	1.32	46.62	0.94	11.94	0.60
225^0	26.67	1.04	32.75	0.93	45.19	0.71	18.73	0.98
270^0	23.62	1.28	30.58	1.25	42.66	0.93	14.76	0.67
315^0	29.52	0.69	37.20	1.01	50.02	0.83	14.31	0.79

Table 4: Mean and standard deviation (SD) of sound pressure levels measured at the level of ear canal at different frequencies and angles.

Frequency	F	p
500 Hz	F(7, 63) = 232.436	.000*
1000 Hz	F(7, 63) = 121.661	.000*
2000 Hz	F(7, 63) = 98.622	.000*
4000 Hz	F(7, 63) = 925.335	.000*

** The mean difference is significant at 0.001 level.*

Table 5: Results of repeated measures ANOVA across frequencies.

It is evident from Table 4 that sound output at angles 0^0, 45^0, & 315^0 resulted in maximum sound pressure level at the ear canal followed by sound from180^0, 225^0, 90^0, 135^0 respectively at all frequencies except 4000 Hz. At 4000 Hz, maximum sound pressure level was obtained for sound output from angles 0^0, 45^0, 225^0 followed by 270^0, 315^0, 180^0, 135^0, 90^0 in that order. Repeated measure ANOVA was done to compare the difference between angles at each frequency (see Table 5). Results revealed that there was a significant difference between angles at each of the four frequencies ($p < 0.001$). Figure 4 is a graphical representation of the mean sound pressure levels across different angles and frequencies.

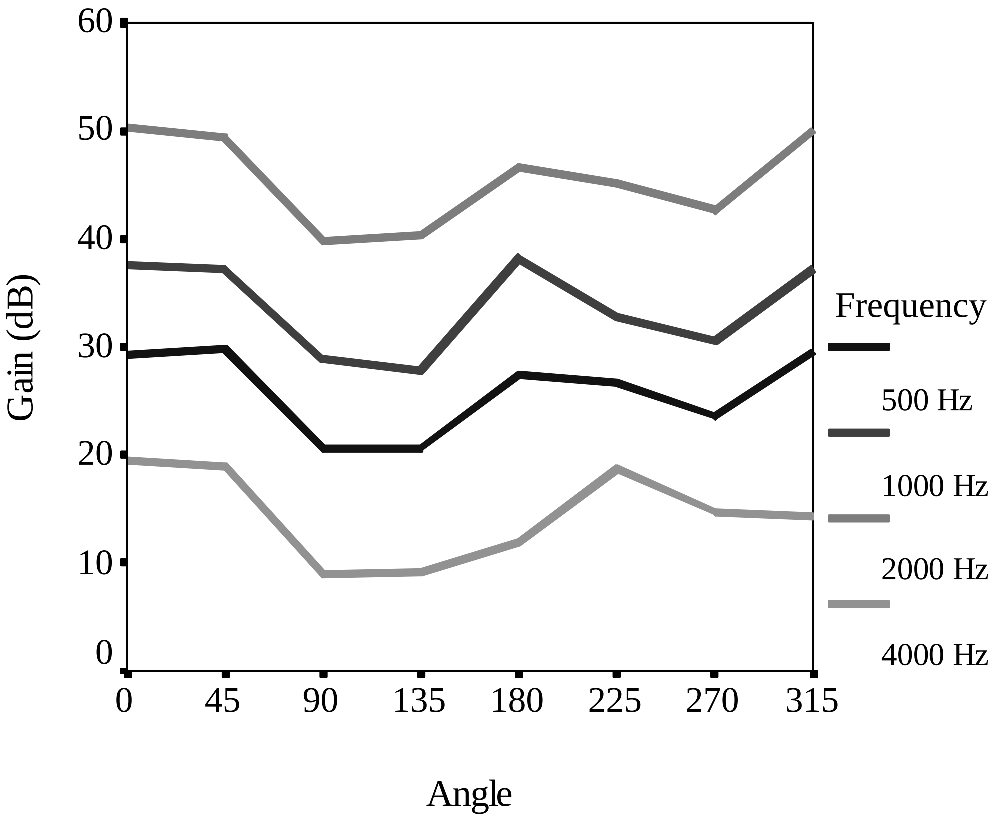

Figure 4: Mean sound pressure levels across different angles and frequencies.

