Project Report

COMPARISON OF CONTRALATERAL ROUTING OF SIGNAL AND BONE ANCHORED HEARING AID IN INDIVIDUALS WITH UNILATERAL HEARING LOSS

A project carried out with Grants from AIISH Research Fund (ARF)

Principal Investigator

Mrs. Devi N.

Lecturer in Audiology

Co-Investigators

Dr.K. J. RamadeviSreenivas

Audiologist Grade 1

Mr.DargaBaba Fakruddin

Audiologist Grade 1

Research Officer

Ms. Suma Chatni

Department of Audiology

All India Institute of Speech and Hearing

Manasagangothri, Mysore-570006

Project funded by AIISH Research Fund (ARF)

Sanction Number:SH/CDN/ARF/4.13/2011-12

Total Grants: Rs. 3,26,000.00/-

Duration of the project:02.09.11 to 12.10.12

Acknowledgements

We would like to thank the Director, AIISH for permitting to conduct this research work and for providing the infrastructure. We thank the HOD – Audiology as well for giving permission to utilize the equipments in the department. We acknowledge the time and patience provided by all the participants during the data collection process.

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Abstract

Individuals with unilateral hearing loss of severe-profound degree with normal or near normal hearing sensitivity in the better ear can listen with ease in quiet environments or when the signal is directed towards the better ear. However, they face listening difficulties while localizing a sound source and while perceiving speech in the presence of noise.Hence, there is need for rehabilitation in such situations. So, the present study was taken up to compare the available rehabilitation options for 24 adults and 15 children with unilateral hearing loss and arrive at a probably appropriate rehabilitation device. The sound field thresholds, speech perception performance in quiet and noise (direct and indirect conditions) and the subjective quality rating of speech were assessed in unaided condition and aided condition, while the participants were aided with either T-CROS or digitally programmable BAHA or trimmer digital BAHA attached to the headband. From the results, it was concluded that both BAHAs attached to the headband and the T-CROS provide significant benefit for both adults and children with unilateral hearing loss. However, the participants performed better with the BAHAs than the T-CROS in both quiet and noise for most of the measures, with both the digitally programmable and the trimmer digital BAHA performing more or less to the same extent. However, in adults, the digitally programmable BAHA showed better speech perception performance in indirect noise condition compared to trimmer digital BAHA and the T-CROS. The current study helps in prioritizing the hearing amplification devices for the trial and also helps inarriving at the appropriate hearing amplification device for the individuals with unilateral hearing loss.

Chapter 1

INTRODUCTION

Individuals with unilateral hearing loss of severe-profound degree with normal or near normal hearing sensitivity in the better ear can perform well, listening in quiet environments without remarkable effort. However, difficulty arises specifically in two listening environments such as localizing a sound source when the signal arrives from the direction of the poorer ear (Hol, Bosman, Snik, Mylanus & Cremers, 2004; Wazen, Ghossaini, Spitzer & Kuller, 2005) and whileperceiving the speech information in the presence of background noise (Bosman, Hol, Snik, Mylanus & Cremers, 2003). Loss of binaural hearing can be quoted as the main reason for the difficulty faced by such individuals in these situations. As a consequence of which, acoustic head shadow will present adverse effects when the sound source is positioned towards the poorer ear. Binaural hearing eradicates the adverse effects of acoustic head shadow, empowers localization and comes as a boon in the presence of noise increasing the loudness of the signal due to binaural loudness summation (Gulick, Gescheider & Frisina, 1989) and the squelch effect.

In the past, unilateral hearing loss was thought to have negligible deleterious impact on the daily listening circumstances and in consequence requires minimal or no intervention. However, currently, more and more individuals with unilateral severe to profound hearing loss are bringing in reports of faced difficulties in daily life listening settings, in turn compelling the professionals to look for a satisfactory rehabilitative approach. In fact, 86% of the individuals with unilateral hearing loss do consider the hearing loss to be a hindrance to social interaction (Chiossoine-Kerdel, Baguley, Stoddart & Moffat, 2000; McDermott, Dutt, Tziambazis, Reid & Proops, 2002). Adults are unable to communicate appropriately in various circumstances, such as listening at office, public places, meetings, social gatherings etc. This affects their emotional, psychological and social aspects. In children, greater difficulty of perceiving speech in noise is noted than adults and this can have a more devastating effect on them since it can affect their speech and language development (Lieu, 2004), which in turn may affect their psychological, social and academic progress (Brown, Holstrum & Ringwalt,2008; Holstrum, Gaffney, Gravel & Oyler, 2008). Hence, this calls for a need to examine the available rehabilitation approaches for individuals with unilateral hearing loss and arrive at the best.

It is imperative to take into consideration the age, listening requirements, work environment and motivation for intervention of the individual with unilateral hearing loss while choosing the rehabilitation options. Counselling the individual about the compensatory strategies to be used for better communication in adverse listening conditions is one way of approaching the problem. Despite the fact that this approach may not work out in all the situations, strategies such as preferential seating, utilising speech reading cues and facing the better ear towards the signal will provide at least some benefit at times (Hol, Bosman, Snik, Mylanus & Cremers, 2004).

As done conventionally, preliminary attempts to assist the individuals with unilateral hearing loss communicate better, were made by providing amplification to the poorer ear. Bergman (1957) reported that for the individuals with restored hearing in one ear after surgery and an ear with hearing impairment, a hearing aid must be considered as a rehabilitation option in order to accomplish binaural hearing. Malles (1963) compared the speech discrimination scores with and without a hearing aid in individuals having unilateral conductive and mixed hearing loss. Results revealed better aided scores compared to the unaided in two signal-to-noise ratios. Similarly, based on the experiences of unilateral hearing loss who were full-time hearing aid users, Harford and Musket (1964) stated that wearing a hearing aid in the poorer ear with usable residual hearing will certainly be beneficial enough to consider amplification in daily listening environments.

However, for those without usable residual hearing in the poorer ear, there are other means of rehabilitation, the traditional line of action being the use of conventional Contralateral Routing of Signal (CROS) hearing aid. Harford and Barry (1965) came first to the rescue of individuals with unilateral severe-profound hearing loss with no operational residual hearing. The device they used had a headband with a wire wound around it which connected the microphone and amplifier positioned on the poorer ear side to the receiver placed towards the better ear. Then the acoustic signal from the receiver was channelled to the ear canal of the better ear through a polythene tube coupled with an open earmold. Later Harford and Dodds (1966) used the CROS hearing aid clinically for individuals with unilateral hearing loss. It consisted of a microphone located on the poorer ear side and the signal was transferred to the better ear via a wire around the neck or by wireless FM transmission (Harford & Barry, 1965; Valente, 1995).

