Dedicated to

Annai

And

My Family

CERTIFICATE

This is to certify that this dissertation entitled **"BINAURAL AMPLIFICATION - DOES TECHNOLOGY MATTER?"** is a bonafide work in part fulfillment for the degree of Master of Science (Audiology) of the student Registration No: 05AUD004. 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 diploma or degree.

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April 2007

CERTIFICATE

This is to certify that this dissertation entitled **"BIANURAL AMPLIFICATION - DOES TECHNOLOGY MATTER?"** has been prepared under my supervision and 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.

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April 2007

DECLARATION

This is to certify that this master's dissertation entitled "BINAURAL AMPLIFICATION - DOES TECHNOLOGY MATTER?" 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.

Registration No. 05AUD004

Mysore
April 2007

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When things go wrong,
As they sometimes will,
When the road you are trudging seems all uphill,
When the funds are low and the debts are high,
And you want to smile, but you have to sigh,
When care is pressing you down a bit -
Rest if you must, but don't you quit.

Life is queer with its twists and turns,
As every one of us some times learns,
And many a failure turns about
When he might have won had he stuck it out.
Don't give up though the pace seems slow -
You may succeed with another blow.

Success is failure turned inside out -
The silver tints of clouds of doubt,
And you never can tell how close you are,
It may be near when it seems so far;
So stick to the fight when you are hardest hit,
It's when things seem worst that you mustn't quit.

I pray for the well being of all the well wishers of this beautiful world.

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Chapter -I

INTRODUCTION

Hearing impairment is a reduction in the hearing sensitivity which will cause deterioration in the speech abilities (Stach, 1997). Sensorineural hearing loss is defined as the cochlear or the retrocochlear loss in the hearing sensitivity due to disorders involving the cochlea and /or the auditory nerve fibre of the eighth cranial nerve (Stach, 1997). It is assumed that a person with a sensorineural hearing loss has an abnormality in the peripheral nervous system, the cochlea, where there is a loss of information concerning the acoustic wave forms.

Although authors like Cherry (1953), Broadbent (1954) and Bocca and Calearo (1963) suggest that only one ear is needed for processing all the acoustic information for perfect speech intelligibility, there is no doubt that the second ear improves intelligibility considerably. Bergman (1957), Groen and Hellema (1960) and MacKeith and Coles (1971) have listed the advantages of binaural hearing as,

- enhanced localization
- summation of energy both at threshold and at supra threshold levels
- summation of information content especially when the hearing loss in the two ears are dissimilar in frequency distribution
- avoidance of head shadow especially when listening in the presence of noise
- better discrimination of speech in quiet and in noise
- ease of listening and
- better quality of sound.

The problems caused by cochlear or sensory hearing impairment may be ameliorated with the use of hearing aids. When compared to unaided hearing, hearing with amplification can increase the amount of relevant information reaching through subject's speech recognition system in two important ways. They are:

1. Amplification provided by the aid might allow more relevant information to be encoded in the eighth nerve.
2. The hearing aid might improve the definition of speech signal at the subject's ear drum, and thus allow the relevant information to reach the speech recognition system.

Hearing aids are thus useful in the restoration of speech perception, in addition to environmental sounds, promoting improvement in communication skills according to Markides (1977). As a primary management tool, amplification aims to raise the input signal level sufficiently to activate the residual hearing while keeping the intensity within comfort range. A further aim is to shape the amplified signal to provide appropriate gain at each frequency in accord with the pattern of the deficit. It aims to provide the best quality of sound for different acoustic environments. Amplification can not restore the lost capacity; but it can help minimize the usefulness of residual hearing (Sanders, 1977). The role of a hearing aid is thus to increase the amount of relevant information received at the speech recognition system, hence improving the communication skills of the user.

/ Current hearing aids are classified into analog and digital depending on the technology they use to process the signal. Analog hearing aids are amplification devices that use conventional, continuously varying signal processing. Digital hearing aids are those that process the signal digitally. The main difference between the analog and the digital hearing aid is that in analog hearing aids, the signal is continuously varying over time, whereas, in the digital technology, the digital signal processing of the input signal takes place.

The so called digital hearing aids are an out growth of the computer revolution that has transformed our society (Ross, 1997). A digital signal processing hearing aid (digital hearing aid) converts the output from the microphone, from analog signal to digital waveform. It uses software algorithms to manipulate gain characteristics and converts the signal back into analog form for delivery to the loudspeaker (Stach, 1997). The digital signal processing used in a digital hearing aid provides a better speech performance, hearing levels, noise reduction mechanism, feed back suppression, etc., compared to the analog hearing aids (Markides, 1977).

The analog amplification schemes had already reached a high level of sophistication before the digital technology was introduced. Nonetheless, the major benefits from the digital hearing aids are not to be underestimated. Also, as the technology improved, the cost of the hearing aid using digital technology also increased.

Many studies have been carried out on the performance of digital hearing aids. Over the past several years, great strides have been made in the areas of fitting of technologically improved amplification devices for individuals with hearing impairment. Evidence also suggests that fitting amplification with such hearing aids offer advantages in improving speech perception (Ross, 1997).

Effective use of hearing aids depends on the optimal fitting. It should be ensured that the individuals with hearing impairment are given adequate opportunity to become sophisticated users of amplification (Sanders, 1982).

Now that the technology has improved so much, it is considered worthwhile fitting the amplification in both ears namely binaural amplification (Sanders, 1993). The application of the two aids, one for each ear, provides true binaural effect. Optimal fitting with proper counseling usually is accepted by the hearing aid user. Some clinicians have contented that binaural hearing loss is symmetrical. This myth has been approved by thousands of successful fittings of individuals with substantial asymmetrical losses. This is true not only of asymmetrical pure tone patterns, but of grossly variant speech discrimination scores as well. There are even extreme cases of fitting individuals binaurally when there is no functional hearing in one ear because they are receiving the 'binaural effect. Unless there are specific contraindications for fitting both the ears, every candidate for hearing aid with bilateral hearing loss should be considered a candidate for binaural amplification. It should be considered a dis - service to individuals with hearing impairment with two usable ears to make only a monaural recommendation (Mac.Keith & Coles, 1971).

Thus, amplification is the primary means of reducing hearing handicap except for the individuals with profound hearing impairment for whom it plays a supportive role in communication. Therefore, the hearing aid user needs to understand what the hearing aids can be expected to do and what they can not do (Sanders, 1993). Though these amplification devices can provide a considerable improvement in the ability of perception of speech, their binaural performance is researched to a greater extent due to the advantage of binaural amplification (Nabelek & Robinson, 1982). So it is essential that we educate the individuals with hearing impairment about the new technological advances so that they can decide about purchasing new hearing aids that might improve listening (Sanders, 1993).

Need for the Study

Even though the digital hearing aids have been commercially available since 1995 (Hirsh, 1995), its high cost reduces the number of seekers especially when the issue is about providing amplification for both the ears. Some of them are ready to use a digital hearing aid in one ear and analog hearing aid in the other till they can afford for binaural digital hearing aids. Condie, Scollie and Checkly, 1984, studied the performance of speech of children and concluded that the performance with binaural digital hearing aids was better compared to binaural analog hearing aids. Also, a significant improvement in speech perception in quiet and in noise was noticed. This study focuses on the performance of individuals with hearing impairment while using one digital and one analog hearing aid in opposite ears.

Aim of the study

The aim of the present study was to compare the performance of the individuals with hearing loss, in terms of improved audibility, understanding and quality of speech using

1. binaural analog hearing aids,
2. binaural digital hearing aids,
3. binaural amplification with analog and digital hearing aids in opposite ears.

Chapter - II

REVIEW OF LITERATURE

Much of the present interest in binaural hearing was stimulated by a short letter from Koenig published in Journal of the Acoustical Society of America in 1950. In this letter, the author asserted that binaural hearing offered certain advantages over monaural hearing, such as:

- a remarkable ability to "squelch" reverberation and background noises
- the power to select one stimulus from a number of stimuli and as it were to "tune in" to one sound source or one person, the "cock tail party effect", and
- to understand speech under extremely unfavorable signal-to-noise ratios.

Following that many other authors studied the advantages of binaural hearing and binaural amplification and its usefulness for the population with hearing impairment.

