EFFECT OF LOW FREQUENCY GAIN ATTENUATION IN BAHA WITH TEST BAND IN INDIVIDUAL WITH SINGLE-SIDED DEAFNESS.

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MANASAGANGOTHRI, MYSORE – 570006

MAY, 2013.

Dedicated to my beloved

Parents, Brothers

&

To my guide

CERTIFICATE

This is to certify that this dissertation entitled "**Effect of low frequency gain attenuation in BAHA with test band in individual with single-sided deafness.**" is a bonafide work submitted in part fulfilment for the Degree of Master of Science (Audiology) of the student (Registration No.: 11 AUD021). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any of the University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this dissertation entitled "**Effect of low frequency gain attenuation in BAHA with test band in individual with single-sided deafness.**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "**Effect of low frequency gain attenuation in BAHA with test band in individual with single-sided deafness.**" is the result of my own study under the guidance of Mr. Kishore Tanniru, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

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CHAPTER-I

INTRODUCTION

Single sided deafness (SSD) or unilateral hearing loss is condition where an individual has non-functional hearing in one ear and having normal hearing thresholds in the other ear. The non-functional ear can also have profound hearing loss but not necessarily. It is assessed that single sided deafness (SSD) afflicts almost nine million people in the United States alone (Wazen, Spitzer, Ghossaini, Fayad, Niparko, & Cox, 2003).

There are several aetiological factors that were well known to cause SSD. The most common causative factor for acquired SSD is sudden hearing loss. Byl (1978), Berg and Pallasch (1981) indicated that sudden hearing loss usually occurs in adolescents or older adults, with greatest incidence occurring between 30 to 60 years of age (Megighian, 1986). Sudden hearing loss is usually unilateral but Rambur (1989) reported incidence of sudden bilateral hearing loss in United States up to 17% of the cases.

The other aetiological factor for SSD is acoustic neuroma or a space-occupying lesion in brainstem (Goodhill, Harris, & Brockman, 1973). Though acoustic neuroma/ space occupying lesion is generally benign and slow developing in nature, surgical intervention for these lesions may damage the auditory nerve. This might lead to permanent hearing loss in ear underwent for surgery. Douglas, Yeung, Daudia, Gatehouse and O' Donoghue (2007) reported about 44 such subjects developed SSD after underwent for the acoustic neuroma surgery. But incidence rate of SSD in subject with acoustic neuroma was not clearly reported.

Hendricks, Munoz and Walton (1988) reported other common cause for SSD as transverse traumatic fracture (sensorineural hearing loss) to the temporal bone, which leads to unilateral hearing loss with other associative symptoms. Schuknecht (1991) reported the causative factor for SSD as Meniere's disease. It has been reported to cause unilateral hearing loss in approximately 50% of all cases.

Other less common causal agents for unilateral hearing loss can be genetic (dominant, recessive and x-linked) or nongenetic [cytomegalovirus (CMV), low birth weight, syphilis and anoxia]. Kinney (1953) reported known causes of unilateral hearing loss in a series of 310 children such as meningitis, measles and infection due to mumps (also reported by Wilson, Veltri, & Laird, 1983) such as labyrinthitis. In addition Cogan's syndrome, multiple sclerosis, perilymphatic fistula, herpes zoster oticus, hemorrhage, thrombosis, embolism, spasms, aneurysm and sludging of blood have been reported to cause unilateral hearing loss (Jerger & Jerger, 1981)

Goodhill et al. (1973) identified labyrinth membrane ruptures (perilymphatic fistula) as causative factors. Mariotto, Alvarenga and Filho (2006) identified ototoxicity and chicken pox as major cause. Laury, Casey, McKay and Germiller (2009) stated that aplasia of the cochlear nerve also might be a cause of unilateral hearing loss.

1.1 Clinical Manifestations of Single-Sided Deafness:-

An individual with congenital/acquired single-sided deafness (SSD) encounters several distinctive and specific listening challenges (Bishop & Eby, 2009). These challenges are often include not able to utilise the binaural cues as one of the ear is not functioning normally.

Binaural hearing (ability to hear with two ears) gives several advantages in listening ability compare to monaural hearing. These advantages includes sound localization, better speech understanding both in quiet and in noise, binaural summation (Lieu, Judith, & Cho, 2004; McKay, Gravel, & Tharpe 2008; Lin, Bowditch, Anderson, May, Cox, & Niparko, 2006). But these advantages are missed out in person with single sided deafness which leads to loss of equilibrium between the two ears.

First advantage of hearing with two ears is localization. Both ears works together and sends signal to the brain so that we can locate where the sound is coming from. This depends on when each ear receives the signal as well as how loud the stimulus is at each ear. Individuals with SSD complaints loss of balance between the two ears and they lose the ability to have stereo hearing.

A second advantage of binaural hearing is the ability to pick out a signal in presence of noisy background known as “binaural squelch” (Lieu et al., 2004; McKay et al., 2008) and also known as the “cocktail party effect”. This ability is different from localization in a way to concerns the ability to focus on speech stimulus when surrounding noise is present. Douglas et al. (2007) used Speech, Spatial and Qualities of Hearing scale (SSQ), in 44 patients with SSD after acoustic neuroma surgery and control group. Result indicated poor scores in subject with SSD on all items but identification of sounds and objects was better. Majority of the error were noted in tasks such as speech understanding in presence of the noise, separating multiple speech-streams and switching between information's and finding the location of unseen objects. All the subjects with SSD have increased listening effort in the above stated circumstances.

The third benefit of binaural hearing is the lowered overall hearing sensitivity i.e. able to detect weaker sounds. This is known as binaural summation. Binaural summation typically gives a 3-8 dB advantage for binaural listeners over those with unilateral hearing (Lieu et al., 2004)

1.2 Rehabilitative options for SSD:-

There are several treatment options available for subject with SSD but the first priority was given to identify correct the causative factor through medical treatment. If the hearing loss in subject with SSD can't be corrected with medical treatment, these are often recommended with amplification devices. At this condition it becomes challenging task for audiologist to fit appropriate amplification devices for individuals with unilateral sensorineural hearing loss. Conventionally there are a few amplification strategies available for individual with SSD and some of them include prescription air conduction hearing aids, bone conduction hearing aids and bone anchored hearing aid (BAHA).

The classical approach in amplification selection for subject with SSD has been with the fit of contralateral routing of signal (CROS).CROS systems are the variation of the air conduction hearing aid which senses sound from a microphone on the affected ear and sends the information to an open fit hearing aid on the normal hearing ear (Dillon, 2001).

Studies by Harford and Barry (1965); Courtois, Johansen and Larsen (1988) reveal that there is adverse sound quality through CROS mainly if hearing in the better ear is within normal limits. This was attributed to the fact that normal cochlea is stimulated by amplified sound through CROS which overlaps with natural sound present at normal ear side. But if normal ear has mild hearing loss present above 1500 Hz in the better ear, then a greater probability of benefit will be achieved.

Problem with the CROS system is that it uses hardwired devices which concerns cosmetic issue (Valente, Valente, & Mispagel, 2007). Thus Along with poor performance from CROS, cosmetic issue which limit the regular use of CROS system (Valente et al.,2007).

To avoid cosmetic issue, transcranial CROS was developed this uses a completely-in-the-canal power hearing aid that fitted to the affected ear and the sound pressure is amplified to vibrate the cranium. This vibration is transmitted to the normal or better cochlea through bone conduction. Major disadvantages of this system was discomfort and occlusion to the subject thus it was not considered as good amplification option (Niparko, Cox, & Lustig, 2003; Lin et al., 2006).

Though there were several modifications have been tried in CROS, all of there were clinically lea accepted due to inadequate ability to form efficient frequency-gain response to deliver the information to the aided ear (Valente et al., 2007; Bishop & Eby, 2010).

Another option was bone conduction hearing aid which uses bone conduction principle to transmit the signal from device is known as bone-conduction oscillators. Vibrations of oscillator were transmitted through the skin to mastoid and there by better cochlea. But these devices require enough pressure applied on mastoid through headband which was the major drawback for all-day or longstanding use.

The most recent amplification approach for subject with SSD is BAHA. BAHA typically uses surgically implanted titanium screw is placed in the parietal/temporal region of the skull on poorer ear. BAHA device is directly coupled to a titanium implant anchored in the temporal bone. Following surgery this typically takes 6 weeks to 3 months at which the screw will be stable and capable of anchoring a BAHA device. The BAHA is connected to the screw via a titanium abutment. It is safe and well tolerated (House & Kutz, 2007; Wazen, Young, & Farrugia, 2008; Newman, Sandridge, & Wodzisz, 2008) with this system.

The other important factors with BAHA is the effect of the skin in terms of dynamic force transmission. Skin attenuates high frequency signals higher than low frequencies (Stenfelt & Hakansson, 1999). If the vibration transducer is coupled directly to the skull bone, as with the BAHA (Snik, Mylanus, Proops, Wolfaardt, Hodgetts, Somers, Niparko, Wazen, Sterkers, Cremers, & Tjellstrom, 2005) coupling system, the attenuation caused by the skin is avoided. In general sensitivity improvement is 5 to 15 dB at frequencies above 1 kHz can be expected when the BC transducer is attached directly to the skull (as with the BAHA) instead of the compressed skin (Stenfelt & Goode, 2005; Eeg-Olofsson, Stenfelt, Tjellstrom, & Granstrom, 2008). Thus BAHA stimulates both the normal and impaired cochleae through bone vibration more efficiently (Sullivan, 1988; Chartrand, 1991; Hol, Bosman, Snik, Mylanus, & Cremers, 2004).

Snik, Mylanus and Cremers (1995) reported significant improvement in speech recognition in quiet among BAHA users who were conventional bone conduction hearing aid users. Cooper, Proops, Powell, Burrell and Bickerton (1996) also reported an improvement, but it was not statistically significant.

Lin et al. (2006) reported loss of directionality in hearing was found when they used CROS device but it was unchanged by BAHA and directional microphone aids. With reference to baseline, CROS, BAHA produced significantly better speech recognition in noise. Short- and long-term efficacy for the BAHA in adults with single-sided deafness for recognition of speech in noise (noise in front, speech lateralized to the poorer ear) was also reported by Linstrom, Silverman and Yu (2009).

Niparko et al. (2003) compared the BAHA and conventional CROS to assess the performance and reported that both devices leads significantly better speech recognition in noise under most of the conditions compare to baseline but within device speech recognition score were found to be better with BAHA in quiet and in noisy conditions as compared to CROS.

Snik et al. (2005) claimed improved communication performance utilizing BAHA. Improve performance of BAHA in localization ability and speech perception in noise was also reported by Hol, Kunst, Snik and Cremers (2010).

In spite of several advantages of BAHA Zawawi, Kabbach, Lallemand and Daniel (2011) reported a retrospective study on 100 patients with SSD referred for BAHA about refusal factor. The main reason for refusal in children was cultural and social acceptance by the family.