Parallel attempts were also made by Fowler (1960) in the direction of the rehabilitation of individuals with unilateral hearing loss. Reduced interaural attenuation for bone conduction pathway was used as an advantage and the usage of a bone conduction hearing aid encased in a spectacle frame was put forth. This consisted of a 'Y' shaped dual microphone arrangement wherein a remote microphone which was placed on the side of the poorer ear whose output was delivered to the better ear along with the output of the microphone placed near the better ear. A simplification of Fowler's device was brought about by Wullstein and

Wigand (1962) by removing the microphone placed on the normal ear side since the signal coming from that side can be readily picked by the normal hearing ear itself. Whereas, the signal from the poorer ear side was picked up by the microphone and transferred to the better ear after modest amplification. Though there was notable improvement in speech discrimination scores with the aid, the participants' device compliance level was rather low.

After around 20 years or so, a percutaneous Bone Anchored Hearing Aid (BAHA) was instigated by Tjellström and colleagues (Tjellström, Lindström, Hallen, Albrektsson & Brånemark, 1981, 1983; Håkansson, Tjellström, Rosenhall, & Carlsson, 1985). The BAHA consists of a vibration transducer directly coupled to a titanium fixture implanted in the temporal bone. Welling, Glasscock, Woods, & Sheffey(1991) tried the BAHA as a transcranial CROS in individuals with unilateral hearing loss. Using the implantable subcutaneous Audiant bone conductor device, they reported positive results in some of their participants.

Hol, Bosman, Snik, Mylanus and Cremers (2005) studied the audiometric and subjective outcome of the BAHA in 29 patients with unilateral sensorineural hearing loss. The audiometric evaluation was done in unaided, and two aided conditions, one with conventional CROS and the other with the implanted BAHA. They made use of four subjective assessment tools, namely, the Abbreviated Profile of Hearing Aid Benefit, the Glasgow Hearing Aid Benefit Profile, the International Outcome Inventory for Hearing Aids and the Single-Sided Deafness questionnaire. Audiometric evaluation revealed that the sound localization ability of the participants with BAHA was at chance level, but observed significant improvement in the speech-in-noise performance. They carried out the subjective evaluation with the same four instruments after one year of BAHA implantation. Results revealed that the participants benefitted from BAHA even after one year follow up.

Sullivan (1988) too reported a rehabilitative approach making use of the bone conduction pathway. The report suggested to use a high gain air conduction hearing aid coupled to a comparatively long ear mould that lay deep into the poorer ear's canal. The advantage of this type of a set-up over the conventional CROS is that the better ear is left unoccluded letting the unamplified signal coming from the better ear side enter without any obstruction. Whereas, the amplified signal coming from the long ear mould causes vibration of the bony walls of the ear canal and gets transferred to the better cochlea via bone conduction through the skull (Chartrand, 1991; Sullivan, 1988). This arrangement was appropriately termed as the transcranial CROS or internal CROS by Valente et al. (1995).

Valente, Potts, Valente and Goebel (1995) compared the wireless conventional CROS versus the BTE transcranial CROS in eight adults with unilateral hearing loss. The transcranial CROS fitting was verified by means of the transcranial threshold (TCT) and Real-Ear Aided Response (REAR) measurement. Each of the devices was given for a trial of one month to the participants and administered a questionnaire throwing light on the subjective assessment of each device. Among the eight participants, two preferred the transcranial CROS, four chose the wireless CROS, one favoured both the devices equally and one wasn't satisfied with either of them. The researchers observed that the participants who went for the transcranial CROS had lower TCT values. However, the study was solely based on the subjective preference of the participants and not backed up by the functional tests evaluating the speech perception performance.

Niparko, Cox and Lustig (2003) included the BAHA and compared with the conventional CROS in ten adults with the unilateral hearing loss. After one month of trial with each of the devices, subjective assessment, localization in noise and speech recognition in quiet and noise were carried out. Participants preferred the BAHA over the conventional CROS which was also indicated by the improved speech recognition scores with the BAHA in both quiet and noise. Localization test results revealed poorer scores in both the devices as well as the unaided condition.

Recently, Hol, Kunst, Snik and Cremers (2010) conducted a pilot study on ten adult participants having unilateral hearing loss. They considered all the existing rehabilitative means, the conventional CROS, transcranial CROS and the BAHA. The battery of measures included localization, speech perception performance in noise and the subjective quality rating with the aid of three questionnaires. The authors witnessed chance level localization in both the aided and unaided conditions, better speech perception in noise with the conventional CROS followed by BAHA; however, only one participant chose the conventional CROS and three picked up the BAHA.

However, there is still a dearth of studies which have analysed the means of rehabilitation for children with unilateral hearing loss. Even though the BAHA is used for children with unilateral hearing loss, not much research has been done to check its benefit in that population (McKay, Gravel & Tharpe, 2008; Oyler & McKay, 2008).Additionally, the number of participants considered in the previously conducted research on unilateral hearing loss rehabilitation is not sufficient enough to generalize the results to the complete population of unilateral hearing loss.

Furthermore, as the technology evolves, there are more and more new and developed devices which will be available for the individuals with unilateral hearing loss. A thorough understanding of their usefulness to the target population and their stand among other similar technological innovations is vital for audiologists to prescribe the best device suitable for a particular individual. There is a dearth of such studies which compare the latest hearing amplification options for the individuals with unilateral hearing loss. Hence, the present study was taken up to determine whether technological advancements in digital signal processing have truly enhanced the efficacy of CROS and BAHA devices and to identify any shortcomings that may have remained. The study specifically aimed at comparing the efficacy of the digitally programmable BAHA, trimmer digital BAHA and the transcranial CROS in both children and adults.

1.1 Objectives of the study:

- To compare the speech perception performance in quiet and noise with trimmer digital BAHA, programmable digital BAHA both attached to the headband and transcranial CROS hearing aid in children and adults.
- To compare the subjective quality rating of the individuals across different amplification devices for adults.

Chapter 2

REVIEW OF LITERATURE

Unilateral hearing loss can be defined as having hearing loss in one ear and normal hearing (15 dB or better in the frequencies ranging from 250 to 8000 Hz) in the opposite ear. It can be either of congenital or acquired nature and can be found in individuals of any age and can be seen as an acute or a progressive condition and range in severity from mild to profound degree. The prevalence of unilateral hearing loss as quoted by Bess and Tharpe (1986) in school aged children is 3 in 1000 who had hearing loss of 45 dB or greater. It has been reported by Miller (1989) that the prevalence is 3% in US. Everberg (1960) reported a higher prevalence of unilateral hearing loss in males (62%) than in females (38%). Unilateral hearing loss though can be easily diagnosed, finding out its cause and an appropriate rehabilitation option for the individual poses a challenge for the Audiologist. If untreated in children, unilateral hearing loss of moderate to profound degree is known to cause significant academic hitches. This can be assumed to be due to the difficulty they face in listening in school environment where noise is notably high. However, there are a certain number of children with unilateral hearing loss who perform well academically and get missed out getting diagnosed as having hearing loss (Peltier, Quinn & Ryan, 2004).