Advantages of Binaural Hearing

The pure tone binaural threshold of hearing is more sensitive than the monaural, the difference being in the region of 3 dB. (Keys, 1947; Shaw, Newman & Hirsh, 1947; Pollack, 1948; Reynolds & Stevens, 1960). This binaural advantage of 3 dB can however be only realized if the stimuli are presented to the two ears not at the same SPL, but at the same equal loudness level. When such "equating of the ears" was established, the authors observed that the binaural threshold for speech in quiet was also around 3dB more sensitive than the monaural threshold. Knudsen (1929) and Keys (1947) reported increased intelligibility with binaural hearing systems.

Following a short experiment with an artificial head, two microphones and two ear phones, Koenig (1950) reported that binaural hearing improved directionality, squelched reverberation and markedly increased speech intelligibility. He also observed that the above effects could not be achieved with a "Y" lead arrangement that is with one microphone feeding two earphones.

Advantages of Binaural Amplification

Valente (1982) reported that most researchers and clinical audiologists would agree that there are five basic goals of a hearing aid fitting namely, sounds at various input levels should be audible across frequencies, sounds at various input levels should not be uncomfortable, sounds should have good sound quality, the amplification should provide a safe listening environment, the amplification should meet the client's needs and expectations. Providing binaural amplification for bilaterally hearing impaired individuals impacts the audiologists' ability to meet at least four of these goals. Olsen and Matkin (1979) reported that binaural amplification provides substantial improvement in intelligibility up to 50 % compared to monaural amplification.

Stach (1997) described auditory deprivation as the diminution or absence of sensory opportunity for neural structures central to the end organ, due to a reductionin auditory stimulation resulting from hearing loss. It may represent itself as a decline in speech recognition ability in the unaided ear of a person with hearing impairment, fitted with one hearing aid, resulting in asymmetric stimulation. So, the auditory deprivation effect is defined as a systematic decrease over time in auditory performance associated with the reduced availability of acoustic information. Gelfand (1995) reported that subjects recovered from auditory deprivation after binaural fitting (at least for four years). He had documented cases in which auditory deprivation effects developed within about two years of hearing aid use and recovered completely within about two years of the binaural use, cases with significant but incomplete recovery from the auditory deprivation and cases in which the auditory deprivation effect took several years of binaural amplification for complete recovery.

Gelfand and Silman (1993) investigated the effects of monaural versus binaural amplification upon the Speech Recognition Scores (SRS) of children with moderate sensorineural hearing loss after more than four years of hearing aid use. There was a significant decrease in SRS for the unaided ears of the monaural hearing aid users, but there was no significant difference between initial and the re-test SRS for both ears of those using binaural amplification. The SRS reduction was found to be large enough to be significant on an individual ear basis in five out of ten unaided ears of the monaurally fitted children, but this did not occur for any of the initial re-test SRS differences in the aided ears of either group. These findings demonstrate that the auditory deprivation effect which has been reported for adults using monaural hearing aids is also found in children.

A study on binaural summation indicated that individuals with hearing impairment performed similar to normal hearing listeners when they were fitted with binaural amplification (Dirks and Wilson, 1969). Dermody and Byrne (1975), Prinz, Nubel and Gross (2002) evaluated Seventeen school children with moderately severe bilateral symmetrical sensorineural hearing loss. Differences in performance between a commercially available fully digital hearing aid and a digitally programmable two-channel hearing aid were evaluated. Of the 17 children, 13 preferred the digital and 4 preferred the analog hearing aid. This shows the better performance of the digital over the analog hearing aid.

Using a different method in evaluating binaural hearing aids, Kodman (1961) selected 50 successful binaural hearing aid users and issued them with a questionnaire. One third of them felt that binaural hearing aids improved their personality (less nervousness, less strain, improved social life). Other advantages mentioned were better sound balance, better localization, and better hearing in a group. Forty percent of the subjects did not report any disadvantage with binaural hearing aids.

The advent of wearable binaural hearing aids had already generated a conflicting literature on the extent of additional benefit that the individual with hearing impairment may expect to derive from binaural versus monaural amplification. Several authors like, Hirsh (1950), Koenig (1950), Bergman (1957), Carhart (1965), and Belzile and Markle (1959) have supported the notion that either some or all hearing aid users may expect anywhere from mild to substantial additional benefit from binaural as opposed to monaural hearing aid use. On the other hand attempts made by Dicarlo and Brown (1960), Hedgecock and Sheets (1958) and Markle and Aber (1958) to demonstrate this advantage objectively and had met with little material success. Haskins and Hardy (1960) noted that in some instances the test variables, with and without binaural aids, were so slight that no quantifiable significance could be derived. In other instances, the variations between monaural hearing and binaural hearing were astonishingly great.

Valente (1982) reported that individuals with bilateral symmetrical sensorineural hearing loss are apt candidates for binaural amplification. Fitting them with monaural amplification should be the exception to the rule and the reason should be carefully noted because the users will lose a variety of advantages that they would benefit from binaural amplification.

Kochkin (1996) surveyed hearing aid users on a variety of dimensions including forty five ratings of consumer satisfaction with hearing aids and hearing health service. Individuals with bilateral hearing loss were divided into two groups, wearing monaural and binaural hearing aids. Among items that would be impacted by hearing, (large groups, sound of their own voice, car, out door, small groups, hearing soft sounds and localization), binaural hearing aid users reported 8 to 14 % more satisfaction than monaural hearing aid users. Kirkwood (2001) reported that binaural fittings have increased each year over the past five years. On an average hearing aid providers reported that 71 % of their fittings were binaural in the year 2000 compared with 68 % reported in 1999. Perhaps it is more appropriate to consider binaural amplification in the context of the overall goals of a hearing aid fitting.

Dillon (2001) suggested that binaural listening provided sound quality superior to that of monaural listening. This advantage was found for a number of attributes such as clarity, fullness, spaciousness, and overall quality. He also reported that individuals with hearing impairment generally made more discriminating judgments about sound when listening binaurally than when listening monaurally.

Belzile and Markle (1959) reported a clear superiority of binaural over monaural hearing aids under adverse listening conditoin. Using PB words they measured the discrimination abilities of 30 subjects, half with conductive and half with perceptive bilateral moderate hearing impairments. The speech discrimination of the subject was measured at signal-to-noise ratios of +20, +10, 0, -10, -20 and -30 dB. Their results showed that for both the conductive and the perceptive deafness groups, there were no significant differences between binaural and monaural listening in quiet, but in the presence of background noise, only 50% discrimination could be achieved when wearing a single hearing aid. Here, in this study, the monaural hearing aids were worn on the chest while the binaural hearing aids were worn on the head. Thus, it was impossible to know whether the differences observed in favour of binaural hearing aids were due to two ears or due to head worn pick-ups or due to a combination of the two. They also failed to realize that their binaural conditions placed one of the two hearing aids in a more advantageous position because it was shadowed from the noise by the subject's head, whereas, in a monaural condition, the single hearing aid worn on the chest did not obtain similar shadowing from the noise. Thus, the head shadow effect is overcome in a binaural amplification condition.

Jerger and Dirks (1961) got results contradictory to that of Belzile and Markle (1959). They criticized Belzile and Markle's study arguing that in Belzile and Markle's study, the single hearing aid was mounted on the body for monaural condition; whereas, in the replication experiment by Jerger and Dirks (1961), the single aid remained mounted on the head. If appropriate allowances for head shadow effect had been made in the study by Belizle and Markle (1959), a great deal of confusion would have been saved. According to Carhart (1965), the physical arrangement used in Belizle and Markle's study gave the binaural aid about 6.4 dB advantages over the monaural aid, which was worn on the chest. The corrected difference therefore, is approximately 3 dB which is attributed to binaural squelch and this is exactly what Jerger and Dirks (1961) found.

MacKeith and Coles (1971) conducted an experiment where the task involved the subjects with asymmetrical sensorineural hearing impairment to listen with ear level hearing aids with external receivers in a non-reverberant environment. Speech was presented from the side of the better ear. The results indicated that the mean binaural scores of the individuals with hearing impairment were significantly superior to their monaural counterparts at all signal-to-noise ratios (SNR) applied (+ 20 dB and + 10 dB). The sensorineural group exhibited significant binaural hearing advantages in terms of squelch and head shadow effect.

Groen and Hellema (1960) and Lochner and Burger (1961) reported a 6% improvement per dB rise in speech discrimination scores associated with PB monosyllabic lists. Connected speech, however has a much steeper articulation function; thus, the difference between binaural and monaural discrimination ability of connected speech can be very substantial. Poulos (1950), Bender and Wiig (1960), Lewis and Green (1962) and Whetnall (1964) concluded that when fitted with binaural hearing aids, children were able to monitor their speech better, were more alert to sound and showed rapid development in speech and language.