Andersen, Schroder and Bonding (2006) evaluated the hearing handicap in 53 patients with SSD. The initial questionnaire revealed high variability within the subject population. Results revealed that 45% perceived having handicap being significantly, 38% perceived that it was moderately and 15% thought it was a minor problem. Twenty-six of the questionnaire respondents actually participated in the

BAHA test band trial. Positive feedback was noted in overall subjective measures. After the test, however, only 25% of all patients decided to go for implantation for BAHA after complete preoperative test.

Though there were several attempts have been made to compare the performance across different amplification methods to improve listening ability of for individuals with SSD, amplification strategies remains a topic of great interest for audiologists.

1.3 Need for the study:

The working principle of BAHA is mainly based on bone conduction (BC) pathway and there are certain frequency dependent variations among BC sound transmission revealed through head related transfer functions.

Acoustically attenuation at the ear contralateral to the sound source is larger at higher frequencies starting from approximately 1.5 kHz and less pronounced at lower frequencies below approximately 1 kHz. According to Shaw (1974), Kompis and Dillier (1993) typical attenuation values are 3 to 7 dB at lower frequencies (200 to 1000 Hz) and 9 to 21 dB for higher frequencies (2000 to 8000 Hz).

When a speech signal is presented on poorer ear side of the subjects with SSD the vowel portions are generally transmitted and perceived in better ear. This is due to the fact that vowels comprise of lower frequency information and bends around the head more easily, efficiently because of its higher wavelength. Whereas, consonant speech segments comprised of high frequencies are reflected off the same side of the head because of its shorter wavelength and therefore the opposite ear/ better ear does not receive the information in individuals with SSD.

Nolan and Lyon (1981) studied the transcranial attenuation using bone conduction audiometry from250Hz to 4 KHz in 15 unilateral hearing loss individuals and 35 normal hearing individuals. The outcome of the study indicated that mean transcranial attenuation was 13dB for both group at 2 KHz but inter-subject variability was extremely high. The inter-subject variability was attributed to the variation in thickness of skull among individuals studied.

Table 1.1 *Mean transcranial attenuation values based on Nolan and Lyon (1981)*

	Frequency in Hz							
	250	**500**	**750**	**1000**	**1500**	**2000**	**3000**	**4000**
Transcranial attenuation(dB)	8.3	9.3	10.3	10.6	10.3	13	10.3	16

The variability of interaural attenuation across frequency can be attributed to due to spring-effect causes the ossicle to vibrate in-phase with the skull at low frequencies. At higher frequencies the ossicles become vibrationally decoupled from the surrounding bone resulting out of phase with stapes footplate and the otic capsule (Stenfelt, Hato, & Goode 2002).

The above two factors signifies that amplification strategies such as BAHA must emphasize on high frequency amplification a lot more than low frequencies. Also that low-frequency sound is more difficult to transmit with less distortion compared with high-frequency sound. Indeed distortion of BAHA devices is most prominent in the low-frequency range.

This indicates the importance of amplifying the high frequency signals alone rather than low frequencies. Thus low frequency attenuation with commercially available BAHA systems would certainly reflect performance changes in speech understanding. Merely only few researchers studied this factor.

One such study by Pfiffner, Kompis, Flynn, Asnes, Arnold and Stieger (2011) revealed benefit from low-frequency attenuation of Bone-Anchored Hearing Aids (BAHA) in users with SSD. Results reveal that high cut-off levels of up to 1500 Hz for low-frequency sound didn't compromise the benefit of BAHA in SSD when noise presented from the front and speech was presented on the side of the BAHA. Detrimental effect on speech understanding can be reduced when noise is presented from the side of the BAHA by higher cut-off frequencies.

Further exploration in this direction using BAHA system is much required to note the effects of low frequency attenuation in BAHA systems would be useful.

1.4 Aim and Objectives of the study:

The aim of the present study was to evaluate effect of low frequency attenuation in pre-implantable BAHA in individuals with SSD. The specific objectives are as follows:

1) To evaluate the effect of the low frequency attenuation in pre-implantable BAHA on speech perception ability in noise.

2) To evaluate the effect of the low frequency attenuation in pre-implantable BAHA on horizontal plane localization.

CHAPTER- II

REVIEW OF LITERATURE

Individuals with SSD have good hearing ability in one ear which helps to cope up with day to day life communication. Thus SSD subjects would normally have higher expectation from amplification devices. Hence audiological rehabilitation for individuals with SSD has remained without rehabilitation. However, a recent published meta-analysis on the consequences of SSD individuals showed an increased difficulty such as loss of binaural hearing, localization and speech perception in noise which has vastly harmful consequences on both individual and socioeconomic basis.

BAHA takes advantages of direct mechanical stimulation to temporal bone for stimulating both the normal and impaired cochlea (Hol et al., 2004) and transferring amplified signal to better cochlea by bone conduction through the cranium (Sullivan,1988 & Chartrand, 1991). Several attempts have been made to compare the performance across different amplification strategies for individuals with SSD. The performance of BAHA is discussed under following:

2.1 Performance of speech perception in noisewithBAHA

2.2 Performance in localization task with BAHA

2.3 Subjective rating scale on BAHA output

2.4 Performance with low frequency attenuation in BAHA:

2.1 Performance of speech perception in noise with BAHA:-

With speech and background noise presented at the same level, persons with unilateral deafness were found to hear only about 30-35% of the conversation. In order to overcome such inconvenience various rehabilitative options have been researched upon, in which BAHA have been the most beneficial.

Snik, Beynon, Pouw, Mylanus and Cremers (1998) studied speech recognition in quiet as well as noise. The results revealed that there was an improvement in directional hearing for binaural BAHA whereas less directional hearing benefit with BAHA in only one ear. Speech recognition threshold in quiet was up to be 3 to 6dB with binaural BAHA and in presence of noise the improvement was of 2.9dB to 6dB with binaural fitting over monaural.

Anderson et al. (2006) studied the benefit of BAHA implantation in twenty six patients with SSD after acoustic neuroma. Speech discrimination in quiet and in noise was measured with the BAHA test band and in the unaided condition using Hearing in Noise test (HINT). The scores showed a significant BAHA benefit when noise was presented to normal hearing ear and speech was presented to the BAHA side. The mean improvement in SNR was 5.5 dB SPL (range 2-11 dB).

Kunst, Hol, Snik, Bosman, Mylanus and Cremers (2008) have reported an average increase in speech recognition of 33% with the BAHA compared to the unaided situation. When speech presented from the side of the poor ear. Similarly, Yuen, Smilsky and Bodmer (2009) tested with HINT in both unaided and aided BAHA conditions on twenty one SSD subjects. Results reveal mean improvement of 5.5 dB SPL (range, 2.0-11.0 dB) over the unaided condition.

Christopher, Linstrom, Silverman and Guo-Pei (2009) studied efficacy of directionality setting in BAHA was tested on seven adult with SSD. The performance was measured using HINT across different directional modalities. Measures included unaided, directional BAHA and omnidirectional BAHA conditions after 1 month, 6 months and 12 months of BAHA use. The SNR results suggested that considerable amount of improvement in BAHA. More benefit was seen for the omnidirectional over directional microphone setting by 0.3 to 3.8dB.

Effectiveness of BAHA was also studied by Martin, Lowthe, Cooper, Holder, Irving, Reid and Proops (2010) in fifty-eight patients with SSD using discrimination task in the presence of directional noise. Results showed decreased scores on speech discrimination test when noise was towards BAHA side. Whereas there was bettered performance noted when noise was towards the side of the normal ear. But five (13%) of the BAHA patients didn't showed any benefit.

Similarly Van Wieringen, DeVoecht, Bosman and Wouters (2011) reported better performance of sentence recognition and self-report outcomes in six patients with SSD. However the results showed that patients with SSD performed mainly with their unaided ear, but use of BAHA elevated the head shadow effect. On self-report outcomes results were not significant between patients with SSD, with different degree of hearing loss in poorer ear.

Lisa, John and Dornhoffer (2012) studied efficiency of BAHA on 23 children with SSD. Pre implant mean HINT scores at speech-noise ratios of0, +5 and+10 dB were 42%, 76%and 95% respectively. Post implant mean HINT scores improved to mean speech-noise ratios of 82%, 97% and 99% at 0, 5 and 10 dB respectively.

Zeitler, Snapp, Telischi and Angeli (2012) again evaluated Signal to noise ratio (SNR) loss and word recognition test in the presence of noise through Quick SIN test in patients with SSD. Enhancement in speech-in-noise measures and decline in disability was noted in aided condition when compared with the unaided condition postoperatively. The same author, also reported that there was no performance difference postoperatively between subject with threshold less than 90dB and subjects with threshold above 90dB.

Overall previous research studies consistently suggest that there is overall improvement in speech perception in the presence of noise when BAHA was opted as a rehabilitative option for those individuals with single sided deafness.

2.2 Performance in localization task with BAHA:

Accurate localization ability is a challenging task in the individuals with SSD. As fitting of BAHA to poorer ear would help in improved binaural benefit, several sound localization acuity measurements have been carried out with various research methodology in individual with SSD.

Wazen, Soha, Ghossaini, Jaclyn, Spitzer, Mary and Kuller (2004) studied efficiency of BAHA in 20 SSD using localization measure. All subjects were implanted with a BAHA on the poorer hearing side. Localization measurement was performed using a specialized array of seven calibrated speakers at head level separated by 15^0. An error analysis matrix was generated to evaluate the confusions and degrees of separation of errors. Results indicated that accuracy of identification of speaker localization was poorer than 50% for 100% in both unaided and aided conditions. Errors were severe, i.e. more than 30 degrees of arc. Thereby it was concluded that BAHA did not result in improved performance on the localization task.

Successively Wazen, Ghossaini, Spitzer and Kuller (2005) tested localization performance in 12 subject with SSD and ten normal hearing subjects. Localization with and without BAHA was assessed using an array of 8 speakers at head level separated by 45 degrees. The average accuracy of speaker localization was 16% in the unaided condition but there is no improvement with BAHA use. Laterality judgments were poor than 43% in both aided and unaided conditions. Thus it was concluded that individuals with unilateral SNHL had poor sound localization and laterality judgment abilities that did not improve with BAHA use. This may be attributed to the fact that the BAHA supplies signals from an entire sound field to a normal cochlea in this indication, sound localization capability would not be expected to improve.

Saliba, Marc-Elie, Fouad and Tony (2011) evaluated 21 individuals in whom BAHA was implanted. Post-operative HINT and localization were conducted after 6 months of BAHA use. Sound localization was done with 10 speakers placed in a circle at 36^0 from each other. Pure tone stimuli of 500Hz and 3000Hz were presented randomly by one speaker at 65 dB sound pressure level (SPL) with duration of 250 ms. The results revealed no statistical difference between the conditions or between the frequencies used for the localization. When compared aided and unaided conditions, the authors did not note any significant improvement with the use of the BAHA.