Sudden sensorineural hearing loss (SSHL) forms a considerable part of the unilateral hearing loss seen clinically. SSHL is defined as at least 30 dB hearing loss seen across three contiguous frequencies within three days of onset (Voelker & Chole, 2010). It can be associated with tinnitus, vertigo and aural fullness (Hughes, Freedman, Haberkamp & Guay, 1996). In the US, its estimated incidence is between 5 and 20 per 1, 00,000 individuals per year (Byl, 1984). SSHL is typically seen in individuals aged between 43 and 53 years and is seen equally dispersed among males and females (Shaia & Sheehy, 1976; Byl, 1984; Rauch, 2008). SSHL most often presents itself as a unilateral condition and rarely as a bilateral condition ranging in percentage from 1-2 (Shaia & Sheehy, 1976; Grandis, Hirsch & Wagener, 1993). Either partial or complete spontaneous recovery is evidenced in around 30 to 65% of individuals (Mattox & Simmons, 1977; Wilson, Laird, Moo-Young, Soeldner, Kavesh & MacMeel, 1982). There are a few indicators of poor prognosis for unilateral sensorineural hearing loss as reported by researchers which include severe to profound hearing loss, high-frequency hearing loss, vertigo and increased age (Shaia & Sheehy, 1976; Byl, 1984). Although 75 to 85% of the unilateral sensorineural hearing loss cases will be idiopathic in nature, there are a few known disorders causing unilateral sensorineural hearing loss (Hughes, Freedman, Haberkamp & Guay, 1996).

Acoustic Neuroma is one among them and is reported to cause progressive hearing loss but 10 to 26% of individuals may present a Sudden SNHL (Higgs, 1973).These tumors generally cause high-frequency hearing loss, although any pattern of hearing loss can be seen (Voelker & Chole, 2010).Also, speech recognition scores will be poor and not in agreement with the pure-tone-average thresholds (Arts, 2005).

4 to 10% of individuals with Multiple Sclerosis are prone to be affected by SNHL (Grénman, 1985) and the hearing loss would be sudden and unilateral in occurrence (Franklin, Coker & Jenkins, 1989).Unilateral SNHL can also be caused by either mechanical or acoustic trauma. Acoustic trauma usually causes a unilateral or asymmetrical hearing loss as a result of damage to the organ of Corti and/or rupture of the cochlear membranes (Arts, 2005). Ototoxic drugs aremostlyknown to cause bilateral hearing loss, but are known to also cause unilateral damage. These drugs

mostly appear to cause high frequency SNHL. Individuals with labyrinthitis usually complain of vertigo and sudden unilateral hearing loss. Cytomegalovirus, rubella, mumps, measles and varicella zoster are the viruses which when infected with can lead to unilateral hearing loss (Voelker & Chole, 2010). There are other infections such as syphilis (Schuknecht, 1993) and Lyme disease (Hanner, Rosenhall, Edström & Kaijser, 1989) which also lead to unilateral hearing loss. Meniere's disease is also known to causeunilaterallow-frequencies fluctuatinghearing loss at the initial stages(Voelker & Chole, 2010).

Around 17 to 33% of individuals with idiopathic sudden sensorineural hearing loss, reported of a viral-like infection affecting their upper respiratory system one month prior to the onset of hearing loss (Shaia & Sheehy, 1976). Further research is needed to arrive at the specific causes underlying the unilateral hearing loss, of which ISSHL forms a major part. Determining the etiology of the unilateral hearing loss is the first step towards rehabilitation. After all the necessary medical treatments are carried out, a permanent unilateral hearing loss can be treated by hearing amplification devices.

2.1 Amplification options for the individuals with unilateral hearing loss

The main concern of the audiologists regarding rehabilitation for the individuals with unilateral hearing loss is who should be provided with hearing devices, which will be most appropriate and how well the devices will be able to reduce the difficulties they face in the daily listening conditions. One way of easing the difficulties these individuals face can be by counselling the family members to use communication strategies while interacting with the individual. The family members must be instructed to be closer to the individual's better ear while speaking to them.

And also they must be educated regarding the ways of improving the signal-to-noise ratio at home which can be done by turning down the volume of the televisions or radios or other extraneous sounds when talking to the individual.

The other way of reducing their difficulties is by providing rehabilitation through hearing devices.

FM Systems:

The reduction in signal-to-noise ratio affects the individual with unilateral hearing loss to a greater extent, because of the absence of the binaural inputs and more so when the noise is towards the better ear. Such low signal-to-noise ratio environments are very commonly encountered such as educational and recreational set ups. Finitzo-Hieber and Tillman (1978) reported that increased background noise, long distances between speaker and listener and long reverberation times are synergistic and affect the speech signals adversely. In such adverse listening conditions, FM systems are known to provide relief to the individuals with unilateral hearing loss. They provide a better signal-to-noise ratio because of the presence of the microphone which will be held in close proximity with the speaker averting the harmful effects of noise and reverberation. The latest FM transmitters possess technologies such as digital noise reduction and directional microphone. Ear-level FM systems have definite merits, such as smaller size and better portability over other speaker types. Also, ear-level FM systems can be used outside the classroom as well. FM receiver can be coupled to the BAHA device or the hearing aid itself the individual is wearing. The option of routing an FM signal to the poorer ear depends on the residual hearing left in that ear. Considering an FM device for child with unilateral hearing loss should be thought of when he/she exhibits poorer than expected classroom performance and speech-in-noise skills. However, more research is required to assess the usefulness of FM devices in individuals with unilateral hearing loss.

Conventional AC Hearing aid:

Fitting a conventional AC hearing aid to an individual with unilateral hearing loss depends on whether the poorer ear is aidable or unaidable. Even in case of an aidable poorer ear, the AC hearing aid may not be completely successful in restoring the binaural benefits available in both the ears with normal hearing. There are reports of reduced speech perception performance in relation to unaided scores, caused when the poorer ear is aided in case of a unilateral hearing loss. This is reported more in geriatrics with asymmetric hearing loss. This poorer binaural performance due to asymmetric input is called as Binaural Interference. This phenomenon was clinically evidenced by Rothpletz, Tharpe and Grantham (2004). They reported that when adults and children were presented with degraded speech through both ears, there was evidence of binaural advantage. However, when they were presented with asymmetrically degraded speech, no binaural advantage was seen. Conversely, adults showed poorer performance in the binaural condition when compared to the monaural condition. This was absent in the case of children.