Chapter 5

Discussion

Results of this study indicated that speech recognition scores were significantly different in normal and hearing impaired subjects in all the test conditions. As can be expected, normals had significantly higher speech recognition scores. Speech recognition scores were significantly different between test conditions and between microphone strategies in the hearing impaired group.

1. Effect of Different Test Conditions on Speech Recognition Scores in Normal Subjects.

Perhaps, it is apparent to even the most naïve amongst us that even the most advanced hearing aid technology does not restore normal hearing and this is also supported by research (Venema, 1999). Therefore, it is not surprising that normal subjects had better speech recognition scores in comparison with hearing impaired groups in all test conditions.

In normal subjects, there was significantly greater speech recognition scores in condition 1 (0^0 & 90^0) and 3 (0^0 & 270^0) in comparison with condition 2 (0^0 & 180^0). As condition 1 and 3 are the front and side angles to the listeners, (see Figure 5), these the angles provided sufficient interaural time difference to the listeners, for them to be able to perceive the two stimuli better. In condition 2, the stimuli were delivered from front and back of the listeners head whose inter aural time difference was zero. Therefore, the listeners tended to get confused when two stimuli were presented from front and back. Perhaps, this resulted in lower speech recognition scores. These results are in accordance with the results of Feddersen et al. (1957) who measured the interaural time and intensity difference for human heads as functions of angles around the head (azimuth) and frequency. They noticed that there was no difference in the arrival time at the two ears when the signals came directly from the front of the listener (0^0) and directly behind (180^0) since the ears are equidistant from the sound source in these two instances.

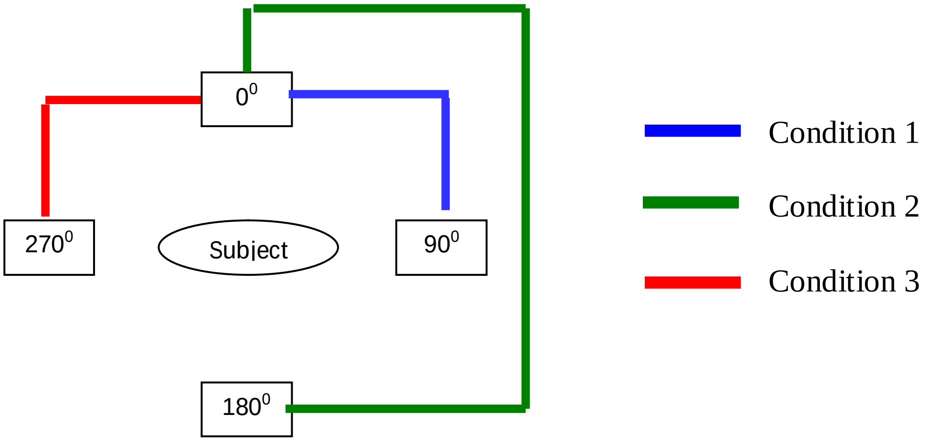

Figure 5: A block diagram of speaker combinations.

2. Effect of Different Test Conditions on Speech Recognition Scores in Hearing Impaired Subjects across Different Microphone Technology.

It can be seen from Table 3 that condition 1 (0^0 & 90^0) and 3 (0^0 & 270^0) resulted in maximum mean speech recognition scores in different microphone strategies. There was statistically no significant difference between condition 1 and 3 ($p > 0.05$). The reason for condition 2 (0^0 & 180^0) resulting in the lowest speech recognition scores, as explained by Feddersen et al. (1957), is that when stimuli are from front and back of the listener, there will be no interaural time difference between the two ears which makes it difficult to perceive such speech sounds.

Higher speech recognition scores were obtained under condition 2 (0^0 & 180^0) with omnidirectional microphone mode in comparison to fixed directional microphone mode. This is because of the hearing aid used in this study (Siemens Triano 3P) uses a hyper cardioid directivity pattern which suppresses noise coming from one direction (back), while retaining good sensitivity to sounds arriving from another direction, say, front (Dillon, 2001). This may also be the reason for decreased scores under condition 2 with fixed directional microphone mode. Again, this may be the reason why a substantial number of subjects switch from fixed directional to omni directional mode in real life though they obtain better scores in fixed directional mode in a confined condition like a sound booth (Cord et al, 2002).