Similarly Grantham, Ashmead, Haynes, Hornsby, Labadie and Ricketts (2012) studied horizontal localization in SSD adults using BAHA. They used a 33-loudspeaker array with angular separation of 5.6^0. Long duration of phrase was either

1250 msec (a male saying "Where am I coming from now?") or short duration phrase of 341 msec (the same male saying "Where?") were presented in both with and without the BAHA device. Overall root mean square error was computed for each condition. Contributions of random error and bias error to the overall error were also computed. Result indicated that there was considerable inters subject variability in all conditions. The SSD individual had significantly more amount of overall error when BAHA was on compare to when BAHA was off. In all condition response was significantly better for long duration signal compare to short duration. Overall results showed localization ability with BAHA enhanced in SSD conductive hearing loss as compare to adult SSD SNHL group in aided condition.

Battista, Mullins, Wiet, Sabin, Kim and Rauch (2013) evaluated the sound localization capabilities of 20 patients with SSD with either BAHA (BP100) or Trans Ear 380-HF bone-conduction hearing device respectively. Sound localization of a three second recorded sound with and without a devices were assessed using an array of seven speakers at head level separated by approximately 45 degrees. The results indicated mean accuracy of speaker localization was 24% and 26% for the aided condition using the BP100 and TransEar devices, respectively. The mean accuracy of laterality judgment was 59% and 69% for the aided condition using the BP100 and TransEar devices, respectively. Further there was no statistical difference in localization accuracy or laterality judgment between the two devices. Either of the device improved sound localization accuracy or laterality judgment ability in patients with SSD compared with performance in the unaided condition.

Sylvester, Gardner, Reilly, Rankin and Raine (2013) evaluated eighteen individuals with SSD pre and post-operative fitted with BAHA. Along with the other outcome measures aided and unaided measures of localization and discrimination were carried out in individuals with SSD. However, the results revealed no significant benefit in localization and discrimination post operatively.

2.3 Subjective rating scale on BAHA output:

BAHA requires surgical process; because titanium screw is getting fixed in the mastoid bone it stimulates the bone conduction pathway which is not a usual pathway for hearing. Therefore the involvement of the bone conduction pathway might change in the sound quality which affects the acceptance, benefit, satisfaction and quality of life. So several attempt were made to measure sound quality using different subjective rating scale.

Arunachalam, Kilby, Meikle, Davison and Johnson (2001) reported Glasgow Benefit Inventory (GBI) scores improved with BAHA were +31 for total benefit, +37 for general benefit, +24 for social benefit and +14 for physical benefit. Reason in improved performance with BAHA was attributed to the fact that less distortion, mainly in the frequency range above 1 kHz, which is the responsible for speech recognition.

Similar results were obtained on GBI by Dutt, McDermott, Jelbert, Reid and Proops (2002) and Hillary, Simon, Fred and David (2012) in the aspects of improved general wellbeing (patient benefit), improved the patient's state of health (quality of life) and efficacy of BAHA respectively.

Niparko et al. (2003) also suggested better satisfaction level with BAHA. There study comprised of data obtained from ten individuals with a pure tone average (PTA) >90 dB HL for the affected ear and normal hearing (PTA <25 dB HL) in the opposite ear. Subjective measures of rehabilitative benefit included in this study were the Abbreviated Profile of Hearing Aid Benefit (APHAB) and the Glasgow Hearing Aid Benefit Profile (GHABP). Results indicated that BAHA scores reached clinical significance for benefit in 3 of the 4 principal listening categories: reverberant conditions, background noise, and ease of communication. A non-clinically significant impact was noted for aversion to loud noise. GHABP data also revealed a variable range of reported experience, with mean scores suggesting greater subjective benefit with BAHA.

Similar study was done by Craig, Newman, Sharon, Sandridge, Lisa and Wodzisz (2008) all SSD individuals underwent unaided and aided BAHA testing. Self-report measures at 6 different post fitting intervals were measured. Results suggested that improved satisfaction level in a variety of situations. So they concluded with the use of BAHA reduces psychosocial consequences of SSD for the long-term. Hillary et al. (2010) also reported that significant improvements in self-reported disability postoperatively.

Christopher et al. (2009) reported an improvement in Abbreviated Profile of Hearing Aid Benefit (APHAB) and Single-Sided Deafness Questionnaire (SSD) score on 7 adults with SSD fitted with BAHA. Significant short- and long-term BAHA benefit was observed on both the profile in all aspect except evasiveness.

Martin et al. (2010) evaluated 58 consecutive patients that had a bone anchored hearing aid for single sided deafness. These individuals completed speech and spatial qualities of hearing questionnaire and the Glasgow Benefit Inventory (GBI). Conclusion from the study was no difference between the Speech and Spatial Qualities of hearing Scores in BAHA users and controls. Further the median Glasgow Benefit Inventory score was 11 in subject with BAHA. Results suggested that BAHA was most useful in small groups or in 'one-to-one' conversation. However, patients with a longer duration of deafness report greater subjective benefit than those more recently deafened, could be due to differing expectations.

Van wieringen et al. (2011) reported about SSQ APHAB scoring in different categories of SSD based on degree of hearing loss in BAHA users. Patients with single-sided deafness performed better mainly with their unaided ear, but use of bone-anchored hearing aid elevated the head shadow effect.Self-report outcomes provided useful information on hearing disability, which was not significantly differently for the 3 groups of patients.

Saliba et al. (2011) evaluated 21 individuals with BAHA. Quality of life was assessed by the APHAB questionnaire. The score improvement is statistically significant for the global score, the background noise subscale at 5 weeks and for the reverberation subscale at 6 months.

Zeitler et al. (2012) evaluated pre and postoperative subjective benefits in patients with SSD using Glasgow Hearing Aid Benefit Profile (GHABP). Variable results were obtained in subjective benefits GHABP results, but better score was obtained by patients with residual hearing in the affected ear leads improved satisfaction with their device postoperatively.

Irumee, Kelleher, Catherine, Terry, Nidhi, Mudit, Alec, O'Connor., Alec, and Jiang (2012) compared pre-postoperative performance of BAHA in 25adult patients with SSD through SSQ. There was a statistically significant improvement in the average SSQ score in all three sections of the questionnaire with the use of the BAHA. Patients experienced most marked benefits in speech hearing in challenging listening situations. All patients remain consistent users and there has been no report of explanation. The bone-anchored hearing aid (BAHA) system can offer significant benefits to patients with single-sided deafness (SSD), primarily by lifting the head shadow effect.

Lisa et al. (2012) also reported improved child and parent satisfaction using BAHA in 3 subjects with SSD on Children's Home Inventory for Listening Difficulties (CHILD) questionnaire.

Doshi and Banga (2013) reported on eight children (4 boys and 4 girls) who had BAHA surgery for single-sided sensorineural deafness. Glasgow Children's Benefit Inventory (GCBI), single-sided deafness (SSQ) Questionnaire and change in health benefit scores (visual analogue scale) were measured. All children showed a positive GCBI score but one of the child that reported a negative score was because of low self confidence and self-esteem issues secondary to bullying at school. The results of the SSD questionnaire were generally positive with a mean satisfaction score of the BAHD as 9/10. All the children had an improvement in heath benefit.

Overall the research indicates that there is an improvement in their quality of life in various parameters of subjective rating task on their daily listening situations with BAHA for those individuals with SSD.

2.3 Performance with low frequency attenuation in BAHA:

Generalized data is available in literature for the speech perception in noise, localization and subjective benefit. But there are lot of disparities in terms of the population studied, method used and the results obtained. To investigate the different setting related change in the performance, Pfiffner et al. (2011) conducted study with low frequency attenuation of BAHA in users with single-sided sensorineural deafness (SSD) and concluded that high cut-off levels of up to 1500 Hz for low-frequency sound doesn't leads to deterioration in the BAHA performance, when noise presented from the front and speech was presented on the side of the BAHA. Detrimental effect on speech understanding can be reduced when noise is presented from the side of the BAHA by higher cut-off frequencies but the problem with study was it uses a speech babble masker which is not as effective as speech noise and also target signal was sentence which is more redundant than word especially in case of the adults. This study was done as an extension of work done by Pfiffner et al. (2011) with the same test like speech perception in noise using SNR-50 method, subjective rating scale but with use of word and speech shaped masker and in addition to that horizontal localization test.

CHAPTER-III

METHOD

All the experimental conditions were performed on participants with single sided deafness (evaluated at department of Audiology, All India Institute of Speech and Hearing) and participated in the study on their own willingness.

3.1 Participants:-

A total of fifteen individuals with SSD were participated in the current study ten participants had post-lingual acquired profound hearing loss in left ear and 5 were having post lingual profound hearing loss in the right ear. Onset of hearing loss was post-lingual for all participants, thus having adequate speech and language. Age range of the participants selected was from 15 to 40 years. All the participants were oriented about the study and written consent was taken regarding their willingness to participate in the study. The participants were selected if they had

- Unilateral hearing loss in one ear (> 90 dB HL) and other ear should be hearing within normal limit (<20 dB HL) with the average of 4 frequency in audiogram.
- First language/ Native language being Kannada language (Language that has been spoken majorly in one of the province in southern part of INDIA).
- Correlation of Speech Recognition Threshold with Pure Tone Average threshold being within ±12 dB.
- Speech identification score using phonetically balanced words should be above 90% in better ear.

- No indication of middle ear pathology in both ears on immittance evaluation at the time of evaluation and study.
- No illness on the day of testing.
- No history of neurologic/ cognitive/psychological problems.
- All the participants were nave to use BAHA and were not had any previous experience with BAHA.

3.2 Test material:

3.2.1 Speech Perception in Noise:-

A list of Kannada bi-syllabic words developed by Saghal (2005) was used to find out the SNR 50. The list has 3 set of 40 words and each set had bi-syllabic words with a combination of low-mid, low-high and high-mid frequency bi syllabic words. Speech noise was used as a background noise for the measurement of speech identification in noise.

3.2.2 Horizontal plane localization:-

Train of white noise pulses with duration of 200 ms separated by 200 ms of silence (Tyler, Parkinson, Wilson, Witt, Preece, & Noble, 2002) were generated for the purpose of localization task. Five sets of stimulus were generated to test five conditions, in which each set consist of 24 train of white noise pulses. Stimulus was generated using Adobe Audition 3.0 software. Each stimulus was randomly assigned for different loudspeaker such that there are 3 stimulus presented per speaker randomly presented randomly. The sound processor of the BAHA was attached to the headband that could be used for evaluation of performance pre-surgical implantation.

3.3 Testing Environment:-

All tests were carried out in a sound treated two room situation. Ambient noise levels in the test rooms were as per the standards of ANSI S3.1 (1999) with adequate illumination.