McKay (2002) carried out a retrospective survey to determine whether fitting a hearing aid for a child with unilateral hearing loss improved his/her quality of life. This was done by administering a questionnaire of 12 questions developed for the study and some questions which were the modified forms of those from Children's Home Inventory for Listening Difficulties (CHILD) (Anderson & Smaldino, 2000) on a group of parents of children with unilateral hearing loss after fitting them with a conventional AC hearing aid. Parents of 20 children, whose ages ranged from 2 to 17 years and who had mild to moderately-severe hearing loss, with useable speech recognition ability in one ear and normal hearing sensitivity in the other ear, were given the questionnaire. Results revealed that wearing a hearing aid did not negatively affect the participant's performance in any listening condition. Only negative responses that were noted were in the area of frustration and confidence level and whether or not the child liked the hearing aid. Nevertheless, all parents were satisfied with the performance of their child with the hearing aid. The authors concluded that fitting a child with unilateral hearing loss with a hearing aid will improve his/her quality of life when compared to no hearing amplification.

Conventional contralateral routing of signal (CROS):

Individuals with unilateral hearing loss who don't benefit from the conventional AC hearing aid, must be considered for the CROS hearing aid fitting. Since many years, CROS hearing aids were the first sought rehabilitation option for the individuals with unilateral hearing loss. The function of the CROS hearing aid is to route the auditory signals coming from the poorer-hearing ear side towards the better-hearing ear, in turn eliminating the effects of head shadow. The signals from the poorer ear side will be picked up by a microphone housed in a behind-the-ear (BTE) unit worn on the poorer ear and sent to a low-gain (BTE) hearing aid worn on the better ear. This routing was previously carried out by a wired connection between the microphone and the receiver.

The drawback of CROS hearing aid is that it requires the individual to wear BTE units on both ears, which many would not prefer. Apart from cosmetic demerits, it has also been found that children wearing CROS hearing aids perform poorer in noise than those wearing FM systems or those without any hearing device but who are given preferential seating in the classroom (Kenworthy, Klee & Tharpe, 1990). This can be because, some children wearing CROS hearing aids might lack the ability to recognise when the microphone placed on the poorer hearing aid is facing the noise sources and spontaneously correct their position.

Transcranial CROS (T-CROS):

The limitations of the conventional CROS hearing aid made way for the transcranial version of it. The transcranial CROS stimulates the contralateral cochlea by means of transcranial hearing when a high-power BTE or in-the-ear or completely-in-the-canal hearing aid is placed in the poorer hearing ear (Chartrand, 1991; Valente, Potts, Valente & Goebel, 1995). Valente, Potts, Valente and Goebel, (1995) compared the performance of the individuals wearing conventional CROS and transcranial CROS. They found diverse results where a portion of the individuals preferred the conventional CROS, some chose the transcranial CROS and one did not perform well with either of the devices.

TransEar is a type of transcranial CROS hearing aid. It consists of a BTE unit which is connected to a hard ear mould placed in the poorer hearing ear. This hard ear mould contains a bone-conduction transducer which transmits the signal from the poorer ear to the better ear via bone conduction. Valente, Valente & Mispagel (2006) first used the device in individuals with unilateral sensorineural hearing loss. They found that three individuals were not able to get sufficient gain without feedback. Later, a new vibrator was developed which provided additional gain in the higher frequencies with its energy peaking at the frequencies ranging from 2100 to 2300 Hz (Ear Technology Corporation, 2009).At present, no research has been conducted to evaluate the effectiveness of the TransEar in the paediatric population.

Soundbite Hearing System:

Sonitus Medical developed a new digital hearing device for individuals with conductive, mixed or unilateral sensorineural hearing loss named as Soundbite hearing system. It consists of a BTE unit which communicates with an in-the-mouth (ITM) piezoelectric transducer wirelessly. The BTE component is connected to a microphone positioned in the ear canal of the poorer ear which picks up the signals from the poorer hearing side. On the other hand, the ITM component is sealed within acrylic material and is placed at the sides of the molar teeth to deliver the signals through bone conduction to the better ear. Popelka, et al. (2010) reported that the transducer provided more output for the higher frequencies, with up to 30 dB additional output, for the frequencies till 12,000 Hz.

Bone-Anchored Hearing Aid:

The concept of transcranial hearing was further continued in a different form, namely, the Bone Anchored Hearing aid (BAHA). BAHA is an implantable device which has its transducer percutaneously connected to the titanium implant fixed in the temporal bone (Tjellström, Lindström, Hallen, Albrektsson, & Brånemark,1981). This device was initially designed for individuals with conductive or mixed type of hearing loss and has been now used as a transcranial CROS for individuals with unilateral hearing loss. The U. S. Food and Drug Administration (FDA) in 2002, gave 510(k) clearance for marketing the BAHA for individuals with single-sided deafness (SSD). According to FDA, SSD is defined as unilateral sensorineural hearing loss in the poorer ear and normal hearing with PTA ≤20 dB in the better ear. However, research reports that even individuals with mild to moderate hearing loss in the better ear have found the implanted BAHA useful (Andersen, Schrøder & Bonding, 2006; Lin, Bowditch, Anderson, May, Cox & Niparko, 2006). Hence, these studies show that the BAHA may provide benefit even for the individuals who have hearing loss up to moderate degree in the better ear and also if the better ear worsens up to an extent after the BAHA has been implanted. Individuals with SSD caused as a result of either congenital or acquired disorders will be candidates for the BAHA. For individuals with SSD, the BAHA is implanted on the poorer hearing ear side and the signal is then transferred to the better hearing cochlea via bone conduction. The BAHA which is implanted percutaneously on the temporal bone passes the energy more efficiently than the conventional BC hearing aids since the signal gets transferred directly from the mechanical oscillator to the bone. Davids, Gordon, Clutton and Papsin (2007) reported that the BAHA gives a better sound quality in comparison with the conventional bone conduction hearing aids since there is no soft tissue in between the transducer and the skull dampening the energy.

Wazen, Spitzer, Ghossaini, Kacker and Zschommler (2001) attempted to evaluate the efficacy of BAHA in nine individuals with unilateral conductive or mixed hearing loss. Pure tone audiometry, speech audiometry and administration of a standardized hearing handicap questionnaire were carried out before and after implantation. Results showed that all the participants showed better tonal and spondee thresholds with the BAHA but the speech recognition scores with the BAHA were as good as the best unaided score. Subjective evaluation revealed that all the participants reported a significant benefit with the BAHA.

Wazen, Ghossaini, Spitzer and Kuller(2005) investigated the localization performance of eight individuals with unilateral hearing loss while they were aided with the BAHA and in the unaided condition. This performance of theirs was compared to the localization performance of 10 normal-hearingadults. The stimuli for the localization task werenarrowbandnoisebursts of 2-s duration, centered at 500and 3000 Hz and were presented at 60 dB HL. The authors used eight loudspeakers which were placed at an interval of 45 degrees. The responses were analysed based on the accuracy of identification and lateralization. Results showed that the normal-hearing individuals performed better than the individuals with SSD irrespective of the presence or absence of the aid. The individuals with SSD performed at chance level for laterality assessment both with the aid and without it. The authors did not find any difference in performance across the frequencies for either of the groups.