Harris (1965) found a binaural advantage even with subjects having asymmetrical losses. Mean word recognition scores for binaural listening, monaural listening with the better ear, and for monaural listening with the poorer ear were 48%, 30%, and 15% words correct respectively. Olsen and Carhart (1967) found a similar binaural advantage with subjects having bilaterally symmetrical hearing losses and also with normal hearing subjects. Dirks and Wilson (1969b) found the same binaural advantage with persons with sensorineural hearing losses in aided and unaided conditions, as they did with normal hearing subjects. Zelnick (1970) found a binaural advantage of about 15% with subjects having bilaterally symmetrical hearing losses and using commercial ear level hearing aids.

Coles (1968) reported that a 20 dB difference between the ears had little effect on binaural summation of speech and even with a 40 dB difference the weaker ear still contributes significant information. Further, he said that it was true that a 3 dB gain at threshold can hardly be considered an advantage for normally hearing people for they seldom need to listen to speech at threshold level. Individuals with hearing impairment however, often find themselves listening to speech at threshold level. It is obvious therefore, that for such individuals even a few dB gain at threshold can be a real advantage. Since comprehension accuracy declines after 60years of age, though semantic component is not affected, syntactic component is affected. Instead of affecting a single component in a language system, normal aging may have an impact on interactions between components of language. A few dB gain may increase their ability to comprehend.

Apart from speech recognition tests, in quiet and in noise, the speech intelligibility rating (SIR) test is being used in clinical comparisons of hearing aid conditions(Cox, 1989). In this, after listening to a short passage of connected speech, the subjects are requested to generate a rating proportional to its intelligibility using a rating scale from 0 to 10. Because like normal listeners, the hearing aid wearers are also exposed to connected speech in their every day lives, validity requirements require that the measurements that quantify the understanding of speech processed through a hearing aid should be a connected speech material.

Monaural and binaural curves were plotted by Bocca (1955) using speech discrimination procedures, and were found that both the curves run parallel to each other, indicating that a higher level is required for monaural listening to achieve the same articulation score as for binaural listening. This horizontal shift was of the magnitude of 3 dB.

Markides (1977) evaluated 22 subjects with bilaterally symmetrical hearing loss. Regardless of whether the hearing loss was conductive or sensorineural in nature, these subjects performed significantly better on the word recognition task when listening with binaural as compared to monaural amplification. Performance with the Y cord system was comparable to that of a monaural aid, both of which were significantly inferior to binaural amplification.

Carhart and Tillman (1967) reported an average of 4.5 % binaural advantage in 18 subjects having sensorineural hearing losses. Koenig (1950) reported that binaural hearing improved "directionality", "squelched" reverberation and markedly increased speech intelligibility. He also observed that the above effects couldn't be achieved with Y lead arrangement that is one microphone feeding two earphones.

In a study by Markides (1977) 8 subjects with bilateral symmetrical sensorineural hearing loss were evaluated. The binaural hearing advantages in terms of squelch and head shadow effects exhibited by each subject with symmetrical hearing impairment when using ear level hearing aids were studied with a view to ascertaining any possible relationship between degree of hearing impairment and binaural hearing aid candidature. The results indicated no significant relationship between degree of hearing impairment and binaural hearing aid candidature. The conclusion was that the persons suffering from symmetrical hearing impairment may be expected to derive substantial benefit in speech discrimination enhancement from two hearing aids as opposed to one. However, it was advisable to issue two hearing aids to individuals with as low as a hearing impairment as 30 dB.

Olsen and Carhart (1967) and Zelnick (1970) reported that binaural advantage can be demonstrated only in the presence of masking noise. In quiet or at high signal-to-noise ratios, the monaural scores already are at plateaus of perception ability of the listeners. Hirsh (1950) concluded that binaural hearing will not be of great advantage for signals in quiet because the binaural advantage is based on discrimination of the useful signal from the background noise.

Markides (1977) observed that when listening with two similar ear worn hearing aids, on an average, the subject scored higher than when listening with dissimilar hearing aids at 0 dB, +5 dB, +10 dB and +20 dB signal-to-noise ratios. The differences observed tended to increase in magnitude with increasing intensity of the background noise, reaching significant values at +5 dB signal-to-noise ratio. Contrary to the popular belief, the pseudo binaural system did not prove more effective for speech reception than a single hearing aid. The inferiority of the pseudo binaural hearing aid was very evident when compared to a true binaural system.

Jerger, Carhart and Dirks (1961) reported a binaural advantage under adverse listening conditions for monosyllabic words. They concluded that binaural hearing aids offered a little demonstrable improvement in speech intelligibility. Markides (1977) evaluated 22 subjects with bilaterally symmetrical hearing loss. Regardless of whether the hearing loss was conductive or sensorineural in nature, these subjects performed significantly better on the word recognition task when listening with binaural as compared to monaural amplification. Binaural superiority was observed for both the ear level and body type hearing aids, but the ear level instruments provided the expected 6 to 7 dB additional head shadow effect. This provides further evidence for the need for dichotic versus diotic stimulation in order for the persons with hearing impairment to benefit from binaural hearing. Similar results were noted for the speech localization task. Both conductive and sensorineural groups with symmetrical hearing losses demonstrated superior localization ability when listening with two hearing aids. While binaural superiority was observed with both ear level and body type instruments, the ear level systems were superior to the body worn instruments. Again the Y cord hearing aid failed to enhance localization over the monaural systems. Results for the 20 subjects with asymmetrical hearing losses also revealed binaural to be significantly superior to monaural amplification. Word recognition performance for these subjects when the better ear was located nearest the speech source revealed a binaural advantage for head shadow from 7.5 to 10 dB and a 1.8 to 2.5 dB superior squelch effect. However, these advantages were maintained even when the poorer ear was located near the sound source and had 6.8 dB to 3.4 dB binaural advantage for the head shadow and squelch effects, respectively. While monaural localization abilities were essentially the same regardless of whether the better ear or poorer ear was aided, binaural localization was significantly superior to either of the monaural conditions.

The findings reported by Markides (1977) clearly demonstrated the advantages in word recognition and speech localization for binaural over monaural amplification. Besides, these results appear related to the ability of binaural amplification to restore, in part, binaural squelch, head shadow, and directional hearing phenomena. The combination of these benefits is indeed considerable and supports the concept of binaural hearing aids.

Jerger, Carhart and Dirks (1961) studied two indices of speech intelligibility obtained from forty-eight subjects with sensorineural hearing loss performed under conditions of both monaural and binaural hearing aid amplification. The results failed to reveal any appreciable advantage for two hearing aids over one.

Jerger, Darling and Florin (1994) studied on binaural amplification where the subjects had to indicate every occurrence of the target word within continuous discourse coming from a loud speaker on one side of the head, while different continuous discourse comes from a second speaker on the other side of the head. Two important details in this study was that all the subjects were experimented at using binaural hearing aids, and the test used hundred target words per amplification condition. The results demonstrated a significant bilateral advantage for seven out of ten clients.

Cox and McDaniel (1984) reported an investigation that explored the feasibility of using speech intelligibility ratings in clinical hearing aid evaluation. The study was designed to assess the validity and sensitivity of intelligibility ratings when employed in a context simulating a hearing aid evaluation. Normal hearing individuals rated the intelligibility of 35-s passages of connected speech produced by three talkers and processed by four hearing aids having rather similar frequency responses. Each subject rated each condition three times and the final rating for the subject condition was the mean of these three conditions. The results indicated that the mean ratings were valid quantifiers of speech intelligibility in the various conditions, the approach was more sensitive to differences among hearing aids when the signal-to-babble ratio (SBR) was adjusted to produce a moderately challenging (not too difficult) listening condition, when three intelligibility ratings were averaged per hearing aid, the highest ranked best hearing aid was significantly differentiated from the third and the fourth instruments, but not necessarily from the second best instrument and the hearing aid rankings depended somewhat on the talker so that the best hearing aid was different for different talkers.