3.4 Instrumentation:-

- A Calibrated MA -53 dual channel sound field audiometer having 2 calibrated MA -53 loudspeakers were used for obtaining SNR-50 which were placed on 45^0 of each side of the individual.
- A calibrated GSI-Tymp Star Middle Ear Analyzer (Version 2) to evaluate the middle ear pathology.
- The sound processor of BAHA was attached to the soft band that could be used for evaluation of performance of pre-surgical implantation used in all testing conditions.
- Personal computer having Intel(R) core (TM) i7 processor, RAM of 2.00GB and 32 bit operating system was installed with NOAH/ cochlear nucleus programming module along with HIPRO interference was used to program BAHA BP100. Specific BAHA cable was used to connect the BAHA to the programming interface, the HI-PRO.
- Another personal computer having a Intel(R) Xeon(R)processor ,RAM 8GB and 64 bit operating system was installed with Cubase 6 software and three Aurora audio signal workstations was used for sound localisation task. Two Aurora 16 and one Aurora 8 AD/DA converters were used to route the noise bursts through Cubase 6 software.
- Eight loudspeakers (Genelec 8020B) mounted on Iso-Pod^{TM}(Isolation position/decoupler^{TM}) vibration insulating table stand were used for

localization task. All the loudspeakers were mounted at ear level and arranged in a circle at eight different angles 0^0, 45^0, 90^0, 135^0, 180^0 225^0, 270^0, and 315^0 with reference to nasion. The radius of the circle was 1 meter from the centre of the subject seating position to avoid multiple reflections from the walls of test chamber.

- Laptop installed with PRAAT and ADOBE AUDITION (version 3.0) was used to record the response from BAHA for in objective verification procedure.

3.5 Calibration of the instrumentation

All the equipment and instrument in used the study were calibrated accordingly of described below-

3.5.1 Speech Perception in Noise test: -

Calibration of the dual channel MA 53 audiometer was performed using Larson-Davis system 824 (model no. 2540) sound level meter (SLM). Sound pressure levels in 1/3 octave spectrum analysis was used to determine the output from Maico loud speakers (supplied along with MA 53 audiometer) and the input signals were live speech (Phonation of /a/ at comfortable level) and speech noise at a level of 65 dB attenuator setting.

Complete calibration procedures were carried out in double room setup and the loudspeakers were placed at $\pm45^0$. For calibration SLM was kept at one meter distance from loudspeaker. The height of the SLM from the floor was adjusted such that it approximated to the participants head centre during sitting position. Live speech material (Phonation of /a/) was presented at a comfortable level and the peak SPL was noted in SLM. Reference equivalent threshold SPL values for loud speakers with reference to 45^0 were used to adjust the attenuator in audiometer according to SLM readings. Instrumental calibration was performed such that the attenuator readings are displayed according to the values shown by the SLM. Similar procedure was repeated to calibrate speech noise levels.

3.5.2 Horizontal sound localization setup:-

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

White noise stimulus generated using Adobe Audition 3.0 on the computer was routed through the speakers and the output of each loudspeaker was calibrated using a Larson-Davis system 824 (model no. 2540) SLM placed at centre with a ½ inch free-field microphone. The microphone of the sound level meter with preamplifier was placed at a position corresponding to the centre of the head and at a height of one meter Sound pressure readings were taken by presenting the noise burst stimuli for 30 second long duration through each one loudspeaker at once. The intensity levels were varied by adjusting the sound output levels in the Cubase 6 such that the readings of SLM show 60dBSPL.

3.6 Determining the cut off frequency gain values BP100:-

Prior to the testing with BAHA minimum gain values at three different cut-off frequencies (250Hz, 750Hz & 1500Hz) in the programming software were determined. The minimum gain values were the gain settings in the programming software at which the output sound pressures levels measured through artificial mastoid (Type 4191, Bruel & Kjær) were same as the sound pressure levels presented in the sound field.

A calibrated MEDSON ITERA dual channel sound field audiometer having with one calibrated ITERA loudspeakers were used. Loudspeaker was placed at $+45^0$ on side of the BAHA device. Distance between loudspeaker and BAHA was maintained at one meter.

The BAHA was connected to a personal computer through HI-PRO interface with specific BAHA cable. Cochlear BAHA fitting software 2.0 versions was used to program and to manipulate the gain setting in BAHA device under all circumstances. Test band was used to couple BAHA with artificial mastoid and tightness of test band was adjusted such that instrument movements and squalling sound was minimised.

Artificial mastoid (Type 4191, Bruel & Kjær) was connected to the SLM (Larson-Davis system 824, model no. 2540) device to monitor the response from BAHA. The output from SLM was connected to a laptop installed with PRAT software to record the response. Additional feature such as directionality as omnidirectional microphone, noise reduction algorithm was deactivated and feedback cancellation and position compensation were on.

BAHA along with headband was fixed on the artificial mastoid for all conditions. Warble tone with frequencies of 250, 750 and 1500 Hz, respectively, was presented through a loudspeaker at 60dBHL. SLM recordings were measured and compared to input sound level such that there is no gain at 60dBHL.

The instrumentation used to determine the gain values is depicted in figure 2.1 and output before and after reduction gain reduction at three different cut-off frequencies is depicted in figure 2.2.

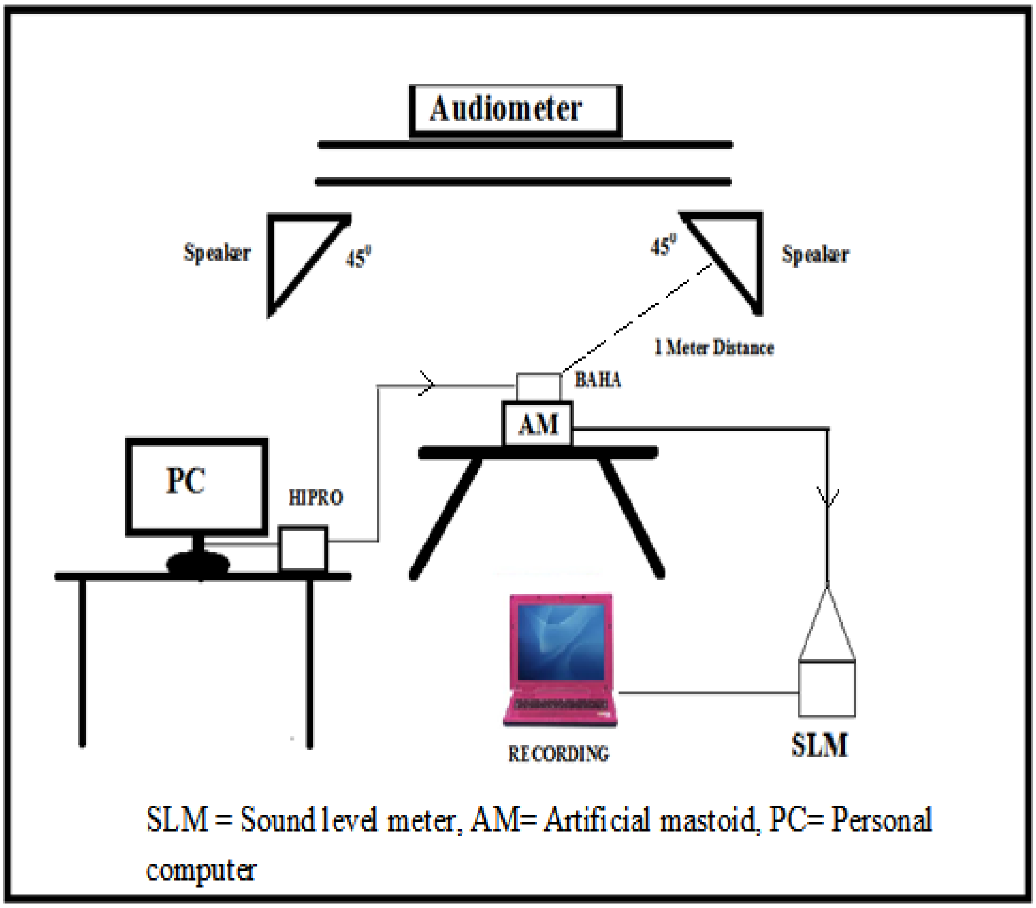


Figure 2.1 Illustration of instrumentation of output verification of BAHA.

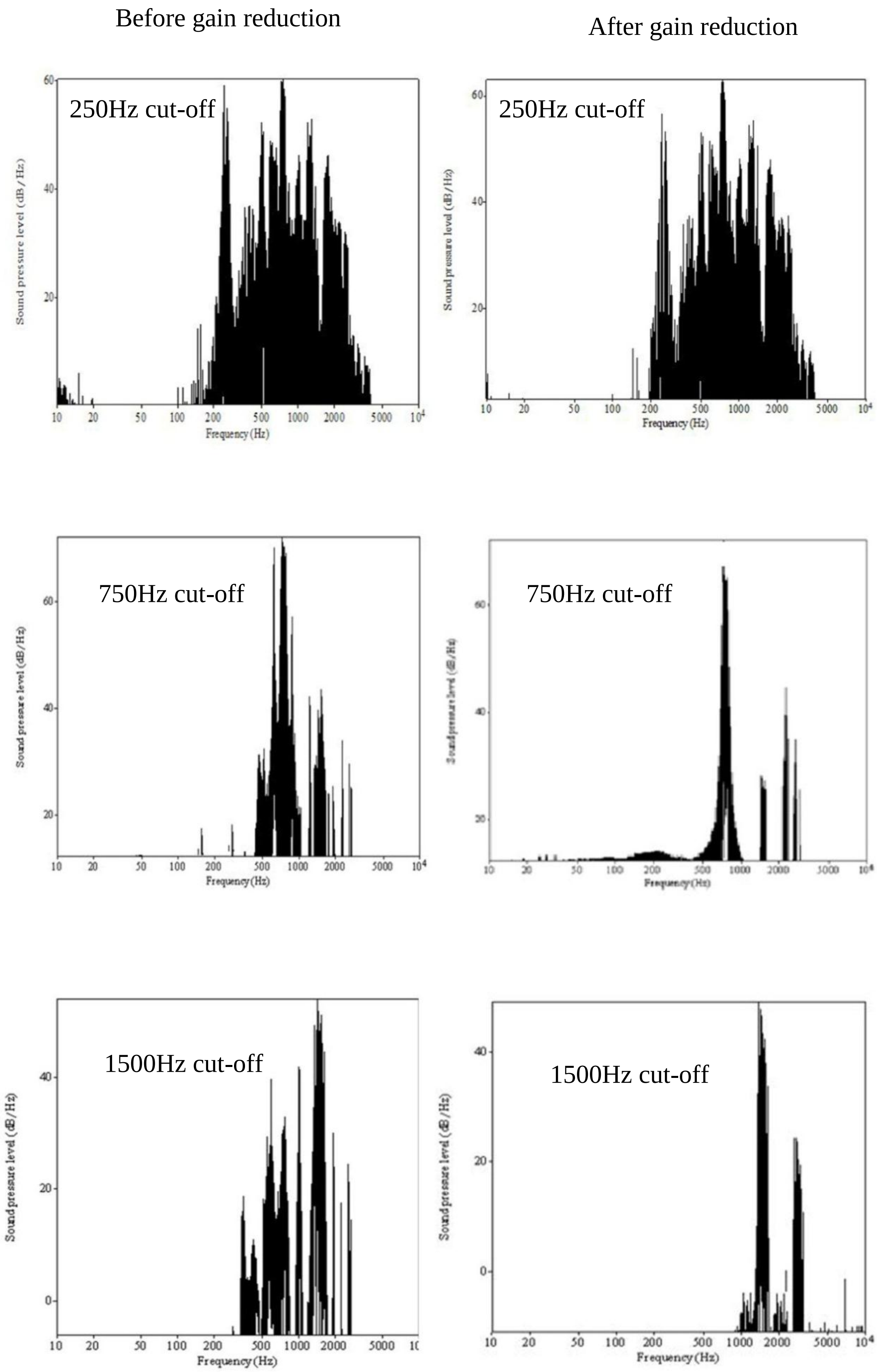


Figure 2.2 Illustration of output before and after gain reduction at three different cut-off frequencies.