Linstrom, Silverman and Yu (2009) conducted a study on seven adults with unilateral hearing loss to assess the usefulness of directional microphone in the BAHA. The authors used the adaptive HINT sentences as stimuli to evaluate the speech performance in three listening conditions, namely, unaided, BAHA with directionality switched on and directionality switched off. The noise was kept constant at 65 dB SPL. The evaluation was carried out in two arrangements. The first one was by presenting the speech from 0 degree, and noise being presented from 90 and 270 degrees and the second one was by presenting noise from 0 degree and speech was presented from 90 and 270 degrees. The results of the study showed that BAHA made a positive difference only when the noise was presented from front and speech from the poorer ear side.

Yuen, Bodmer, Smilsky,Nedzelski,and Chen (2009) conducted a similar study as Linstrom, Silverman and Yu (2009), wherein he assessed the perception of adaptive HINT sentences in 21 adults with unilateral hearing loss. The evaluation was carried out in unaided condition and aided with BAHA condition. The testing was done with three speech-in-noise arrangements, speech was presented at 0 degree and noise at 180 degrees, then noise was given at 90 degrees and speech at 270 degrees and finally, noise at 270 degrees and speech at 90 degrees. The noise level was fixed at 65 dB SPL. The authors reported significant improvement with the BAHA when the speech was presented to the poorer ear and noise to the better ear and also, performance deteriorated with the BAHA when the noise was given from the poorer ear side or from behind.

Newman, Sandridge and Oswald (2010) tried to explore the relationship between the pre implant BAHA expectations and the post implant BAHA satisfaction since the satisfaction is dependent on the expectation. The study was carried out in 10 individuals with acquired unilateral sensorineural hearing loss. Two questionnaires were used, The Expected Consequences of Hearing Aid Ownership (ECHO) was used before BAHA fitting and the Satisfaction with Amplification in Daily Life (SADL) was administered at 1, 3, 6, 9, 12, and 18 months post fitting of BAHA. The authors reported no significant difference between the expectations and the satisfaction of the participants. In general, the authors observed that patients' satisfaction after BAHA fitting was higher when compared to their pre implant expectations and that satisfaction was maintained for 18 months. The authors concluded saying that forming of realistic expectations during pre-implant counselling and also ongoing counselling are necessary before BAHA implantation.

Wolf, Hol, Mylanus, Snik and Cremers (2011) conducted a retrospective study where they evaluated the benefit of BAHA in children in daily listening conditions. They considered 38 children who were at least 4 years at the BAHA fitting stage and had 1-4 years of experience with the BAHA. The participants had either bilateral conductive or mixed hearing loss or unilateral conductive hearing loss. The outcome measures used for the subjective evaluation were Glasgow Children's Benefit Inventory, Abbreviated Profile of Hearing Aid Benefit(APHAB) and Health Utilities Index Mark 3. The authors observed that the Glasgow Children's Benefit Inventoryshowed an overall benefit of 32 for the children with bilateral conductive hearing loss, 26 for children with unilateral conductive hearing loss and a benefit of 16 for children with mixed hearing loss on a scale of −100 to +100. The APHAB scores indicated that all the 3 groups obtained benefit from the BAHA and that the children with bilateral hearing loss (7 patients [70%]) were benefitted more than those with unilateral hearing loss (4 patients [27%]). The scores on the Health Utilities Index Mark 3 were similar for the three groups. The authors concluded that fitting BAHA will provide significant benefit for children with both bilateral and unilateral hearing loss.

Pai, et al. (2012) aimed to assess the efficacy of BAHA in 25 adults with unilateral profound hearing loss with normal or mild high frequency hearing loss in the better ear. The pre and post implant speech, spatial and qualities of hearing scale (SSQ) scoresand subjective report from the participants after a home trial with the BAHA worn on a softband were obtained. The post implant SSQ scores were obtained after 6 months of experience with the BAHA. The post implant SSQ scores improved significantly in speech, spatial and qualities sections of the questionnaire. The authors concluded that all the participants remained as consistent users of BAHA and that there has not been any explantation needed.

Research has majorly reported improved performance with the BAHA in terms of the quality of life, sound quality and greater patient satisfaction (Wazen, et al., 2003; Hol, Bosman, Snik, Mylanus & Cremers, 2005; Lin, Bowditch, Anderson, May, Cox & Niparko, 2005). However, there is a dearth of literature related to the usefulness of BAHA in the paediatric population with unilateral hearing loss.

2.2 Comparative research related to rehabilitation options for individuals with unilateral hearing loss

Kenworthy, Klee and Tharpe(1990) attempted to compare the speech recognition scores as six children with unilateral sensorineural hearing loss ranging from moderately-severe to profound degree wore the conventional CROS and FM system separately in a simulated classroom set up. The testing was conducted in three listening conditions, namely, monaural direct (MD), monaural indirect (MI) and midline signal with omnidirectional noise (MS/ON) using two types of test materials, Nonsense Syllable Test and American English adapted Bamford-Kowal-Bench Sentence List test. These testing conditions were simulated in a classroom and were recorded via a tape recorder and presented to the participants through headphones to avoid the effects of SNR and head shadow. Results revealed that the participants scored poorest in the MI unaided condition and the CROS hearing aid improved the scores in the MI condition but adversely affected the scores in the MD condition. Further, the authors reported that the FM system yielded high scores in all the listening conditions tested and also with both the speech materials.

Updike (1994) compared the efficacy of conventional AC hearing aids, conventional CROS hearing aids and FM devices in the rehabilitation of six children with unilateral hearing loss ranging in age from 5 to 13 years. Among 6 participants, one had hearing loss of mild degree, one of moderate degree, one of moderately-severe, one of severe degree and two more of profound degree. The participant was seated in a classroom with two tape recorders placed on either sides presenting speech noise and one more tape recorder placed in the front presenting the test signal. The word recognition ability of the participant was measured in quiet and at 6dB SNR in unaided condition and with conventional AC hearing aids, conventional CROS hearing aids and FM devices. Goldman-Fristoe-Woodcock Test of Auditory Discrimination (GFWTAD) was used which tested the speech and sound discrimination by asking the participant to point to one out of four pictures showing the target word. Results showed that the participant with mild unilateral hearing loss obtained significantly higher scores ($p<0.01$) in quiet with the conventional AC hearing aid compared to that in unaided condition, whereas, no significant improvement was observed in noisy condition. The participant with moderate unilateral hearing loss showed no significant improvement in word recognition ability in quiet with a conventional AC hearing aid compared to unaided condition, but in turn showed a significant decrement ($p<0.01$) in the scores with the conventional hearing aid in the presence of noise. The participant with unilateral hearing loss of moderately-severe degree, obtained significantly ($p<0.01$) lower scores with a conventional AC hearing aid in quiet than the unaided condition and no significant change in the presence of noise. Further, the participant with severe-profound hearing loss showed no difference between the conventional AC hearing aid and unaided condition in quiet and noisy conditions. So, in summary, fitting a conventional AC hearing aid to a participant with unilateral hearing loss of any degree higher than mild doesn't significantly improve word recognition ability both in quiet and may affect adversely in the presence of noise. Similar results were obtained with the conventional CROS with word recognition scores decreasing in the presence of noise. However, results showed that the participants benefitted with FM system both in quiet and in the presence of noise and the participants with greater loss reaped more benefit. Since the study was conducted with only one participant representing each degree of hearing loss, the results can't be generalized and hence, the results should be considered with caution.