Narendran, Humes and Larry (2003) evaluated the test of quality rating namely the "Judgment of Sound Quality Rating Procedure" on sixteen subjects with individuals with hearing impairment using hearing aid. The participants provided ratings on eight dimensions of sound quality namely, softness, brightness, clarity, fullness, nearness, loudness, spaciousness and total impression. The ratings were done at four stimulus conditions namely speech at 65 dBSPL with a + 8 dB SNR, speech at 65 dBSPL in quiet, music at 90 dBSPL and music at 75 dBSPL. Significant differences were observed between unaided and aided ratings for the dimensions of clarity, nearness, loudness and total impression.

Dillon (2001) commented on the disadvantage of binaural amplification, the main reason being the cost of two hearing aids. He reported that unless the hearing aids are given free to the clients, the cost of the second hearing aid and the batteries for it, it would be a major disadvantage for many clients regarding the issue of the cost of the hearing aids and it's accessories.

Effect of Digital Processing Delay on Speech Perception

One of the properties of the digital technology is that it always takes time to process digital data. An analog signal should turn into digital information, performs some kind of algorithm to amplify the signal, and turns back into an analog sound wave for the ear to hear. This processing delay for some hearing aids is so less that it is imperceptible to the human ear. The processing delay for some other hearing aids can extend to several milliseconds, Frye (2001).

Frye (2001) reported that one of the properties of the digital technology is that it always takes time to process digital data. As a miniature computer, the digital hearing aid takes an analog sound wave, turns it into digital information, performs some kind of algorithm to amplify the signal, and turns it back into an analog sound wave for the ear to hear. The processing delay for some hearing aids is so less that it is imperceptible to the human ear. The processing delay for other hearing aids can extend to several milliseconds. For analog hearing aids, the processing delay would be comparatively very less because it does not perform any signal processing activities like the digital hearing aid. Various authors had proposed various views about the acceptable processing delays for the digital hearing aids which are discussed below. The following figures, Fig. 2.1. and Fig. 2.2. explains the processing delay for an analog and digital hearing aid respectively.

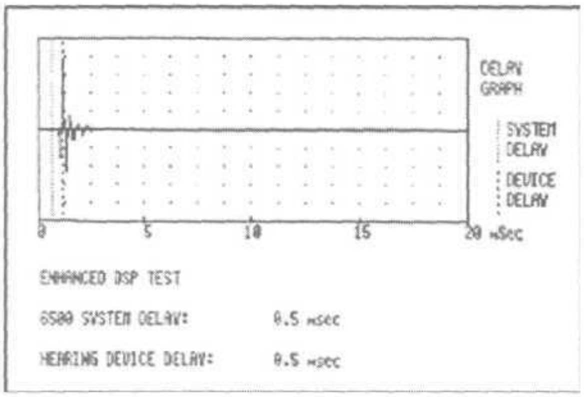

Fig. 2.1: Processing delay for an analog hearing aid

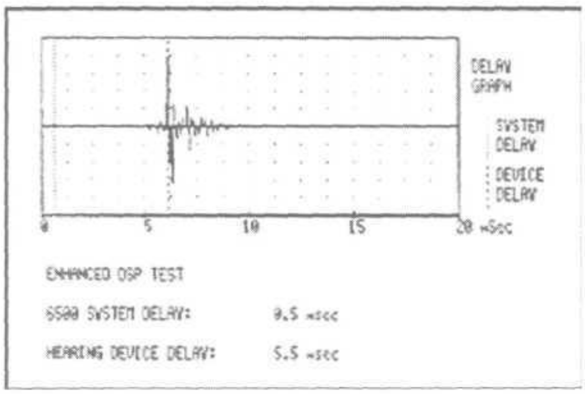

Fig. 2.2: Processing delay for a digital hearing aid.

Frye (2001) speculated that "echo effects" may be found with digital hearing aids and since echoes in a room adversely affect intelligibility the same can be said of the artificial echoes generated by delay in a hearing instrument. A digital processing delay of more than one msec. may be important in such a case as this. He also suggested that delay and phase problems could be a part of invisible differences between patient satisfaction and rejection of amplification but offers no evidence.

Flame (2002) expressed concern that delay time may not be bilaterally matched, either because of the unilateral fitting or mismatched delays in a binaural fitting. He states that if mismatch in delay times doesn't change often, people adapt with a period of hours or days.

Stone and Moore (2002) studied 32 normal hearing adult listeners. The subjects listened to their own voices using wearable digital processing devices and head level microphones in two acoustic environments. The results suggested that a 15 msec. delay is acceptable. For similar levels of subjective disturbance processing delay can be about 4 msec. longer in a reverberant acoustic environment than in a near anechoic room.

Flame (2002) reported that regarding delay localization, that the primary problem with long delay times is the destructive interference between the acoustic signal that passes by the hearing aid and the amplified sound. For some amounts of delay, the interference could move onto frequency regions where the audibility of the localization cues is reduced. Also, the delay time might not be bilaterally matched, either because of a unilateral fitting or because of a mismatched fitting for binaural hearing aid users. However, if the mismatch in the delay times does not change often, the users adapt to the new interaural time difference cues over a period of hours or days.

Stone and Moore (2003) studied that subjective ratings indicated that delays of 9 msec or more had a significant deleterious effect. There was no significant effect of delay on speech production rates for up to 24 msec.

Dillon (2001) reported in a study using both normal and individuals with hearing impairment listening to music, speech and their own voice through five digital hearing aids with processing delays ranging from 1.2 to 10 msec. Results suggested no overall significant differences among the devices and for listeners with hearing impairment; there was no significant correlation between device preference and processing delay.

Dillon, Keidser and 0' Brien (1998) had 10 normal and 10 subjects with hearing impairment listen to male, female, male in noise, piano music, own voice and quiet through 5 commercial digital hearing aids in a paired comparison procedure. Hearing aid output in 2 cc coupler were equalized and presented binaurally through 2 ER3 A insert phones via, vented ear molds. Processing delay varied from 1.2 to 10 msec. across aids. Results revealed no significant differences among the devices for both the groups. For listeners with hearing impairment there was no significant correlation between preference and processing delay.

Arehart and Kates (2004) reported on a study using both normal and individuals with hearing impairment listening monaurally through headphones to clicks, vowels and sentences delayed by 2 to 5 msec. in the low frequencies and decreasing to 4 msec, at 4 kHz. He determined the just noticeable difference (JNDs) for normals to be about 5 to 25 msec, depending on the stimulus. Chung (2004) stated that in clinical practice, clinicians need to test the processing delay of the digital hearing aids and choose hearing aids with a balance between the signal processing and the amount of processing delay.

Henrickson (2004) reported processing delays between 1 and 11 msec. for current digital hearing aids. Dillon reported group delays between 3 and 11 msec. for 5 hearing aids and these processing delays were reasonably constant with frequency. Schweitzer (2002) reported of a client with modearate degree of hearing loss who preferred a hearing aid with 1 msec. delay over the one with 10 msec. delay.

Henrickson (2004) reported that temporal cues are important for speech processing and temporal distortion affects the perception by the hearing impaired using amplification he gives psychoacoustic evidence showing that Inter Aural Time differences were 0.1 to 0.7 msec. disrupt localization while larger ITDs disrupt lateralization. He reported delays in analog hearing aids of 0.3 to 0.7 msec. with delays in the digital aids between 1 and 11 msec.

Henrickson (2004) reported delays for analog aids of about 0.3 to 0.7 msec. and for digital aids from 1 to 11 msec. He also noted a variation between manufacturers and between models with manufacturer. He noted that delay didn't vary with gain settings and changed by as much as 0.1 to 0.2 msec. from one program to another. He speculated that asymmetrical delays or phase between ears may cause critical problems, but offered no evidence.

Chung (2004) suggested that, in clinical practice, clinicians need to test the processing delay of digital hearing aids and choose hearing aids with a balance between the signal processing complexity and the amount of processing delay. In certain cases, commercial hearing aids with long processing delays, with a high number of frequency channels are not recommended to some hearing aid users.

Kates (2003) suggested that digital processing delay is the negative of the slope of the phase response at any frequency. It can have both positive and negative values and has peaks at each abrupt change in the amplitude frequency response curve. The processing delay depends on the sampling rate and the algorithm being implemented. In general, better the frequency resolution, greater the group delay.

Stone and Moore (2002) opine that digital processing does not hold very important when it comes to the selection and fitting of digital hearing aids. Stone and Moore (2003), rated the disturbance of own voice by measuring the rate of speech production on subjects fitted bilaterally with four channel WDRC processors. The minimum group delay was 15 msec. at all frequencies (500 Hz to 4 KHz). The results suggested an acceptable delay of about 23 msec. for very mild losses and about 15 msec. for losses around 35 dB (mild) and about 32 msec. for losses around 55 dB (moderate). There was no effect on speech production rates. There was acclimatization to effects of the delay.