3.7 Procedure:-

Participants were selected based on the participant selection criteria and on willingness to participate. Cases were taken from the Department of Audiology who were diagnosed as having unilateral profound hearing loss in the one ear and normal hearing sensitivity in other ear**.**

3.7.1 Programming and / or optimizing the digitally programmable BAHA.

The BAHA was fitted to subject during programming through test band. The digitally programmable BAHA was connected to the HI-PRO, using specific BAHA cable. The HI-PRO was in turn connected to the personal computer having the BAHA specific fitting software. Initially BAHA was programmed based on the audiometric thresholds and cochlear BAHA prescriptive fitting formula. BAHA was programmed for overall gain condition in which the gain values were increased or decreased to the point where the feedback was not reported.

For three different low frequency cut-off condition the attenuation or reduction in gain was tuned up to the point which was obtained through objective verification but the gain values above cut-off were maintained to the target gain curve where no feedback was reported by participant but in case of acoustic feedback problem gain was reduced at high frequency to such an extent that no acoustic feedback.

3.7.2 Audiological measures:-

The following tests were carried out for each participant:-

3.7.2.1 Speech perception in noise, signal to noise Ratio required for the 50 % correct repetition of the Kannada words (SNR-50).

3.7.2.2 Horizontal Localization task

3.7.2.3 Quality assessment of speech using rating scale

3.7.2.1 Speech Perception in Noise: SNR-50 values were determined under following condition

1) Unaided

2) Aided response

   a) Without low frequency attenuation

   b) Low frequency attenuation at and below 250 Hz

   c) Low frequency attenuation at and below 750 Hz

   d) Low frequency attenuation at and below 1500Hz

Speech perception in noise was obtained in unaided and aided condition under the following conditions (depicted in figure2.3):

i) Speech stimulus presented to the poorer ear side and speech noise from better ear side (Indirect condition).

ii) Speech stimulus presented to the normal hearing ear side and speech noise presented to the poorer ear side (Direct condition).

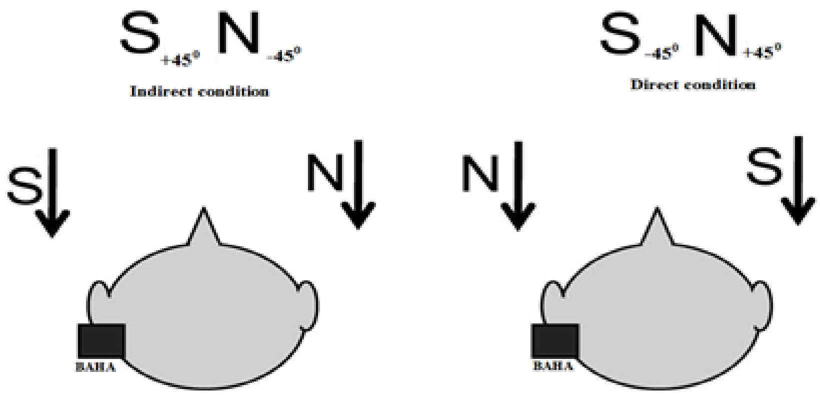


Figure 2.3 Illustration of mode of presentation used in SNR-50 i.e. indirect vs. direct condition.

For the purpose of the study, signal to noise ratio (SNR-50) is defined as the difference between the intensity of speech and the intensity of the competing speech noise in dB when the individual correctly repeats at least two words in a set of three words being presented in the presence of competing speech noise.

In current study SNR-50 was measured in a sound-field condition using the Kannada word list (developed by Sahgal, 2005) and procedure used by to obtain SNR-50 was similar use by Hawkins and Yacullo (1984). The speech material was presented lively through the audiometer to the loud speaker located at one meter distance from the participant at $\pm45^0$ azimuth. The presentation level of the speech material was constant at 45 dB HL through the testing. The speech noise was presented at an intensity 15 dB lower than the speech presentation level initially and manipulated systematically.

The participants were instructed to repeat the words heard in the presence of the competing speech noise. The participants were presented a set of three words at each level of noise. If the participant repeated at least 2 words out of 3 words correctly, then the level of noise was increased by 5dB initially. If not the level of noise was decreased in 10 dB steps. After 3 to 4 reversals the step size was decreased to 2 dB for increment or 4 dB for decrement. This was continued to obtain the highest level of speech noise that was enough for the participant to repeat at least 2 out of 3 words and it was continued until 4 to 5 reversals were obtained. The final signal to noise ratio difference were used in determining the SNR50 ratio for 50% correct performance.

Procedure was carried out in the order of unaided condition followed by overall gain setting followed by 250 Hz cut-off setting, followed by 750 Hz cut-off setting and then for 1500Hz cut-off setting.

3.7.2.2 Horizontal localization task:-

The participant was seated in the centre of surrounded by eight loudspeakers. Train of white noise burst were routed in random order. Three set of noise burst were used. Each set of stimuli consisting of 8 similar trains of white noise burst. Each train of white noise were consisted of a four burst of white noise.

The stimuli were presented at 60dBSPL. During the test, the participants were instructed to maintain the designated position/orientation of the head. The participants were instructed to point out speaker position from which they heard noise stimulus. The location of the loudspeaker to which participants pointed was noted down in terms of azimuth. Feedback was not provided during data acquisition under any conditions.

For the purpose of the study, Degree of error (DOE) was measured for the localization task. Degree of error corresponds to the difference in degrees between the degrees of azimuth of the loudspeaker of actual presentation of the stimuli, to the degree of azimuth of the loudspeaker identified as the source of the stimulus by the participant.

3.7.2.3 Subjective rating scale: -

Subjective rating scale were used to determine the quality of sound in different condition and it was adopted from Pfiffner et al. (2011), in which each subject was asked to rate output using 11 point (that was vary from +5 to -5) where the -5 is the lowest score and +5 is highest score. Parameters of scale were:-

1. Brightness
2. Softness
3. Clarity
4. Reverberation
5. Fullness
6. Loudness

The subjective rating scale was administered with BAHA with overall gain setting and with two extreme cut-off frequencies i.e. 250 and 1500Hz.

CHAPTER IV

RESULTS AND DISCUSSION

The present study aimed to evaluate benefit of low frequency attenuation in pre-implantable BAHA in individuals with single-sided deafness. The specific objectives were to evaluate the effect of the low frequency attenuation in pre-implantable BAHA on speech perception in noise, horizontal plane localization and subjective rating scale. For each participant speech perception in noise, horizontal localization and subjective rating scale were administered using different conditions. Conditions were coded as either unaided (UA), without low frequency attenuation (WA) and with low frequency attenuation at different high pass cut-off frequencies i.e. 250Hz cut-off (LA250), 750Hz cut-off (LA750) and 1500Hz cut-off (LA1500) condition. Data obtained through different experiments was analysed using the SPSS software (Version 17). The results were discussed under speech perception in noise, localization and subjective rating scale separately.

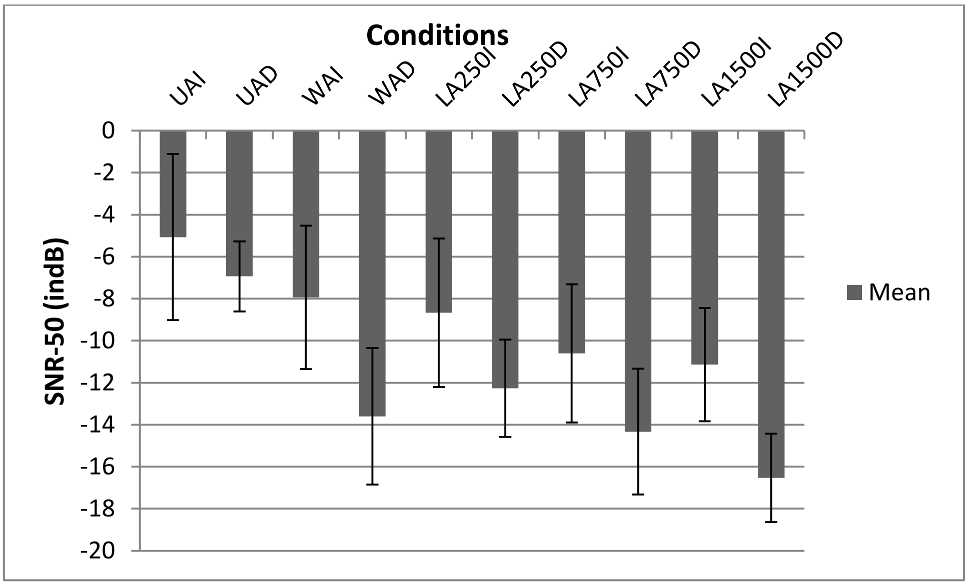
4.1: Speech perception in noise:-

For statistical analysis for speech perception in noise (SNR-50) was computed across different conditions as difference between signal level (maintained at 45dB HL) and noise level at which 50% of spoken words were repeated. In each condition there were two mode of presentations i.e. indirect mode (I) and direct mode (D). All 15 participants' data were grouped for the analysis. Mean and standard deviation of SNR-50 for unaided (UA), without low frequency attenuation (WA) and with low frequency attenuation (LA250, LA750 and LA1500) were obtained in the two mode of presentations (I & D). These values decimated to two values and were shown in the Table 4.1.

Table 4.1 *Mean and Standard deviation of SNR-50 obtained across different condition*

Statistical measures	**Conditions**									
	UA		**WA**		**LA250 Hz**		**LA 750 Hz**		**LA1500 Hz**	
	I	**D**	**I**	**D**	**I**	**D**	**I**	**D**	**I**	**D**
Mean(dB)	-5.06	-6.93	-7.93	-13.6	-8.67	-12.27	-10.6	-14.33	-11.13	-16.53
Standard Deviation	3.95	1.67	3.41	3.24	3.54	2.31	3.29	2.99	2.69	2.09

Note: I = Indirect condition; D = Direct condition.