Bosman, Hol, Snik, Mylanus and Cremers (2003) compared the conventional CROS and implanted BAHA in 9 participants with unilateral sensorineural hearing loss after a month's habituation of each of the devices. Localization, speech in noise and subjective evaluations were carried out. A 9 speaker array was utilized for the sound localization, SRT was measured using Dutch sentences and the subjective evaluation was carried out using APHAB. The performance was checked in three conditions, unaided and after habituation for a month with the CROS device and the implanted BAHA. The localization test results revealed no difference between the aided and the unaided conditions. It was also observed that the speech perception performance in presence of noise with the BAHA and the CROS was comparable and better that unaided condition. And the subjective evaluation results revealed that most of the participants preferred the BAHA.

Hol, Bosman, Snik, Mylanus and Cremers (2004) carried out a similar study with 20 participants and compared the performance of Conventional CROS and BAHA after a habituation period of one month with both devices. The BAHA was given for pre-implantation trial with the headband for a period of 1-2 weeks. Sound localization and lateralization performance was assessed using a 9 speaker array, SNR50 was measured using Dutch sentences presented in presence of spectrally shaped noise. Unlike their previous study, in this study, they conducted the subjective evaluation using APHAB after a month of usage with each of the devices. Results showed that there was no difference between the aided and unaided conditions in terms of localization performance. Overall, participants performed better with the BAHA as compared to the Conventional CROS in presence of noise and poorest in unaided condition. Subjectively also BAHA scored better than the Conventional CROS.

Schrøder, Ravn and Bonding (2010) studied the subjective benefit from BAHA in 21 participants having unilateral sensorineural hearing loss. The questionnaire was given to 23 BAHA implanted participants and among them, 21 responded. After 6 months of implantation, 20 of the participants were using their BAHA device. Among 21, 14 judged BAHA to be significantly better and the other 7 as moderate. The participants rated the handicap as 7.4 without the BAHA and 2.3 with the BAHA. All the participants who were former users of CROS preferred the BAHA and all participants would recommend BAHA to others.

Wolf, Shival, Hol, Mylanus, Cremers and Snik (2010) conducted a retrospective evaluation where they focussed on the quality of life of 134 older adults who were BAHA users. The authors sent 4 questionnaires namely Glasgow Benefit Inventory, Abbreviated Profile of Hearing Aid Benefit [APHAB], Nijmegen Cochlear Implant Questionnaire [NCIQ], and the Hearing Handicap Inventory for the Elderly screening version [HHIE-S] to individuals who had used BAHA for a minimum of one year. They considered the participants' age, years of BAHA usage, previously used amplification device, the recent bone conduction thresholds and the air-bone gap to analyse statistical correlations. The researchers also calculated the inter-questionnaire correlations. The response rate was 80%. The authors noted that more than 80% of the participants were wearing their BAHA for more than 8 hours a day. And also a trend was observed with respect to the pure tone average at octave frequencies from 500 to 4000Hz for bone conduction thresholds. As the thresholds became poorer, the mean benefit scores on the questionnaire reduced. The authors reported that the participants were able to handle the device appropriately and were also able to clean the area around the implant. In total, most of the participants reported increased general benefit and good quality of life with the BAHA.

However, for the individuals with Unilateral hearing loss, the most appropriate rehabilitation option still remains a question. Hence, the present study was taken up involving both adults and children and comparing the two types of amplification devices, namely, BAHA and Transcranial CROS.

Chapter 3

METHOD

The study aimed at comparing the sound field thresholds, speech perception performance in quiet and noise and the subjective quality rating of speech with Transcranial Contralateral Routing of Signal (T-CROS) and Bone Anchored Hearing Aid (BAHA) attached to the headband in individuals with Unilateral hearing loss.

3.1 Participants

The participants were divided into two groups. Group I consisted of 15 children(9 to 14 years, Mean age =12 years, 8 males & 7 females) and Group II comprised of 24 adults (17 to 56 years, Mean age = 34 years, 16 males & 8 females).Participants in both the groups had unilateral hearing loss with either severe mixed or sensorineural hearing loss or profound hearing loss in the poorer ear and normal or near normal hearing sensitivity (PTA < 25 dBHL) in the better ear.

All the participants were native speakers of Kannada language with adequate speech and language skills and none of them had a prior experience with hearing amplification.

3.2 Test materials

1. Kannada Phonemically Balanced (PB) bi-syllabic word lists which are eight in number consisting of 25 bi-syllabic words each, developed by Yathiraj and Vijayalakshmi (2005) were used for adults to measure the speech identification scores in quiet.
2. Kannada Phonemically Balanced (PB) bi-syllabic word lists consisting of 50 bi-syllabic words in each of the two lists developed by Yathiraj and

Vandana(1998) were used for children to measure the speech identification scores in quiet.

3. A list of 40 sets of Kannada bi-syllabic words developed by Sahgal and Manjula (2005) was used to find out the SNR 50 for both children and adults. Each set has three words consisting of low-mid, low-high and high-mid frequency speech sounds.
4. A Kannada passage developed by Sairam and Manjula (2002) was recorded by a female native speaker of Kannada with normal vocal effort and used for the subjective quality ratings. A modified five point quality rating scale given by Gabrielsson et al. (1979) was used to assess the subjective quality of speech perception through the hearing amplification devices.

3.3 Instrumentation

1. A calibrated diagnostic two-channel audiometer, Maico MA-52 to carry out pure tone audiometry, speech audiometry and aided performance assessment.
2. A calibrated GSI-Tymp Star Middle Ear Analyzer to assess the middle ear functioning.
3. Two personal computers, one to present the recorded speech material through the auxiliary input of the audiometer and the other with NOAH-3 embedded with the hearing amplification device specific programming software. Suitable cable was used to couple the hearing amplification device to the programming interface, the HIPRO, which was in turn connected to the personal computer.
4. A real-time analyser, Fonix 7000 to measure the Transcranial thresholds (TCTs) and Real-Ear Aided Response (REAR) to verify the fitting of transcranial CROS.