Kates (2003) suggested that even before the delay in the digital processing is considered, the other components of the hearing aid (microphone, receiver, A/D or D/A) and the acoustic interactions will contribute from 2 to almost 5 msec. group delay. Response peaks in the analog hearing aids will be associated with large amount of group delay because of the steep slopes of the response on either side of the peak. A low pass or high pass filter with a steep slope will have a greater group delay, especially in the region surrounding the cut-off frequency, than a filter having a shallow slope.

Stone and Moore in 1999, 2002 and 2003 concluded that

- For consonant delays across frequency, the delay that is likely to be acceptable when speaking is around 23 msec for very mild losses, about 15 msec for losses around 35 dB and about 32 msec for losses around 55 dB. There was no effect on speech production rates.
- For delay that decreases with frequency, low frequency delays of 50 msec or more had a small but statistically significant deleterious effect on the ability to identify VCV nonsense syllables while subjective ratings of the disturbance while listening to one's own voice indicated that delays of 9 msec or more had a significant deleterious effect. There was no significant effect of delay on speech production rates, for across frequency delays up to 24 msec.

- For delays exceeding about 25 msec. listening to one's own voice, the associated percept is primarily of an echo. This echo is different from the echoes heard in every day life. For delays less than about 10 msec. the associated percept is more of a subtle change in the timbre of the sound.
- There appears to be acclimatization to the effects of the delay on the time scale of about one hour.

Thus, quite a number of studies conducted by various investigators have been discussed which explain the advantages of binaural hearing and binaural amplification. Though a few studies do not support the notion of binaural advantage with binaural hearing aids, lot many studies report improved reduced head shadow effect, prevention from auditory deprivation due to monaural amplification, speech perception in presence of noise which are discussed.

Chapter - III

METHOD

The study intended to compare the performance of fifteen individuals with bilateral symmetrical hearing loss, in terms of improved audibility, recognition and quality of speech using three aided conditions which are binaural analog, binaural digital and analog hearing aid in one ear and digital hearing aid in the opposite ear. To accomplish the above, the following method was designed.

Participants

To compare the performance using different combinations of analog and digital hearing aids, 15 individuals participated in the study. All the participants had bilateral moderate to moderately severe (pure tone average ranging from 41 to 70 dBHL) symmetrical (less than 20 dB difference between the ears) sensorineural hearing loss. Their age ranged from 16 to 60 years with a mean age of 49.06 years. All the participants were naive users of hearing aids and all of them were native speakers of Kannada. The tests were carried out with the informed consent from the participants to under go the tests.

Instruments Used

1) A calibrated sound field audiometer for unaided and aided testing.

2) A CD player connected to the audiometer for playing the speech material.

3) Two digital Behind-The-Ear (BTE) hearing aids and two analog hearing aids with a fitting range to suit the hearing loss of the participants. Appropriate ear tips to fit the ears of the participants.
4) Hipro and a personal computer with a soft ware to program the digital hearing aids
5) Calibrated FP 40 (version 3.5) test system to measure the Real Ear Insertion Gain (REIG).
6) Fonix 7000 (version 1.4) for measuring group delay of the hearing aids.

Speech Material Used

1) Four lists of Phonemically Balanced Kannada words, developed by Yathiraj and Vijayalakshmi (2006), for measuring Speech Recognition Scores. Each list consisted of 25 words. All the four lists were recorded using an adult female voice with normal vocal effort.
2) A standard passage in Kannada was used for rating the quality of speech through the hearing aid combinations. The passage contained all the speech sounds of the language. The sample (one minute and twenty seconds) was recorded by an adult male voice with normal vocal effort.

The speech material used in the study is given in the Appendix A

Test Environment

The test was conducted in a sound treated environment with ambient noise levels within permissible limits as per ANSI (1991, cited in Wiber, 1994).

Procedure

The testing procedure consisted of five phases.

1) Pre - selection and programming of the hearing aids

2) Measurement of the insertion gain for hearing aid selection.

3) Establishing the Speech Recognition Scores, (SRS) using various combinations of the selected hearing aids.

4) Quality rating of each combination of the selected hearing aids.

5) Group and phase delay measurement.

Phase 1: Pre-Selection and Programming of Hearing Aids

Commercially available two digital and two analog BTE hearing aids were selected with the fitting range to suit the hearing loss of the participants. The digital hearing aid was connected through a Hipro to the Personal Computer (PC) with software for programming. After the hearing thresholds were fed into the software (NOAH - 3.0 and Connex 5), the digital hearing aids were programmed based on the NAL - NL1 prescriptive procedure. An acclimatization level of 2 was used while programming and the volume control was disabled for the digital hearing aids.

Phase 2: Insertion Gain Measurements

The following steps were used to select the hearing aid for each participant before the measurement of the aided benefit.

- Otoscopic examination was done before the commencement of the testing to rule out any contraindication for insertion gain measurement.
- The participant was seated in front of the loudspeaker of the FP 40 (version 3.50) instrument for the measurement of the insertion gain. For this purpose, the loud speaker of the FP40 was located on the speaker stand at 45 degrees and at a distance of one foot from the participant's test ear.
- The reference and the probe tube microphones were placed near the test ear and the instrument was leveled.
- The audiometric thresholds of the subject were fed in to the system (FP40) and the target gain curve was derived based on NAL-2 fitting formula.
- The stimulus was routed through the loudspeaker. The stimulus was American National Standards Institute (ANSI) digi - speech at 50, 65 and 90 dBSPL. The sound pressure level in the ear canal of the test ear was measured by means of a pre-measured length of the probe tube microphone inserted in the test ear. The reference microphone was located on the band above the test ear. The reference microphone also measured the signal level at different frequencies. The difference between the levels measured by the probe tube microphone and the reference microphone was displayed on the monitor of FP40. Thus, the real ear unaided response (REUR) was measured and stored.
- Then, the programmed digital hearing aid was switched "on" and fitted to the test ear of the participant. Care was taken to see to it that the length of the probe tube in the ear canal was not changed. The real ear aided response (REAR) was measured for the same stimulus i.e., ANSI digi-speech at 50, 65 and 90 dBSPL.

- After the measurement of the REUR and REAR, the Real Ear Insertion Gain (REIG = REAG - REUR) at different frequencies was computed by the instrument. The REIR was displayed. Thus, the Real Ear Insertion Response curve was obtained for the hearing aid for both the ears of each subject.
- This was repeated for three hearing aids in order to select the best hearing aid for testing performance based on the REIR that matched the target gain curve.

Phase 3: Establishing of Speech Recognition Scores (SRS)

The participants were seated comfortably in the sound treated audiological test room with appropriate placement of the speakers that is one meter from the participant at 45 degree Azimuth. The Speech Recognition Scores (SRS) for Kannada Phonemically Balanced word list (Yathiraj & Vijayalakshmi, 2006) for each participant was noted down in the following four conditions.

1. Unaided condition
2. Aided conditions -

2. A. with binaural analog hearing aids

2. B. with binaural digital hearing aids

2. C. with digital hearing aid in one ear and analog hearing aid in the opposite ear. In the unaided condition the SRS was obtained. For this, one of the four Phonemically Balanced word lists (Yathiraj & Vijayalakshmi, 2006) was presented using live voice, at 45 dBHL, in sound field condition where the stimulus was routed through the speaker. The participant was instructed to repeat the words presented. The numbers

of words repeated correctly were scored. Each correct repetition was given the score of one, the maximum score being 25, as the list consisted of 25 words.

Then one of the combinations of the hearing aids (2 A, 2B or 2C) was fitted in the participant's ear. If it was the condition 2C, then, analog hearing aid was fitted in one ear and the digital hearing aid in the other ear. Order of testing the aided condition was randomized across the participants to overcome the effect of order of the conditions i.e., the conditions in which the participants were tested were randomized between subjects in order to avoid the order effect.

Thus, at the end of the third phase, SRS in the four test conditions (unaided and three aided conditions) were obtained for each participant.