Graph 4.1 Mean and Standard deviation of SNR obtained across different conditions and mode of presentations.

From table 4.1, it can be noted that mean SNR-50 thresholds obtained among the mode of presentation across different conditions were lower in direct stimulus presentation. This indicates that when speech stimulus is presented to the normal ear and noise to the poorer ear of SSD, higher noise values were tolerable to maintain 50% speech understanding.

It can also be observed that the SNR-50 values were lowered as the high pass cut-off frequency increased from 250Hz to 1500Hz, indicating that higher amounts of noise levels were tolerated by SSD participants as low frequency attenuation increased. Further analysis was carried to explore significant difference across conditions and mode of presentations.

4.1.1: Comparison of SNR-50 across conditions and modes of presentation:-

Two way repeated measures ANOVA (5 conditions × 2 modes of presentation) was carried out to find significant difference in the SNR-50 obtained across five different conditions. The result showed a significant difference across the conditions [F (4, 56) = 40.201, p = 0.004] and in two mode of presentation [F (1, 14) = 148.476, p = 0.00]. Further analysis revealed significant interaction between conditions and two mode of presentations [F (1, 14) = 148.476, p = 0.000; F (4, 56) = 3.937, p = 0.004]. Post hoc analysis was performed using Boneferroni multiple pair wise comparison to see the pairwise significant difference across conditions irrespective of mode of stimulus presentation. Results were tabulated in table 4.2.

Table 4.2 *Pair wise comparisons across conditions*

Conditions	UA	WA	LA250Hz	LA750Hz	LA1500Hz
UA	--	SD (p=.000)	SD (p=.000)	SD (p=.000)	SD (p=.000)
WA	SD (p=.000)	--	NSD	NSD	SD (p=.001)
LA250 Hz	SD (p=.000)	NSD	--	NSD	SD (p=.000)
LA750 Hz	SD (p=.000)	NSD	NSD	--	NSD
LA1500 Hz	SD (p=.000)	SD (p=.001)	SD (p=.000)	NSD	--

Note: SD: Significant difference, NSD: No significant difference (P> 0.005).

Pair wise comparison shows that unaided (UA) SNR-50 scores were significantly different from aided conditions (with and without low frequency attenuation), indicating that better speech perception skills in increased background noises with BAHA. Among aided conditions there was no significant difference observed without low frequency attenuation and with low frequency attenuation up to 750Hz. Low frequency attenuation below 1500Hz was significantly different from other aided conditions revealing that low frequency attenuation is most useful if the high pass cut off frequency is at 1500Hz among the tested conditions. But there was no significant difference observed in SNR-50 values obtained with low frequency attenuation at 750Hz and at 1500Hz.

The above results reveal that as the low frequency attenuation increased the amount of energy reaching better cochlea through BAHA stimulation is reduced leading to lesser masking affect. Thus, improving the speech understanding in presence of back ground noise.

4.1.2: Performance across conditions through indirect mode of presentation:

One way repeated measures ANOVA was performed to note significant difference between indirect modes of presentation across the conditions. The results revealed that there was a significant difference [F (4, 56) = 10.896, p= .000] between indirect mode of presentation across conditions. Boneferroni multiple pair wise comparison was carried out for indirect mode of presentation across conditions, and the results were as given in the table 4.3.

Table 4.3 *Pair wise comparison of SNR-50 obtained for indirect mode of presentation across conditions*

Conditions	**UAI**	**WAI**	**LA250HzI**	**LA750HzI**	**LA1500HzI**
UAI	--	SD (p=.015)	NSD	SD (p=.003)	SD (p=.001)
WAI	SD (p=.015)	--	NSD	NSD	SD (p=.014)
LA250 Hz I	NSD	NSD	--	NSD	NSD
LA750 Hz I	SD (p=.003)	NSD	NSD	--	NSD
LA1500 Hz I	SD (p=.001)	SD (p=.014)	NSD	NSD	--

Note: *SD: Significant difference, NSD: No significant difference.*

Results indicated that unaided and aided low frequency attenuation at 250Hz was significantly different from other aided conditions. Also, performance of low frequency attenuation at 1500Hz was significantly different from unaided and without low frequency attenuated conditions. Across aided conditions performance in without attenuation condition was significantly different from only 1500Hz high pass cut-off frequency.

4.1.3: Performance across conditions through direct mode of presentation:

Repeated measures ANOVA was done to see the significant difference between the direct modes of presentation across the conditions. Results showed shows that there was a significant difference [F (4, 56) = 63.503, p=0.000] between direct mode of presentation across conditions.

Table 4.4 *Pair wise comparison for direct mode of presentation across conditions*

Mode	UAD	WAD	LA250HzD	LA750HzD	LA1500HzD
UAD	--	SD (p= .000)	SD (p= .000)	SD (p= .000)	SD (p= .000)
LWAD	SD (p= .000)	--	NSD	NSD	SD (p= .001)
LA250 HzD	SD (p= .000)	NSD	--	SD (p= .004)	SD (p= .000)
LA750 HzD	SD (p= .000)	NSD	SD (p= .004)	--	SD (p= .004)
LA1500 HzD	SD (p= .000)	SD (p= .001)	SD (p= .000)	SD (p= .004)	--

Note: - SD: - significant difference, NSD: - no significant difference.

Form the table 4.4 it can be observed that in the direct mode of presentation unaided is significantly different from all other aided condition (with and without low frequency attenuation). There were no significant differences in the performance till the high pass cut-off frequency below 1500Hz and without low frequency attenuation. Only low frequency attenuation below 1500Hz resulted in significantly lower SNR-50 values than other tested conditions.

In conclusion when the speech stimulus was presented on the normal hearing ear side and speech noise from the poorer ear side, only low frequencies attenuated below 1500Hz would yield significantly differences in the performance.

4.1.4: Performance between modes of presentation in different conditions:

Simple paired t-test was carried out between modes of presentation under each condition to note any significant difference between modes of presentation. Statistical t-values and p-values were given in table 4.5.

Table 4.5 *Levels of significant difference between two modes of presentation within each condition*

Statistical measure	Conditions				
	UA	**WA**	**LA250 Hz**	**LA 750 Hz**	**LA1500 Hz**
t- values	2.101	10.319	4.054	4.346	9.121
P- values	0.054	.000*	.001*	.001*	.000*

*Note: * indicate the measures were significantly different at p<0.005.*

Results from paired t test (table 4.5) indicated that in unaided condition there was no significant different between both modes of presentation, whereas with BAHA across conditions there is significant difference. These findings indicate that while testing with BAHA the mode of presentation contributes significantly.

From table 4.1 & 4.5, it could be easily understood that better speech perception was noted in direct mode i.e. when signal is presented to better ear and speech noise to the BAHA ear. In aided condition the mean difference between modes of presentation was same when the conditions were without attenuation (difference in mean = 5.67dB) and with attenuation below 1500Hz (difference in mean = 5.4dB), whereas for low frequency attenuation with 250Hz and 750 Hz showed improvement only 3.6dB and 3.76dB successively (difference in mean values were given).

4.1.5 Speech performance with low frequency attenuation in BAHA:

To conclude the result of speech perception in noise, the present study reveal that there is an improvement in the speech perception ability in the presence of noise as the high pass cut-off frequency increases till up to 1500Hz. Secondly better speech perception score were noted when the speech signal was presented towards the better ear/ normal ear rather than speech presented to ear fitted with BAHA.

Similar results were reported by Pfiffner et al. (2011) regarding improvement in term of SNR by 2.8 - 3.1dB when the noise was presented from 0^0 and speech presented to 90^0 to BAHA side but deterioration in the performance were seen in S_0N_{90} condition. But Pfiffner et al. (2011) reported no difference across three cut-off frequencies used.

In the present study the lowest SNR-50 were noted up to even -20 dB SNR in the direct condition. This may be attributed to fact that masking effect of speech noise was reduced when presented to the poorer ear/ BAHA ear. The SNR-50 values obtained without low frequency attenuation with BAHA and speech perception without BAHA were in well correlation with previous research findings.

The present study reveal higher mean values -13.60dB to -16.53dB in direct mode of presentation and low frequencies attenuated up to 1500 Hz. Similar observations of improved speech perception in direct mode of presentation was reported by(Bosman et al., 2003; Hol, Bosman, Snik, Mylanus, & Cremers, 2004, 2005; Linstrom et al.,2009; Dumper, Hodgett, & Liu, 2009). But this improvement was typically only -0.7 to -2.5 dB in S_0N_{90} setting as there was no attenuation measures performed. Study by Lisa et al. (2012) reveal significant high improvement in speech perception using HINT and the score improved by 69 to 93% after post implant of BAHA at 0 dB SNR.

4.2. Horizontal plane localization:-

The responses from the localisation experiments were used to calculate root mean square degree of error (rms DOE). These rms DOE were used for further statistical analysis. As there were three stimuli presented from each speaker, error in localisation in calculated based on the responses of the participants and the three errors at each speaker (degree of stimulus presentation) were averaged. Right and left ear rms DOE were computed separately for all participants. While calculation of right ear rms DOE responses obtained from 0^0 to 135^0 (constituting 4 azimuths) were considered. Similarly for left ear rms DOE responses from 180^0 to 315^0 were considered. The following formula was used to compute rms DOE for each ear separately. Similar formula were used to compute rms DOE by Ching, Incerti and Hill (2004).

$$\text{rms DOE} = \sqrt{\frac{(DOE_1)^2 + (DOE_2)^2 + (DOE_3)^2 + (DOE_4)^2}{4}}$$

Where DOE_1; DOE4 are averaged degree of errors from first speaker to fourth speaker successively & rms DOE is root mean square degree of error.

