Binaural Amplification – Does Technology Matter?

Anusha & Manjula P*

Abstract

Hearing impairment is a reduction in the hearing sensitivity which will cause deterioration in the speech abilities (Stach, 1997). Hearing aids, in particular, binaural amplification are useful in the restoration of speech perception, in addition to perception of environmental sounds, promoting improvement in communication skills according to Markides (1977). The present study aimed at comparing the performance of the individuals with hearing loss, in terms of improved audibility, understanding and quality of speech using binaural analog hearing aids (AA), binaural digital hearing aids (DD), binaural amplification with analog and digital hearing aids in opposite ears (AD). 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. 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.

Key words: Analog hearing aids, digital hearing aids, speech recognition scores, quality rating of speech, processing delay

Introduction

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 listener's speech recognition system. 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. It also aims to shape the amplified signal to provide appropriate gain at each frequency in accordance with the pattern of the deficit. Further, it should 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). There are different types of hearing aids, analog and digital, depending on the technology they use to process the signal. The so called digital hearing aids are an outgrowth of the computer revolution that has transformed our society (Ross, 1997). The digital signal processing used in a digital hearing aid provides a better speech performance,

* Professor in Audiology, All India Institute of Speech and Hearing, Mysore, India
e-mail: manjulap21@hotmail.com

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. 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). Unless there are specific contra-indications 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 (MacKeith & Coles, 1971). Binaural performance is researched to a greater extent due to the advantage of binaural amplification (Nabelek & Robinson, 1982). It is essential that we educate the individuals with hearing impairment about the new technological advancements so that they can decide about purchasing new hearing aids that might improve listening (Sanders, 1993).

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.

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

Method

Participants

The data from 15 participants were collected. The participants gave informed consent and fulfilled the following selection criteria:

- Age range from 16 to 60 years (mean = 49.06 years)

- first time hearing aid users, native and fluent speakers of Kannada
- Bilateral moderate to moderately severe (PTA = 41 to 70 dBHL) symmetrical (<20dB difference between the PTA of right and left ears) sensorineural hearing loss

Equipment

The following instruments were 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 sized 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 hearing aid test system to measure the Real Ear Insertion Gain (REIG).
6. Calibrated hearing aid test system 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) were used for measuring Speech Recognition Scores. Each list consists 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.

Test Environment

The test was conducted in a sound treated environment with ambient noise levels within permissible limits.

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 hearing aid test system for the measurement of the insertion gain. For this purpose the loud speaker of the test system was located on the speaker stand at 45 degrees Azimuth 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 participant were fed into the hearing aid test system 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 dB SPL. 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 the hearing aid test system. 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 dB SPL.
- 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 REIG at different frequencies was displayed as Real Ear Insertion Response curve (REIR). Thus, the REIR was obtained for the hearing aid for both the ears of each participant.
- This was repeated for three hearing aids in order to select the best hearing aid based on the REIR that matched the target gain curve for testing the performance.

Phase 3: Establishing of Speech Recognition Scores (SRS)

The participants were seated comfortably in the sound treated audiological test room with the appropriate loud speakers located at one meter from the participant at 45 degrees 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 (AA)
   2. B. with binaural digital hearing aids (DD)
   2. C. with digital hearing aid in one ear and analog hearing aid in the opposite ear (AD).

In the unaided condition the SRS was obtained. For this one of the four Phonemically Balanced word lists (Yathiraj & Vijayalakshmi, 2006) was presented using monitored 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 number of words repeated correctly was 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 (2A, 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 participants 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 (AA, DD & AD), 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 correct understanding ability of the speech units. 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 quality rating of connected discourse was also analyzed in order to find out the difference in speech perception when using any of the three conditions.

Phase 5: Measurement of signal processing delay

The group delay is the amount of time it takes the digital hearing aid to process sound. The processing delay for some hearing aids is so slight that it is imperceptible to the human ear. The processing delay for other aids can extend to several milliseconds- longer than the calculating time for an analog hearing aid. If an individual is fit monaurally with an aid with a significant digital processing delay that person might experience some confusion because his unaided ear will be hearing sounds slightly faster than his aided ear. The processing delay of the hearing aids used was measured for the purpose of comparing 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 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 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 processing delay measurements the hearing aid test 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 were displayed in the graphical format as amplitude vs. time (Figures 1&2). 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.

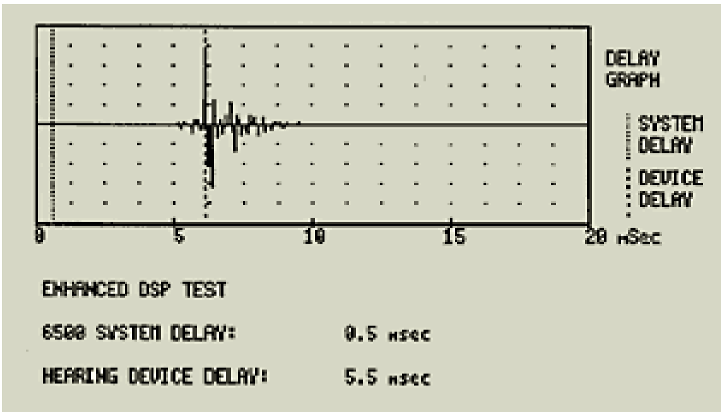

Fig. 1**.** Measurement of the processing or group delay of a digital hearing aid