Phase 4: Quality Rating of Speech through the Hearing Aids

In each test condition (2A, 2B & 2C), after the SRS was obtained, the participant listened carefully to a CD recorded sample of a passage in Kannada played through a CD player connected to the audiometer. Each participant was instructed to listen to the recorded passage and to rate the quality of the recorded passage. The rating was based on three parameters of aided speech such as loudness, clarity and intelligibility. Loudness was defined as the perception of psychological impression of intensity of sound (Stach, 1997). Clarity was defined as the distinctness (or) purity of tone (Cecil & Patridge, 1970). Intelligibility was defined as the percentage of speech units understood correctly by a listener in a communication system, customarily used for regular messages where the

Context aids the listener, in distinction to articulation. It is also known as speech intelligibility (Lapedes, 1978). A ten point rating scale was used for rating each of these parameters. The scale for the three parameters of aided speech was as follows:

For loudness:

1 - Very soft (can't hear)......................10 uncomfortable.

For clarity:

1 - Completely unclear.........................10 very clear

For intelligibility:

1 - Completely unintelligible.................10 fully intelligible.

The participant was instructed to listen to the recorded passage presented at 45 dBHL through loud speaker of the audiometer. Using the above rating scale, the participant was requested to listen to and rate the recorded passage in each of the three aided conditions.

The scores of each participant in the three aided conditions of testing (2 A, 2B and 2C) using PB words were compared. The quality rating of connected discourse was also analyzed in order to find out the difference in speech perception when using either of the three conditions.

Phase 5: Measurement of Signal Processing Delay

The processing delay of the hearing aids used was measured for the purpose of comparing t the performance of the hearing aids in the three aided conditions. The following steps were used for measuring the processing delay of the hearing aids used.

- The enhanced DSP screen was selected from the opening screen of the Fonix 7000 hearing aid test system.
- The sound chamber was leveled and the hearing aid was placed for testing in the sound chamber. That is, the hearing aid was connected to a 2 cc coupler and the output was collected through a test microphone for analysis.
- The hearing aid with the coupler and the microphone were placed in the anechoic chamber and the measurement for the group/processing was performed.
- The processing delay measurement was taken by sending a short impulse from the sound chamber speaker to the hearing aid.
- For the group delay measurements, the Fonix 7000 system microphone collected information from the hearing aid for 20 msec from the time the impulse was delivered which was a series of varying amplitudes.
- The data collected in the digital processing delay measurement was displayed in the graphical format as amplitude vs. time. The delay point is represented by a dotted vertical line along with the display of numerical data. There was a second dotted vertical line showing the delay for reference.
- The data collected from this measurement was displayed in a graphical format 20 msec wide. The measurement from the vertical point to the response wave of the hearing aid is taken as the group delay of that hearing aid.

- Similarly the group delay of all the test hearing aids used was measured and the values were compared according to which pair of hearing aids had been used for the test procedure.
- When measuring the set of binaural hearing aids, the group delay of the two hearing aids should match fairly closely.

Thus, the SRS, ratings for quality of speech (loudness, clarity and intelligibility) were made for the three aided conditions and the processing delay measurements were collected and the results were analyzed to fulfill the objective of the study.

I. Speech Recognition Scores (SRS)

The SRS in the three aided conditions were analyzed. Table 4.1 depicts the mean and standard deviation (SD) values of the SRS obtained in the three aided conditions. The three aided conditions include analog binaural hearing aids (AA), digital binaural hearing aids (DD) and analog hearing aid in one ear and digital hearing aid in the other ear (AD). As can be observed in the Table 4.1, the mean SRS value was more in the DD condition and least in the AA condition. The variation of SRS, i.e., SD, in different conditions was comparable.

Table 4.1: Mean and Standard Deviation values of SRS obtained in the three aided conditions.

	Mean	SD
SRS-AA	19.60	4.03
SRS - DD	22. 13	3.54
SRS-AD	21.33	3.59

Note:
SRS-AA: SRS with binaural analog hearing aids
SRS-DD: SRS with binaural digital hearing aids
SRS-AD: SRS with analog hearing aid in one ear and digital hearing aid in the opposite ear.

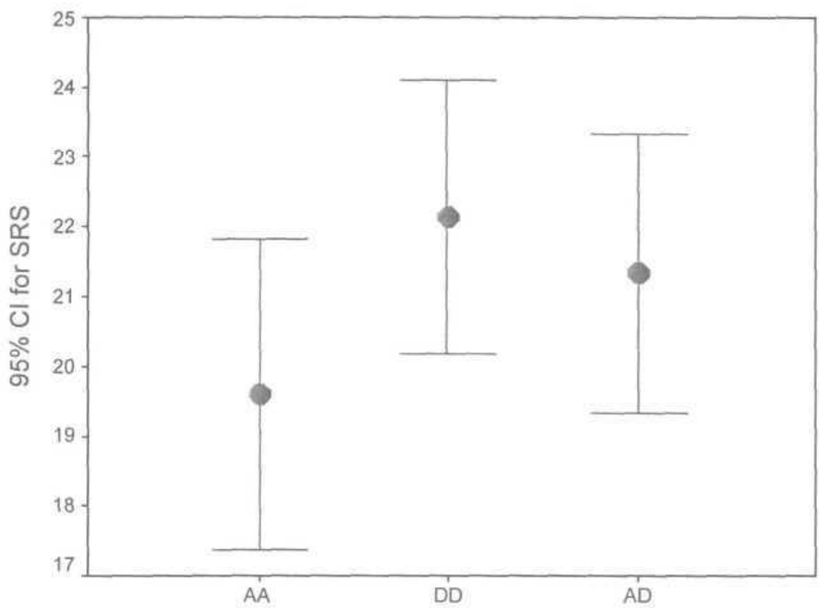

Fig. 4.1: Mean SRS (with 95% CI) in AA, DD and AD conditions.

The above observation is also evident from the Figure 4.1. It can be seen that there is an overlap in the SRS values (95% Confidence Interval (CI) of mean) and the maximum difference in mean SRS values was between AA and DD conditions, with the mean SRS being least in the AA condition.

Further, one way repeated measures Analysis of Variance (ANOVA) was performed to see if the difference in the mean SRS values in the three aided conditions were significantly different. The results showed that there was a significant difference between the three conditions, $F = (2, 28) = 9.73$, ($p < 0.01$), indicating that there was a significant effect of the aided conditions. Further, the mean values of SRS in AD condition was higher than the mean value of SRS in AA condition; and the mean SRS values in DD condition was higher than that in the AD condition. From Bonferroni's multiple comparison, it was observed that there was no significant difference between the

AA and AD conditions, and the AD and DD conditions ($p > 0.05$). However, there was a significant difference between AA and DD conditions ($p < 0.05$).

This result is consistent with the study done by Prinz, Nubel and Gross (1997) who had got similar results while testing on individuals with bilateral moderately-severe symmetrical hearing loss. Interestingly, all the studies that had proved the advantage of binaural amplification had used ear level hearing aids, such as those by, Jerger and Dirks (1961), MacKeith and Coles (1971) and the others.

II. Quality Rating of Speech

Quality rating of hearing aid processed speech was done on three sub-scales. They were loudness, clarity and intelligibility. The three sub-scales were rated on a ten-point rating scale, one being very soft and ten being uncomfortable for loudness, one being completely unclear and ten being very clear for clarity, and, one being unintelligible and ten being fully intelligible for intelligibility.

Table 4.2: Mean and standard deviation (SD) of ratings on loudness, clarity and intelligibility in AA, DD and AD conditions.

Quality sub-scales	Aided conditions	Mean (N=15)	SD
Loudness	AA	6.93	2.46
	DD	7.93	1.98
	AD	7.66	2.05
Clarity	AA	6.40	2.13
	DD	8.20	1.42
	AD	8.00	2.00
Intelligibility	AA	7.06	2.15
	DD	8.46	1.30
	AD	7.86	1.95

From the Table 4.2, it can be observed that the mean values for quality ratings of loudness, quality and intelligibility is higher for the DD and the AD conditions compared to the AA condition but in all the quality ratings, the value of DD condition is higher than the AD condition. The variation as revealed by the SD was slightly higher in the AA condition than in the AD condition, which in turn was higher than in the DD condition.

II. a. Loudness

The mean and 95% of CI of loudness ratings is shown in the Figure 4.2. It can be seen from the figure that there is an overlap between the loudness ratings and there was no significant difference between the mean ratings on loudness in AA, DD and the AD conditions.