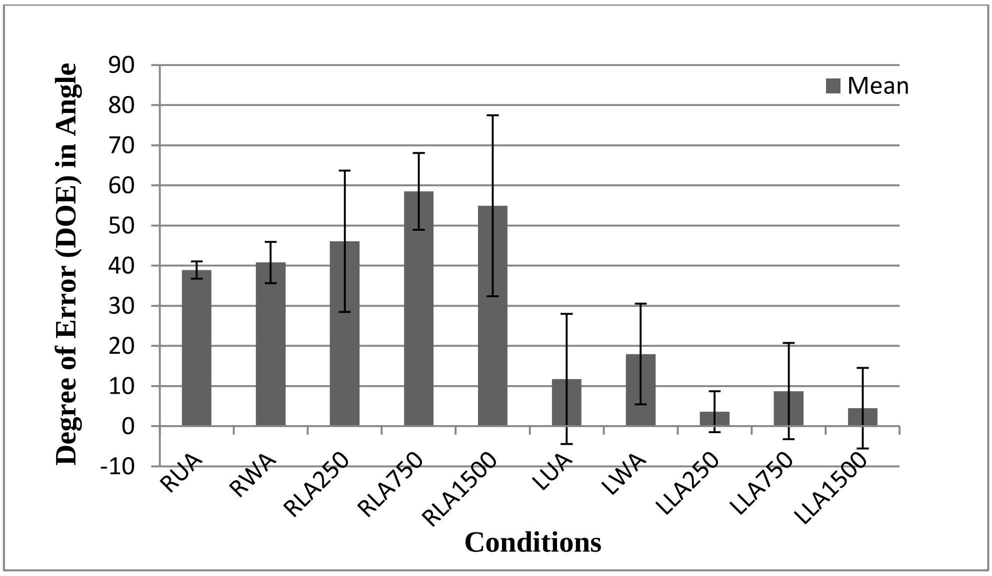
Overall the data obtained was divided into two groups based on poorer ear (right ear vs left ear). First group data consisted DOE of participants having right ear profound hearing loss (n=5) and second group had data from left ear profound hearing loss (n=10). The comparisons were made in each group between right ear vs. left ear rms DOE across unaided (UA) and without (WA) and with low frequency attenuation (LA250Hz, LA750Hz and LA1500Hz) using statistical analysis.

4.2.1: Localization performance in group I participants (Right ear unilateral hearing loss)

The data comprised of DOE values computed from five participants with right ear unilateral profound hearing loss. Basic statistics was carried out for DOE values separately for right and left ears across all the experimental conditions i.e. unaided, aided without and with low frequency attenuation (using three high pass cut-off frequencies). The results were as in Table 4.6.

Table 4.6 *Mean and Standard deviations (SD) of DOE for participants with right ear unilateral hearing loss across different conditions*

Statistical measure	Conditions									
	UA		WA		LA250 Hz		LA 750 Hz		LA1500 Hz	
	RE	LE	RE	LE	RE	LE	RE	LE	RE	LE
Mean(degree)	38.92	11.77	40.82	18.00	46.09	3.62	58.53	8.74	54.94	4.50
Standard Deviation	2.17	16.21	5.14	12.55	17.65	5.08	9.55	11.98	22.55	10.06
Median	38.97	0.00	40.39	15.00	38.24	0.00	57.61	0.00	49.18	0.00



Graph 4.2 Mean and Standard deviation (SD) of localization for left for both ears across different condition.

From graph 4.2, it can be observed that mean right ear DOE is more compared to left ear across conditions. These results indicate that though hearing loss was present in only right ear, some localisation errors noted on the normal hearing/ left ear side. These errors were less in magnitude but highly variable than the poorer ear side.

Thus nonparametric test (Friedman Test) was performed to see statistical difference across conditions and right ear vs. left ear performance. Results indicated that there was no significant difference across condition in right ear [χ^2 (4) = 7.510, p = 0.111] and left ear, [χ^2 (4) = 5.492, p = 0.240]. These findings signifies there is no improvement seen in localisation with BAHA, indeed the localisation errors were increased slightly with BAHA in both with and without low frequency attenuation. But there was a significant difference between overall the right ear scores and left ear is which is depicted in the table 4.7.

Table 4.7 *Levels of significance between right vs. left ears DOE for participants with right ear unilateral hearing loss across different conditions*

Statistical measure	**Conditions**				
	UA	**WA**	**LA250 Hz**	**LA 750 Hz**	**LA1500 Hz**
Z- values	-2.032	-2.032	-2.032	-2.032	-2.032
P- values	0.042*	0.042*	0.042*	0.042*	0.042*

**indicates significant difference was noted at p<0.05.*

From table 4.7, results show that there was a significant difference between right ear vs. left ear across all the conditions experimented. DOE values were higher for right ear as compare to left ear. These results notify that in participants with right ear profound hearing loss the errors were significantly higher on poorer ear side even with BAHA.

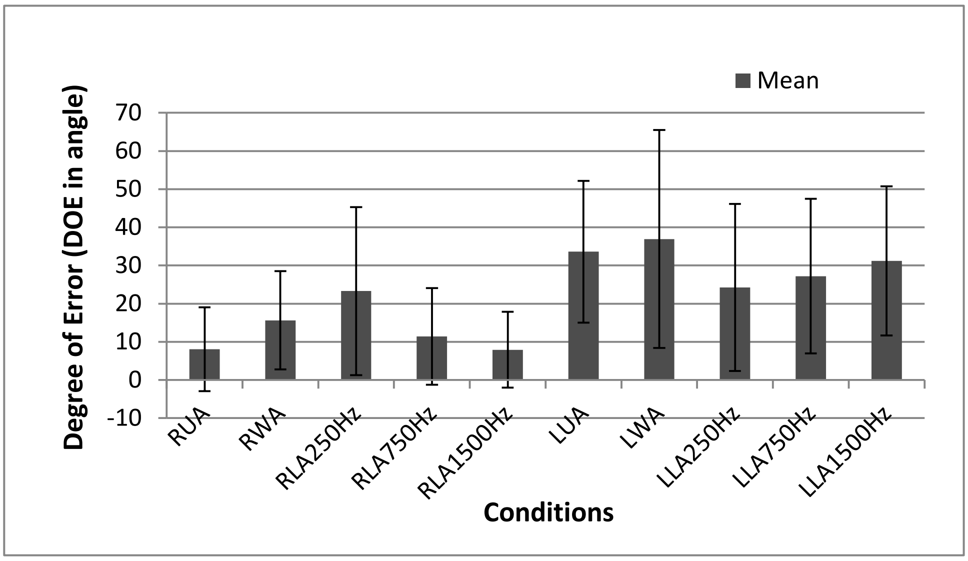
4.2.2: Localization performance in group II participants (Left ear unilateral hearing loss):

The data comprised of DOE values computed from ten participants with left ear unilateral profound hearing loss. Basic statistics was carried out for DOE values separately for right and left ears across all the experimental conditions i.e. unaided, aided without and with low frequency attenuation (using three high pass cut-off frequencies). The results were given in Table 4.8.

Table 4.8 *Mean and Standard deviation (SD) of right and left ears DOE for participants with left ear unilateral hearing loss across different conditions*

Statistical measure	Conditions									
	UA		WA		LA250 Hz		LA 750 Hz		LA1500 Hz	
	RE	LE	RE	LE	RE	LE	RE	LE	RE	LE
Mean (degree)	8.08	33.64	15.64	36.95	23.30	24.22	11.43	27.22	7.92	31.21
Standard Deviation	11.01	18.58	12.87	28.53	22.00	21.88	12.68	20.25	9.95	19.53
Median	0.00	36.96	18.11	35.89	19.63	23.04	7.50	29.87	3.75	29.03

From Table 4.8, it can be observed that mean of left ear DOE was high compared to right ear DOE across all the experimental conditions, revealing that high amounts of errors were noted towards the poorer ear/ BAHA ear. And also large standard deviation than average values indicates that the results were highly variable across participants. It can also be noted that across conditions there is less variance in DOE for both right and left ears. The graphical illustration of these results was given in graph 4.3.



Graph 4.3 Mean and Standard deviation (SD) of localization for left for both ears across different condition.

Further Friedman test was done to see statistical difference between DOE across all experimental conditions. Results indicated that there was no significant difference across condition in left ear DOE [χ^2 (4) = 8.022, p = 0.091], but there was a significant difference across conditions in the right ear DOE [χ^2 (4) = 11.944, p = 0.08]. These findings indicate that there are no significant differences in localisation task without and with BAHA when the signal was presented to the poorer ear.

Further Wilcoxon Signed Ranks Test was carried for pair wise comparison to note any significant difference across right ear DOE scores. Table 4.9, shows levels of significance obtained through Wilcoxon Signed Ranks Test for right ear DOE in group II participants.

Table 4.9 *Comparison of right ear DOE across different experimental conditions for participants with left sided profound hearing loss*

Condition	**Compared with**	**Z-values**	**P= values**
RUA	R WA	-1.47	0.141
	R LA250 Hz	-2.36	0.018*
	R LA 750 Hz	-1.63	0.102
	R LA1500 Hz	0.00	1.00
R WA	R LA250 Hz	-1.05	0.293
	R LA 750 Hz	-0.507	0.612
	R LA1500 Hz	-2.19	0.028*
R LA 250 Hz	R LA 750 Hz	-2.19	0.028*
	R LA1500 Hz	-2.20	0.027*
R LA 750 Hz	R LA1500 Hz	-0.94	0.345

**indicates significant difference at p<0.05*

The results showed significant difference between low frequency attenuation at 250Hz and other experimental conditions, indicating that if only lower than 250Hz cues are attenuated in BAHA would impair the localisation for the sound presented towards the better ear. Further no other significant differences were revealed from the paired comparison in the better ear localisation responses.

The results from nonparametric test (Friedman Test) also indicated significant difference between right and left ear's DOE in some experimental condition. These values were tabulated in 4.10.

Table 4.10 *Levels of significance between right vs. left ear's DOE for participants with left ear unilateral hearing loss across different condition*

Statistical measure	Conditions				
	UA	**WA**	**LA250 Hz**	**LA 750 Hz**	**LA1500 Hz**
Z- values	-2.429	-1.53	-0.059	-1.992	-2.547
P- values	0.015*	0.126	0.953	0.046*	0.011*

** indicates significant difference at p<0.05.*

In experimental conditions BAHA without low frequency attenuation and BAHA with 250Hz and below cut off frequencies showed there is no difference in right vs. left ear DOE. And in all the other conditions DOE values were higher for left ear as compare to right ear.

Overall the performance of participants with SSD on localisation task yield three most important results that

1. There are localisation errors in participants with SSD when the sound source located even on the side of normal hearing ear.
2. Apparently there is no improvement in the localization performance without and with BAHA.
3. No effect of low frequency attenuation in BAHA on the localization performance.
4. Localisation errors were highly variable across the participants with SSD.

Poorer localization of sounds in SSD subjects fitted with BAHA was also reported by Wazen et al. (2005). These authors attributed to the fact that the BAHA supplies signals from entire sound field to the normal cochlea. Thus only one cochlea receiving the whole spectral and temporal cues present in the sound field which is not a true binaural ability. Thus the sound localization task would not expect to improve with BAHA devices. Similarly Wazen et al. (2005) also stated that use of BAHA creates more confusion to individual with SSD as compare to unaided condition.