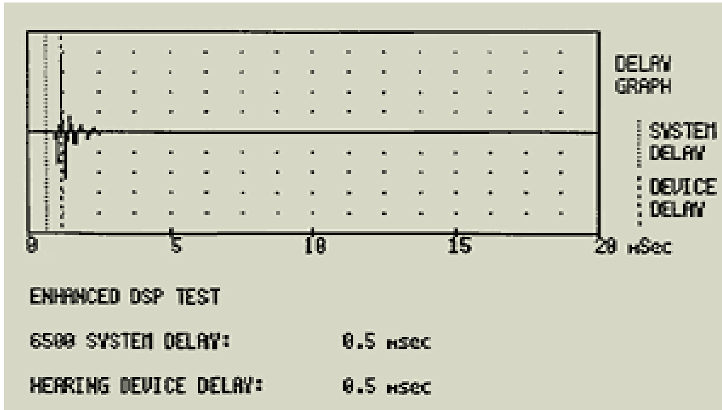

Fig. 2. Measurement of the processing or group delay of an analog hearing aid

- 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 processing delay of that hearing aid.
- Similarly the processing delay of all the test hearing aids used was measured and the values were compared according to different aided conditions for the testing.

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

Results and Discussions

The objective of the study was to compare the performance of 15 participants with bilateral symmetrical sensorineural hearing loss, in terms of audibility, recognition and quality of speech using the three aided conditions, viz., binaural analog hearing aids, binaural digital hearing aids and binaural amplification with analog and digital hearing aids in opposite ears.

The objective of the present study was evaluated by obtaining the Speech Recognition Scores (SRS) and the quality rating of speech. The quality of speech was rated on three parameters such as loudness, clarity and intelligibility in the three aided conditions; AA, DD and AD. The data were tabulated and statistically analyzed using the Statistical Package for Social Sciences (SPSS, version 10.0).

The mean and standard deviations of the following measures were computed for all the three aided conditions. Following this, pair-wise comparisons were made to see if there was a significant difference between the aided conditions. The results are given below under three main headings.

I) Speech Recognition Scores (SRS)
II) Quality rating of speech
III) Hearing aid processing delay.

I. Speech Recognition Scores (SRS)

The SRS in the three aided conditions were analyzed. Table 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 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 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.

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 that reported by Prinz, Nubel and Gross (2002) 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.

From the Table 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.

Table 2: Mean and 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

II. a. Loudness

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

Friedman's test was used for comparison of ratings for clarity in the three aided conditions and 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 which 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

Friedman's test was used for the comparison of intelligibility ratings for the three aided conditions which showed significant difference between the aided conditions [$X^2 = 6.545$, ($p < 0.05$)]. Wilcoxon's signed rank test was performed for the pairwise comparison of the three aided conditions which revealed 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.

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 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 it can be seen that the processing delays of the two analog hearing aids were the same and that of the two digital hearing aids were also the same. As suggested by Stone and Moore (2003) a processing delay of 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 to10 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 another digital hearing aid. However, the processing delay of the hearing aids needs to be measured for optimum performance in such situations. This is due to 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 and loudness.

References

Condie, R., Scollie, S. & Checkly, S. (1984). Children's performance with analog vs. digital adaptive dual microphone hearing aid. *Ear & Hearing*, 19(5), 407-413.

Frye, G. J. (2001). Testing digital and Analog Hearing Instruments: Processing Time Delays and Phase Measurements. A look at the potential side effects and ways of measuring them. http://www.frye.com/library/acrobat/hrarticle2.pdf.

Jerger, J. & Dirks, D. (1961). Binaural hearing aids: An enigma. *Journal of the Acoustical Society of America*, *19*, 629-631.

Mc. Keith, N.W. & Coles, R.A. (1971). Binaural advantages of hearing in speech. *Journal of Laryngology and Otology*, 85, 231-232.

Markides, A. (1977). *Binaural amplification*. NY: Academic Press.

Yathiraj, A. & Vijayalakshmi, C. S. (2006). *Phonemically balanced word list in Kannada* developed at the dept. of Audiology, AIISH.

Kates, J. M. (2003). *Dynamic range compression using digital frequency wrapping.* US patent application 20030081804, tia.sagepub.com/cgi/content/ref/8/3/84.

Hirsh, I. J. (1995). Pre-attentive discriminability of sound order as a function of tone duration and interstimulus interval: A mismatch negativity study. *Audiology and Neurotology*, 4(6), 303-310.

Nabelek, A. K. & Robinson, P. K. (1982). Monaural and binaural speech perception in reverberation for listeners of various ages. *Journal of Acoustical Society of America*, 71, 1242-1248.

Prinz, I., Nubel, K. & Gross, M. (2002). Digital and analog hearing aids in children. Is there a method for making an objective comparison possible? http://www/medical/mm_0093_coveragepositioncriteria_hearingaids.pdf

Ross, M. (1997). A retrospective look at the future of aural rehabilitation. *Journal of American Academy of Audiology*, 30, 11-28.

Sanders, D.A. (1977). *Auditory perception of speech*. NJ: Prentice Hall, Inc.

Sanders, D.A. (1982). *Aural rehabilitation; A management model*. 2nd edn. NJ: Prentice Hall, Inc.

Sanders, D.A. (1993). *Management of hearing handicap: Infants to elderly*. NJ: Prentice Hall, Inc.

Stone, M.A. & Moore, B.C.J. (2003). Tolerable hearing aid delays: effect on speech production and perception of across frequency variation of delays. *Ear & Hearing*, 24(2), 175-183.