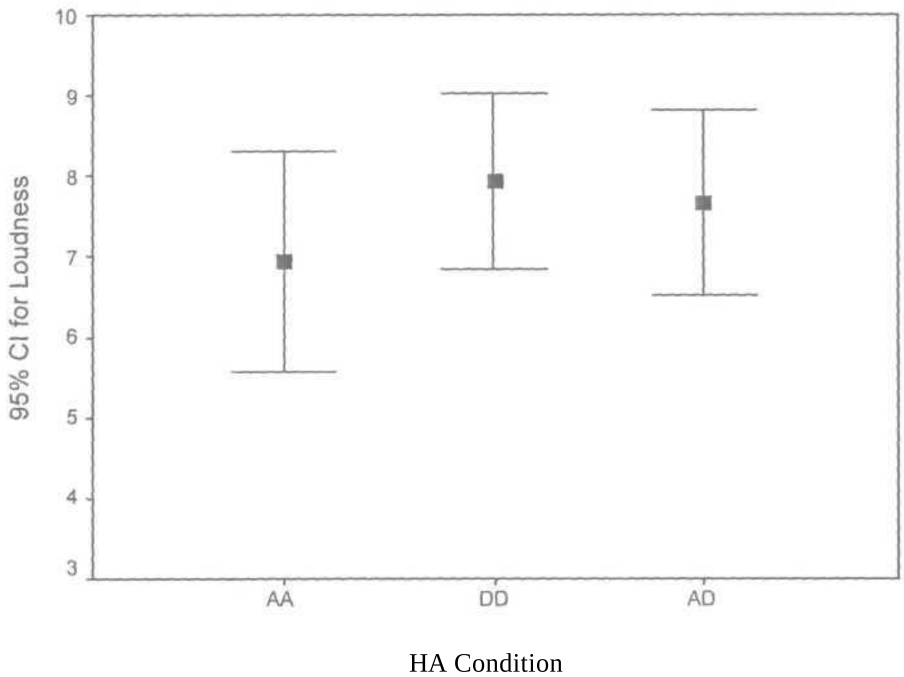

Fig. 4.2: Mean (with 95% CI) ratings on loudness in AA, DD and AD conditions.

Friedman's test, a non-parametric equivalent of one way repeated measures ANOVA, was used for comparison of ratings for loudness between the three aided conditions. From Friedman's test, no significant difference was found between the loudness ratings of the three aided conditions [$X^2(2) = 5.568$, $p > 0.05$].

II. b. Clarity

It can be noted from Figure 4.3, that there was an overlap in the rating of clarity (95% CI of mean) and the maximum difference in mean ratings of clarity was seen between AA and DD, and, AA and AD conditions.

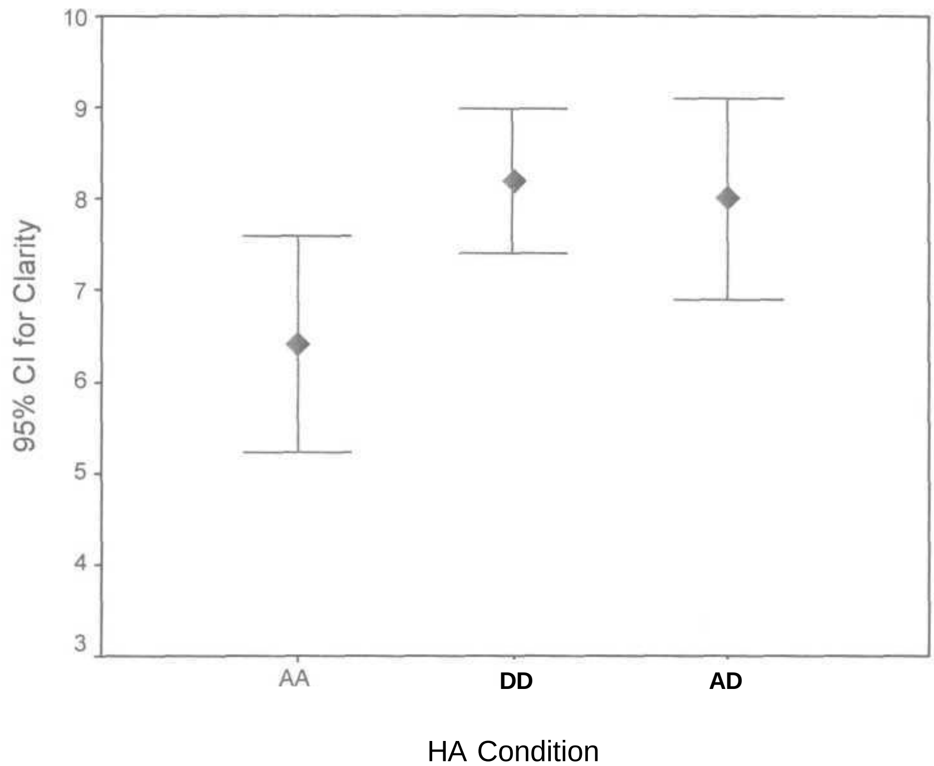

Fig. 4.3: Mean (with 95% CI) ratings on clarity in AA, DD, and, AD conditions.

Friedman's test was used for comparison of ratings for clarity in the three aided conditions. From Friedman's test, the results showed a significant difference between the aided conditions, AA, DD and AD [X^2 (2) = 13.792, ($p < 0.01$)]. Wilcoxon's signed rank test (a non- parametric equivalent of paired t-test), was used for pair - wise comparison of the three aided conditions. Wilcoxon's signed rank test revealed no significant difference between the AD and DD conditions ($p > 0.05$). However, a significant difference between AA and AD conditions ($p < 0.01$) and the AA and DD conditions ($p < 0.01$) were noted.

II. c. Intelligibility

On observation, it is evident from the Figure 4.4, that there was an overlap between the three aided conditions in the intelligibility rating. A maximum difference was noted in mean value of quality rating of intelligibility between DD and AA conditions.

Friedman's test was used for the comparison of intelligibility ratings for the three aided conditions. From the Friedman's test, significant difference between the aided conditions was noted [$X^2 = 6.545$, ($p < 0.05$)]. Wilcoxon's signed rank test was performed for the pairwise comparison of the three aided conditions. Wilcoxon's Signed rank test revealed that there was no significant difference between the AD and AA ($p > 0.05$) and AD and DD ($p > 0.05$) conditions. However, a significant difference between the DD and AA ($p < 0.05$) conditions was noted.

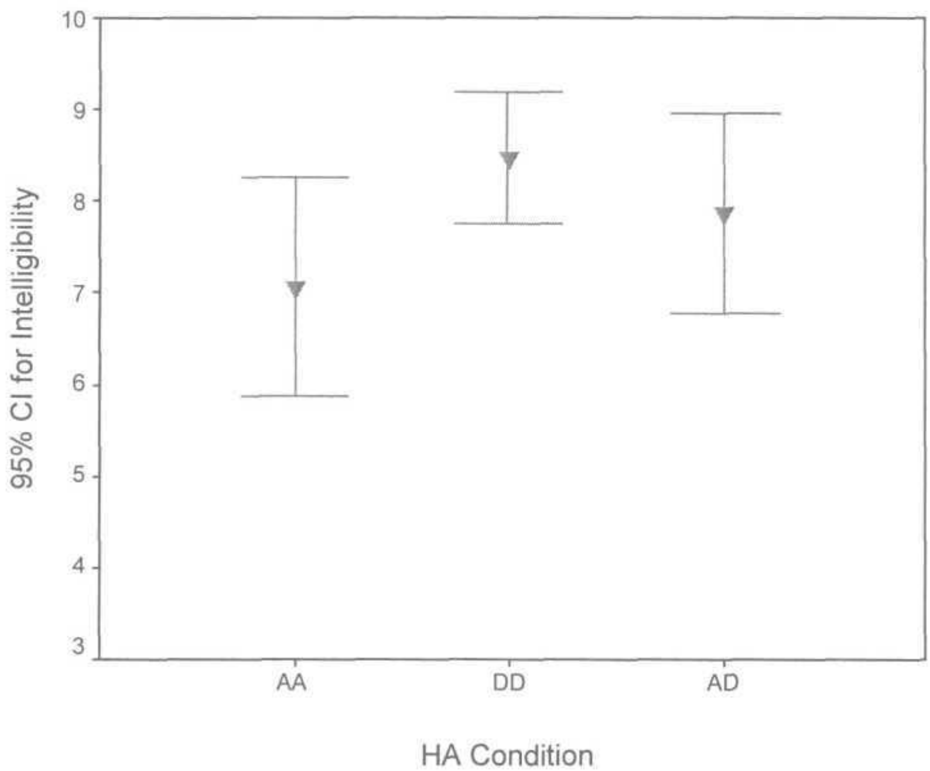

Fig. 4.4: Mean (with 95% CI) ratings on intelligibility in AA, DD and AD conditions.