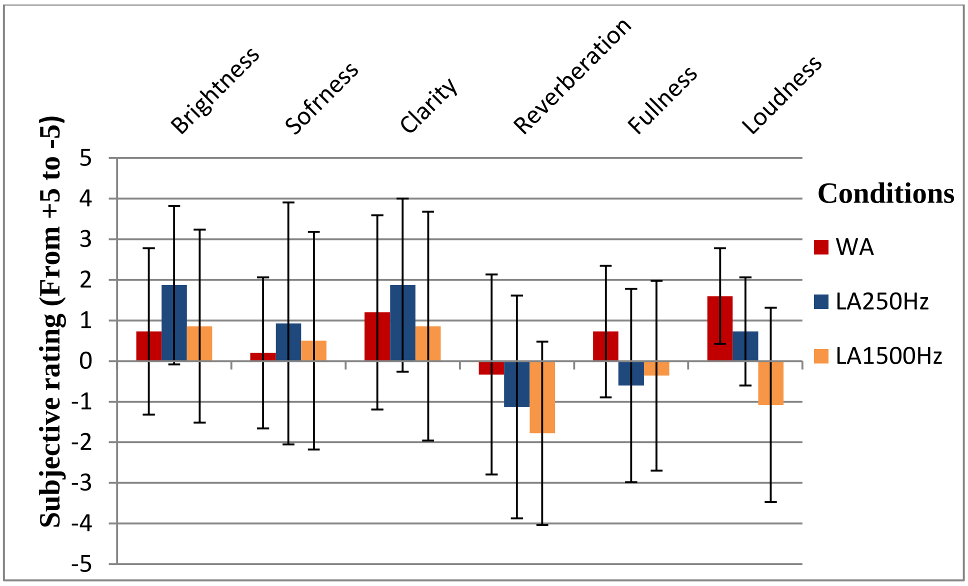
4.3: Subjective rating scale:-

The participants were asked to rate the sound quality of BAHA on six parameters using eleven point rating scale. The parameters included were Brightness, Softness, Clarity, Reverberation, Fullness and Loudness. Subjective rating scale was obtained in only three experimental conditions i.e. BAHA without low frequency attenuation, BAHA with low frequency attenuation below 250Hz and BAHA with low frequency attenuation below 1500Hz. Simple statistics of the subjective ratings across three experimental conditions and parameters were given in table 4.11.

Table 4.11 *Mean and Standard deviation (SD) of subjective rating scale for the quality of sound across three different conditions*

Conditions	**Statistical parameter**	**Subjective parameters**					
		Brig	**Soft**	**Clar**	**Reverb**	**Fulln**	**Loud**
WA	**Mean**	0.73	0.2	1.2	-0.33	0.73	1.6
	Std. Deviation	2.05	1.86	2.39	2.46	1.62	1.18
	Median	1	0	1	0	0	2
LA250Hz	**Mean**	1.87	0.93	1.87	-1.13	-0.6	0.73
	Std. Deviation	1.95	2.98	2.13	2.74	2.38	1.33
	Median	2	2	3	-1	0.0	.00
LA1500Hz	**Mean**	0.86	0.5	0.86	-1.78	-0.36	-1.08
	Std. Deviation	2.38	2.68	2.82	2.26	2.34	2.39
	Median	2	0.5	1.5	-0.5	0.0	-2

Note: *Brig: Brightness, Soft: Softness, Clar: Clarity, Reverb: reverberation, Fulln: Fullness, Loud: Loudness.*



Graph 4.4 Mean and standard deviation values across quality of sound in three different conditions.

Non parametric test (Friedman Test) was carried out to find out if there is a significant difference across experimental conditions.

The result of Friedman Tests indicated that there was a significant difference in loudness across conditions [χ^2 (2) = 8.652, p= .130]. There was no significant differences observed in parameters across conditions brightness; [χ^2 (2) = 2.711, p =0.258], softness; [χ^2 (2) = 1.574, p = 0.455], clarity; [χ^2 (2) = .360, p = 0.835], reverberation; [χ^2 (2) = 4.383, p = 0.111], fullness; [χ^2 (2) = 3.931, p 0.140]. These results suggest that there is no effect of low frequency attenuation in BAHA on subjective perception of sound quality except loudness is decreased.

Since there was significant difference between the across conditions in loudness Wilcoxon Signed Ranks Test was done to see which group has significant difference.

Table 4.12 *Shows levels of significance for loudness in each pair*

Statistical values	Loud 250 – loud WA	loud1500 – loud WA	loud1500 – loud 250
Z-values	-2.05	-2.85	-2.12
P- values	.040	.004	.033

Results from Wilcoxon Signed Ranks Test (table 4.12) reveal that there was a significant difference in loudness across all experimental conditions tested, indicating loudness decreases as the attenuation frequency increased from 250 Hz to 1500 Hz. Without low frequency attenuation the loudness was higher. This can be attributed to importance of low frequency in perception of loudness.

Overall results suggest that low frequency information only contributing to loudness of the sound not affecting to other quality of sound. This result is in agreement with that of reported by Pfiffner et al. (2011) where they reported that no significant difference between the ratings of the two BAHA settings that 270Hz and 1500Hz cut-off setting. However, reverberation and loudness are rated higher for the cut-off frequency of 270 Hz than for 1500 Hz. Thus attenuating low frequency information up to 1500Hz doesn't change the sound quality to great extent except loudness.

CHAPTER-V

SUMMARY AND CONCLUSION

BAHA provides promising results in rehabilitation of individuals with unilateral hearing loss/SSD mainly to improve speech recognition abilities (Niparko, Cox, & Lustig 2003; Snik et al., 2005; Hol, Kunst, Snik, & Cremers, 2010). But the device works on principle of bone conduction for transmitting information from implanted ear to better cochlea. Through BAHA amplification at low frequencies would lead to produce distortion due to lesser transcranial attenuation. Thus lower frequency attenuation could provide better speech understanding in the noisy background and also provide better sound quality. Hence the present study was conducted with the aim of examining the effect of the low frequency attenuation in pre-implantable BAHA on speech perception ability in the presence of noise, horizontal plane localization and subjective rating.

The results of the present study revealed that improvement on speech perception ability in the presence noise through SNR-50 indicating that individuals with SSD can tolerate more background noise levels with low frequency attenuation. The improvement was proportionate to the high pass cut-off frequency.

Further better performance on SNR-50 was noted when speech stimulus was presented from the normal ear side and speech noise to the poorer ear/ BAHA ear. In conclusion it is recommended that low frequency attenuation would benefit to the individuals with SSD up to 1500Hz, thus can be implemented programming/ fine tuning mainly for speech in background noise program.

From the localisation data of present study, it was noted that individuals with SSD would have auditory localization errors even when the stimulus is presented form normal hearing ear field. Thus a sample study on four individuals with normal hearing was conducted with the same localization instrumentation and procedure. However there were no errors in locating the auditory stimuli noted in individuals with normal hearing. Further there in no significant difference noted in localization abilities without and with BAHA as well as low frequency attenuation in individuals with SSD. Which suggest localization ability is still not resolved in individuals with SSD.

The results from subjective rating scale indicate that there are no deleterious effect on acoustic output quality with low frequency attenuation. But there was significant difference noted in loudness without on with low frequency attenuation, indicating that low frequency gain in the BAHA only adds loudness which is not required for the speech intelligibility.

Further after subjective rating scale each participant was asked for their preference across BAHA conditions (without and with low frequency attenuation at two high pass cut off frequencies 250Hz & 1500Hz). Nine participants of 15 preferred low frequency attenuation with 250Hz condition followed by 1500Hz conditions than without low frequency attenuation. Four participants preferred without low frequency attenuation setting and two participant preferred low frequency attenuation with cut-off 1500Hz conditions. As most of participants preferred low frequency attenuation of 250Hz it can be said that loudness is not changed significantly preserved while preserving the speech perception cues. Hence low frequency attenuation below and at 250Hz would be most appropriate option while programming BAHA.

Implications of the study:

The results of present study can be implemented in clinical setting while programming of BAHA in individuals with SSD. The implications of the present study are

1. Low frequency attenuation of 250Hz can be provided as additional program for speech in noise while initial fit/ reprogramming BAHA.
2. The results can be used to counsel patient with SSD about realistic expectation for localization.

Limitations of the study:

The few limitations noted during the study were as follows.

1) All the data acquired during the study was with test band as pre-operative testing thus results might not be applicable for post-operative directly.

2) Localization was studied with only eight speakers having separated by 450 from each, which could have been more precise by having more number of speakers.

3) Stimulus used for localization was white noise bursts, further frequency specific signals would have led to better conclusions about low frequency attenuation.

Future directions:-

Further exploration on effects of low frequency attenuation with BAHA could provide useful information to minimizing the physical dimension of BAHA unit by changing the receivers suitable for only high frequencies.

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Appendix – A (Word list for SNR-50)

Word list with a combination of low-mid, low-high and high-mid frequency speech sounds developed by Sahgal (2005)

	Low-Mid	Low-High	High-Mid
1	/gu:be/	/nalli/	/tʃa:ku/
2	/me:ke/	/sɛ:bu/	/ko:Li/
3	/bi:ga/	/mola/	/la:ri/
4	/mu:gu/	/bassu/	/d̪a:ra/
5	/rave/	/bal.e/	/kivi/
6	/kaNNu/	/d̪ana/	/tʃikka/
7	/ni:ru/	/tʃindi/	/i:ruLLi/
8	/mara/	/ni:vu/	/kuTTu/
9	/kone/	/mi:se/	/tʃakra/
10	/pu:ri/	/t̪inDi/	/dʒinke/
11	/bekku/	/haNa/	/radʒa/
12	/ganTe/	/suma/	/si:re/
13	/ru:pa/	/biLi/	/gaɳTe/
14	/nid̪re/	/tand̪e/	/kat̪t̪i:/
15	/kabbu/	/tʃenDu/	/giNi/
16	/magu/	/d̪o:Ni/	/vitʃa:ra/
17	/kappu/	/ʤi:pu/	/se:ru/
18	/bi:ru/	/To:pi/	/ko:ti/
19	/na:ri/	/bila/	/tʃikka/
20	/mu:ru/	/ba:vi/	/rutʃi/
21	/kemmu/	/ni:li/	/sukha/
22	/pad̪a/	/baTlu/	/i:ruLLi/
23	/ravi/	/d̪i:pa/	/kelasa/
24	/reppe/	/Dabbi/	/katte/
25	/buguri/	/hind̪e/	/kuLLi/
26	/kombe/	/ivanu/	/roTTi/
27	/ra:Ni/	/bi:dza/	/ko:su/
28	/ma:rga/	/baTTe/	/iruve/

29	/pennu/	/moLe/	/sari/
30	/gamana/	/t̪amma/	/guDi/
31	/rama/	/meTlu/	/geʤʤe/
32	/be:ru/	/beTTa/	/railu/
33	/maŋga/	/me:ʤu/	/rasa/
34	/guNa/	/ba:Le/	/ka:su/
35	/pa:naka/	/no:vu/	/ke:Lu/
36	/kappe/	/bassu/	/kelavu/
37	/nu:ru/	/ma:tre/	/tʃakli/
38	/gombe/	/noDu/	/kaDDi/
39	/ramja/	/haNNu/	/ka:fi/
40	/nuŋgu/	/beTTa/	/go:De/