5. Hearing amplification devices:

    a. A digitally programmable BAHA (BAHA 1) consisting of a sound processor placed on the mastoid with the aid of a headband. The sound processor had 10 bands and 12 channels with 3 user-defined programs. This device is suitable for individuals with bone conduction thresholds ≤ 45 dB HL averaged across 500, 1000, 2000 and 3000 Hz. The programming software allows to manipulate the directionality, noise reduction and feedback reduction of the device. The posterior placement of the device can be compensated for by turning on a setting named position compensation which provides equal loudness for the sounds arriving from front and back direction. The microphone relative Direct Audio Input (DAI) setting allows the adjustment of the intensity of the DAI with respect to the microphone input. When turned on, this feature sets the intensity of the DAI 6 dB higher than the microphone input. If turned off, both the microphone and the DAI are given equal importance.

    b. A trimmer digital BAHA (BAHA 2) including a sound processor placed on the mastoid with the help of a headband. This device was equipped with three programs; Program one suitable for most listening environments, Program two with bass cut, suitable for noisy environments and the third program mutes the microphone and can be used for external audio inputs. The device also had tone control and a gain control to tailor the amplification to individual needs. BAHA 2 is reported to be suited for those who have bone conduction thresholds within 42, 44, 58 and 48 dB HL at 0.5, 1, 2, and 4 kHz, respectively (Bosman, Snik, Mylanus, & Cremers,2009).

c. A digitally programmable high-power air conduction behind-the-ear hearing aid (Maximum Power Output = 144 dB SPL; Maximum gain = 85 dB; frequency range = < 100-5000 Hz) served as the Transcranial Contralateral Routing of Signal (T-CROS) hearing aid. This hearing aid had 6 channels and 6 bands. The hearing aid was used along with a custom soft earmold.

3.4 Test Environment

Audiological testing as well as the recording of the test stimulus was conducted in an acoustically treated room with noise levels within permissible limits (ANSI S3.1, 1991). The Pure-tone audiometry and speech audiometry were carried out in a double room suite.

3.5 Test procedure

The study was implemented in three phases:

Phase I: Selection of participants for the study.

Phase II: Optimizing the amplification devices for each participant.

Phase III: Assessing the usefulness of the devices:

a. Sound field warble tone thresholds
b. Speech Identification Score in quiet
c. SNR50 in direct and indirect conditions
d. Subjective quality rating

Phase I: Selection of participants for the study

A set of preparatory tests were carried out to ensure that the participants were candidates for the study. It included a detailed case history of their otological and neurological conditions followed by Pure-tone audiometry, speech audiometry and tympanometry.

Pure-tone thresholds were obtained at octave frequencies between 250 Hz and 8000 Hz for air conduction and between 250 Hz and 4000 Hz for bone conduction using modified Hughson-Westlake procedure (Carhart & Jerger, 1959). Speech audiometry comprising of Speech recognition threshold (SRT), Speech identification Score and Uncomfortable Loudness level (UCL) was carried out. Tympanometry with 226 Hz as probe tone presented at 85 dB SPL was conducted to know the middle ear status and ipsilateral and contralateral reflex thresholds at 500, 1000, 2000 and 4000 Hz were acquired. Those participants with active ear discharge were not included for the study.

Participants who had unilateral hearing loss with either severe or profound hearing loss in the poorer ear and normal or near normal hearing sensitivity (PTA < 25 dBHL) in the better ear were selected.

Phase II: Optimizing the amplification devices for each participant

1. **T-CROS:**

   The poorer ear of each participant was aided with air conduction digitally programmable behind-the-ear hearing aid attached to a custom-made silicone shell earmold. The hearing aid was coupled to the HIPRO using suitable programming cable. The HIPRO was in turn attached to the personal computer in which the device specific programming software was installed. DSL (I/O) prescriptive formula was used for participants within the age range of 7-14 years and NAL-NL1 for individuals with age greater than 14 years. The hearing aid settings were programmed to get the maximum output and a feedback test was run if there was any trace of feedback.

The acoustic head shadow effect is frequency dependent with attenuation greater at higher frequencies starting from approximately 1.5 kHz and less prominent at lower frequencies below approximately 1 kHz (Shaw, 1974; Kompis et al., 1993; Algazi et al., 2002). As a consequence, for individuals with SSD, sounds below approximately 1.5 kHz reach the better ear without significant attenuation with a sound source placed at the side of the poorer ear. Whereas, the high frequency sounds from the same source suffer a remarkable attenuation by reason of the acoustic head shadow effect. Hence, low-frequency attenuation was incorporated into the study cutting down the gain for frequencies below 0.75kHz in the hearing aid. The directionality of the hearing aid microphone was set to omnidirectional and noise reduction was switched off to keep the features uniform across all the devices used in the study since BAHA 2 is devoid of directionality and feedback reduction. Lastly, before saving the settings into the hearing aid and database, the volume control was disabled, TacTronic switch was deactivated and Boot up delay was chosen.

Subsequent to the programming of T-CROS, a verification process was carried out to check whether the gain was sufficient enough to cross over and be available for the better ear. The following measurements were performed for the same:

A. Measurement of transcranial thresholds (TCTs)

B. Measurement of Real Ear Aided response (REAR)

The below mentioned step-by-step procedure outlined by Valente, Potts, Valente and Goebel (1995) for measuring the overall usefulness from the T-CROS was adopted. The participant was instructed to have his/her head steady while testing with TCROS.

Measurement of transcranial thresholds (TCTs):

1. The probe microphone from a real ear analyser (Fonix 7000) was equalized.
2. The probe tube was placed in the ear canal of the poorer ear along with the custom soft earmold at a predetermined length of 5 mm from the tip of the ear canal portion of the earmold.
3. An insert earphone (ER-3A) connected to a calibrated audiometer (Maico MA-52) was coupled to the tubing of the soft earmold using an adapter.
4. Pure tones were presented at 0.5, 1, 1.5, 2, 3 and 4k Hz and unmasked air conduction thresholds were obtained. At the obtainedthreshold level, the signal was presented continuously with the Fonix 7000 analyser set to ‘calibrate probe microphone’ and the SPL in the ear canal was read from the monitor of the analyser.
5. These SPL values procured represent the TCTs and function as baseline for assessing if the measured REARs for input levels of 50, 70, and 80 dB SPL overreach the TCTs.

Measurement of Real Ear Aided Response (REAR):

1. The sound field was equalized.

2. The TCTs were fed in as Hearing Threshold Levels (HTLs) in the target screen.
3. NAL-NL1 prescriptive formula was chosen.
4. As a consequence, target gain was obtained at different frequencies on the real ear SPL screen.
5. The Real Ear Aided Response (REAR) procedure was subsequently executed for input levels of 50, 70, and 80 dB SPL with Digi speech as the signal. For this, the loudspeaker was placed at a distance of one foot from the surface of the head and at ear level of the participant. The probe tube was placed in the ear canal of the poorer ear along with the custom soft earmold at a predetermined length of 5 mm from the tip of the ear canal portion of the earmold. The hearing aid was coupled to the tubing of the soft earmold.