The results are in agreement with the study done by Dillon (2001) who reported a binaural advantage for a number of attributes such as clarity, fullness, spaciousness and overall quality. He had also reported that individuals with hearing impairment generally made more discriminating judgments about sound when listening binaurally than when listening monaurally. Though there were no significant differences between the aided conditions, the scores for the DD condition was higher than the scores for the AD condition, highlighting the importance of digital binaural amplification.

III. Hearing aid processing delay

Frye (2001) reported that one of the properties of the digital technology is that it always takes time to process digital data. Group delay is the delay between input and output of the digital hearing aid (Kates, 2003). The processing delay for some hearing aids is so less that it is imperceptible to the human ear. The processing delay for other hearing aids can extend to several milliseconds. For analog hearing aids, the processing delay would be comparatively very less because it does not perform any signal processing activities like the digital hearing aid. Kates (2003) suggested that even before the delay in the digital processing is considered, the other components of the hearing aid (microphone, receiver, A/D or D/A) and the acoustic interactions will contribute from 2 to almost 5 msec. group delay. This depends on the sampling rate and the algorithm/s implemented. The processing delay of the hearing aids used in the present study is tabulated below.

Table 4.3: Processing delay of the hearings aids used.

Hearing aid	Processing delay (msec)
Analog 1	0.4
Analog 2	0.4
Digital 1	0.9
Digital 2	0.9

From the Table 4.3, it can be seen that the processing delays of the two analog hearing aids was the same and that of the two digital hearing aids were also the same. As suggested by Stone and Moore (1999, 2002 and 2003), a processing delay of till 32 msec. could be allowed for an effective speech perception for individuals having hearing impairment of about 55 dBHL. The finding of the study done by Henrickson (2004) also supported that of Stone and Moore concluding that processing delays of about 0.3 to 0.7 msec. are acceptable for analog hearing aids and about 1 to 11 msec. are acceptable for digital hearing aids. Dillon (2001) by comparing five digital hearing aids on individuals with hearing impairment concluded that a processing delay of 1.2 to 10 msec. were acceptable and there was no correlation between hearing aid preference and the processing delay. Flame (2002) concluded that if mismatch in delay times did not change often, individuals with hearing impairment adapt with a period of hours or days. Though presently there is a difference in the group delay between the analog (i.e., 0.4 msec.) and the digital (0.9 msec) hearing aids, with evidence from the literature, in the present study also it is inferred that the individuals with hearing impairment will adapt to the processing delays between analog and the digital hearing aids. However, audiologist should keep in mind that the group delays between the two hearing aids should not vary much for providing effective speech perception.

From the findings of the present study, it can be inferred that the clients could be recommended with one analog and one digital hearing aid in the opposite ears till they could afford for another digital hearing aid. This is due to the the advantages of binaural amplification and keeping in mind the better performance of binaural digital hearing aids compared to analog, in terms of clarity, intelligibility, loudness and other parameters as discussed by many investigators such as Hirsh (1950), Markides (1977), and Gelfand and Silman(1993).

Chapter - V

SUMMARY AND CONCLUSION

A recent advancement in the hearing aid technology is the digital hearing aids. Binaural amplification with digital hearing aids is said to improve the performance in terms of audibility, recognition, quality of speech etc. In the Indian context, the major problem with the binaural fitting of digital hearing aids is their expensive nature. Clients come up with enquiries like whether they can use analog hearing aid in one ear and digital hearing aid in the opposite ear till they could afford for another digital hearing aid.

The present study aimed at comparing the performance of individuals with hearing impairment in terms of audibility, understanding and quality of speech using three aided conditions. The three aided conditions were binaural analog hearing aids (AA), binaural digital hearing aids (DD) and an analog hearing aid in one ear and digital hearing aid in the opposite ear (AD).

The testing procedure consisted of five phases.

1. Pre - selection and programming of the hearing aids
2. Measurement of the insertion gain for hearing aid selection.
3. Establishing the Speech Recognition Scores (SRS) in each of the three aided conditions.
4. Quality rating of speech in terms of loudness, clarity and intelligibility, each of the three aided condition.
5. Processing delay measurement of the selected hearing aids.

Results indicated no significant difference between the DD and the AD conditions though the mean performance in the DD condition was higher than that of the AD condition, for both the SRS and the quality rating of speech. Though presently there is a difference in the group delay between the analog and the digital hearing aids, the performance in AD condition is closer to the DD condition than the AA condition. The audiologist should keep in mind that the group delays between the two hearing aids, which should not vary much for providing effective speech perception.

Thus, it is implied from the present study that the individuals with hearing impairment can be suggested to use analog hearing aid in one ear and digital hearing aid in the opposite ear, till they can afford for binaural digital hearing aids considering the expensive nature of the digital hearing aids. However, this is to be considered as a temporary measure till they can afford binaural digital hearing aids.

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APPENDIX - A

Passage in Kannada

(in IPA)

suḷḷina p^{h}ala

ondu haḷḷijalli obba kuruba huḍuga va:sava:giddanu. avanu mundza:neje: ka:ḍige ho:gi allije: dz^{h}arijalli sna:na ma:ḍi sandzejavarege kurijannu me:jisi, sandze haḷḷige va:pa:sa:gu- ttidda. omme avanu kuri me:jisuva:ga iddakkiddanteje: hattirada holadalli kelasa ma:ḍuttidda raitarannu tama:çe ma:ḍa be:ku endu konḍa. anteje: avanu ajjo! huli! huli! ka:pa:ḍi endu ku:ga toḍagida. idannu ke:ḷida raitaru k^{h}aḍgagaḷannu tegedukonḍu hulijannu kollalu sidd^{h}ara:gi o:ḍi bandaru. idannu noḍida huḍuga nakku biṭṭa. raitaru ko:pagonḍu va:pa:sa:daru. huḍuga ide: ri:ti aida:ru ba:ri ma:ḍida. raitaru a: huḍugana me:lina nambike kaḷedu konḍaru.

omme suma:ru hanneraḍu g^{h}anṭe, bisilu ta:ḷala:rade huḍuga tʃ^{h}atri jannu hiḍidu kuḷittidda. iddakkiddante nidzava:giju ṭ^{h}akka huli bande: biṭṭittu. huḍuga matte ka:pa:ḍi! ka:pa:ḍi ! endu tʃi:rida. a:dare ja:ru saha avana sahajakke baralilla. huliju avana saṇṇa saṇṇa kurigaḷannu kolla la:ramb^{h}isitu. adannu ka:pa:ḍalu ho:da a: huḍugana mele a: huli ha:ri, avanannu konditu. i: kat^{h}eja ni:ti enendare - "suḷḷu ga:ranige ʃikçetappadu".

Phonemically Balanced Word List Developed by Yathiraj and Vijayalakshmi (2005).

rait̪a	tʃukki	huḷu	va:tʃu
anna	hagga	su:dzi	hoṭṭe
mola	bat̪t̪a	roṭṭi	d̪öni
tʃa:ku	mantʃa	gu:be	vadzra
t̪uti	bekku	akka	va:ṇi
me:ke	lo:ṭa	e:ḷu	t̪ale
ha:vu	ba:la	vi:ṇe	kat̪t̪e
kat̪t̪u	dze:bu	d̪imbu	me:dzu
bi:ga	manḍi	vaḍe	na:ji
o:d̪u	noṇa	go:li	ba:lu
baḷe	maḷe	ha:lu	ni:li
mu:ru	ṭi:vi	amma	gombe
ra:ṇi	d̪i:pa:	dzana	ka:ge
tapa:	rave	ravi	ad̪u
ta:ra:	moḷe	tande	dra:kṣi
brʌṣu	railu	rakt̪a	bægu
hasu	ka:ru	sut̪t̪u	kaṣṭa
dzaḍe	divja	ja:va	paisa
nalli	a:ru	tʃandra	mara
kivi	pu:ri	ja:ke	hu:vu
varṣa	had̪d̪u	ʃa:le	t̪innu
ja:ru	suṣma	aidu	iḍli
da:na	t̪a:ji	nad̪i	ke:ḷu
ʃæmpu	d̪ana	uppu	sara
ili	ʃa:lu	kriṣna	pada