The adaptive directional microphone mode provided the best speech recognition scores in all conditions in comparison to fixed directional and omnidirectional microphone modes. In the adaptive polar condition, the polar automatically adjusts its pattern in such a way that the null is placed at the azimuth of the primary sound source (Bentler et al, 2004). This may be the reason for better speech recognition scores with the adaptive directional microphone mode. There was statistically no significant difference between the three conditions in omni directional mode ($p > 0.05$). This may be due to the omni directional microphone’s configuration in an in situ polar directivity pattern which reveals similar average sensitivity for all the angles around the azimuth (Ricketts, 2000b).

3. Effect of Different Angles on Sound Pressure Levels Measured at the Level of Ear Canal at Different Frequencies.

Sound pressure was measured in the left ear. Therefore, 0^0, 45^0, & 315^0 become front angles and resulted in maximum sound pressure level at the ear canal followed by sound from other angles at all frequencies except 4000 Hz. At 4000 Hz, maximum sound pressure level was obtained for sound output from angles 0^0, 45^0, 225^0 followed by sounds from other angles. This may be because of the fact that the polar plot of fixed directional (hyper cardioid) microphone has a narrow pick-up pattern in the front hemisphere and deeper nulls at 90^0 and 270^0 (Compton et al, 2004). The variation at 4000 Hz may also be because of some subjective variation, particularly movement of the head, which could have occurred during testing.

Results also revealed a significant difference between angles at each of the four frequencies. This result refutes the findings of Fedderson et al. (1957) who reported that interaural intensity differences were negligible at 200 Hz, but increased with frequency, reaching as much as 20dB at 6000 Hz. They also reported that lower frequency has reduced variability of gain (dB) between angles, but this variability increased with increase in frequency.

Chapter 6

Summary and Conclusions

There has been substantial research examining the effects of different microphone technologies on speech recognition scores presented from different angles around the azimuth. There has also been significant research examining the perception of speech in the presence of back ground noise arising from different directions. In contrast, very little work has been done on the perception of speech when there is speech in the back ground arising from different angles. One is more likely to come across a situation in real life where there is speech coming from all directions.

The present study aimed at assessing the benefits of directional, adaptive directional and omnidirectional microphone technology in identifying speech coming from different directions other than the direction of interest in laboratory conditions.

The objectives of this study were to

a) quantify the difficulty a hearing aid user faces in understanding speech arising from different angles around the azimuth with different microphone technologies

b) assess the ability of hearing aid users to perceive speech through different microphone technologies in the presence of speech coming from a direction different from that of speech of interest, and

c) to identify the angle at which speech is best perceived in directional mode by measuring aided sound pressure level at the level of ear canal using probe microphone and hearing aid analyzer.

The present study was carried out as follows: Subjects were selected following detailed audiological examination. The hearing impaired subjects were fitted with Siemens Triano 3P hearing aid. First experiment aimed at obtaining speech recognition scores in normal and hearing impaired subjects at three different test conditions (see Table 1). In hearing impaired subjects speech recognition scores were measured at three different test conditions in directional, omnidirectional and adaptive directional microphone modes. Second experiment aimed at studying the angle(s) from which speech is best perceived in the fixed directional microphone mode by measuring sound pressure level in the ear canal in response to output from speakers located at different angles.

The following were the major results of the study:

- There was a significant difference on mean speech recognition scores in normal and hearing impaired subjects in all the test conditions.

- There was a significant difference on mean speech recognition scores at all the test conditions and microphone technologies in hearing impaired subjects.

- Sound pressure level at the ear canal had a significant difference between angles at each of the four frequencies.

Limitations

- The speakers in the present study were placed in fixed position, but at different angles. However, one is more likely to come across a situation in real life where speech is not only moving, but also comes from different directions.

Implications

- The present study provides guidelines to an audiologist in selecting an appropriate microphone strategy taking into consideration the clients listening needs.

- This study provides guidelines to an audiologist for effective counseling on the potential benefits expected from each microphone strategy.

Future research

- A replication of the study with moving sound source from different angles around the azimuth and the resultant effect on speech perception would be very valuable.

- Identification of angle(s) from which speech is best perceived in the adaptive and omnidirectional microphone modes would also be very useful.

Chapter 7

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