2. Bone Anchored Hearing Aids:

BAHA 1:

The digitally programmable BAHA was connected to the personal computer loaded with the device specific programming software via the HIPRO with the help of an appropriate cable. The device was programmed based on the participant's better ear thresholds and their listening needs, according to the company's prescription for bone conduction for SSD.

As mentioned previously, sounds with frequency content lower than 1.5 kHz cross over to the opposite ear without noteworthy attenuation due to the frequency specific acoustic head shadow effect. Also, BAHAs tend to induce more distortion at lower frequencies (Pfiffner, Kompis, Flynn, Asnes, Arnold & Stieger, 2010). Moreover, as reported by Pfiffner et al. (2010) low frequency attenuation of up to 1.5 kHz in the BAHA sound processor will not undermine the advantages provided by BAHA in individuals with unilateral hearing loss in presence of noise coming from the front but in turn reduces the detrimental effects of noise arriving from the BAHA side. This reduction in the adverse effects of noise on speech perception was seen to increase with the low-frequency cut off values. Therefore, low-frequency attenuation was implemented with cut-off frequency of 0.75kHz. Two programs were switched off keeping one active for everyday listening situations. The microphone was set to omnidirectional mode, noise reduction was switched off and feedback reduction was kept to default. Volume control was disabled and position compensation was turned on. The BAHA was coupled to the headband and placed on the poorer ear mastoid prior to testing.

BAHA 2:

The settings on the BAHA 2 were optimized based on the identification of the Ling's six sounds for each participant. The trimmer controls were set to attenuate frequencies below 0.75 kHz.

Phase III: Assessing the usefulness of the devices:

a. Sound field warble tone thresholds

Warble tones were presented at frequencies 0.5, 1, 2 and 4k Hz through the loudspeaker placed at 45^0, towards the side of the test ear and at one meter distance from the participant. Instructions were given to the participant to indicate whenever he heard a tone, no matter how soft it was. The lowest intensity at which the participant responded positively 50% of the time was taken as the threshold. This procedure was conducted in unaided and three aided conditions. Aided conditions included testing with T-CROS, with BAHA1 and BAHA2. The better ear of the participant was blocked by a combination of ear plug and ear muffs (NRR = 39 dB approx.) both in aided and unaided conditions (Wazen, Spitzer, Ghossaini, Kacker & Zschommler, 2001). Blocking the better ear was chosen over masking by noise since noise would adversely affect the performance of the better ear for transcranial conduction, in turn reducing the efficiency of the amplification devices. The order of aided conditions was randomised among the participants to hinder the order effect. Consequently, four sets of warble tone thresholds were acquired for each participant.

b. Speech Identification Score in quiet

SIS was obtained using PB word list in Kannada (Yathiraj & Vijayalakshmi, 2005) for adults. Whereas, the PB word list developed by Yathiraj and Vandana (1998) was made use of for children. The loudspeaker was located at 45^0, towards the side of the test ear and at one meter distance from the participant. The participation of the better ear was excluded by blocking it with the help of ear plug and ear muffs. The list was presented at 40 dB HL at a distance of 6-7 inches from the microphone of the audiometer and the participant was instructed to repeat the words comprehended. The total number of correctly repeated words was noted to calculate the SIS. This was repeated for each of the aided conditions and in unaided condition.

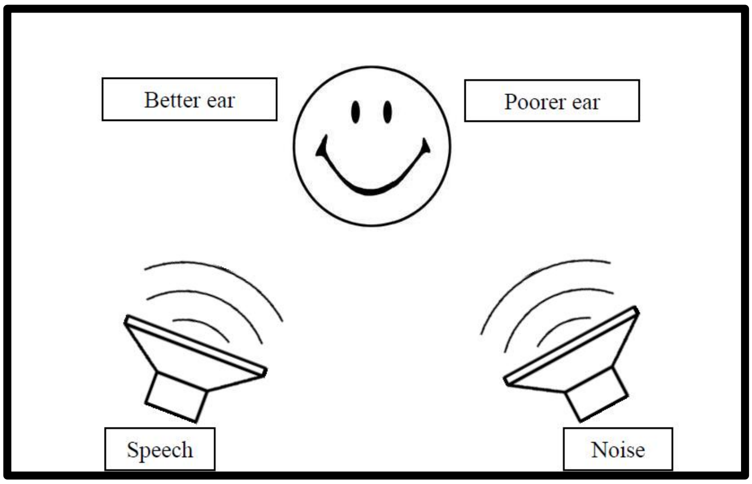
c. *SNR50 in direct and indirect conditions*

Signal to Noise Ratio - 50 (SNR-50) is defined as the difference between the intensity of the live speech material and the intensity of the speech noise in dB when the participant repeats back at least two words in a set of three words presented along with competing speech noise. The SNR-50 was obtained in two conditions for each of the aided conditions and in unaided condition as depicted in the Figure 3.1:

Direct: Signal presented towards the better ear and noise towards the poorer ear.

Indirect: Signal presented towards the poorer ear and noise towards the better ear.

A) Direct condition



B) Indirect condition

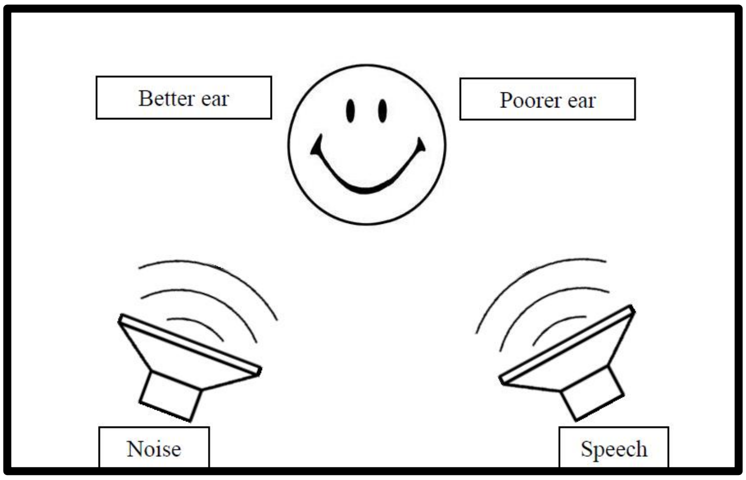


Figure 3.1: Depiction of A) Direct condition in which the signal is presented to better ear and noise to the poorer ear. B) Indirect condition in which the signal is presented to poorer ear and noise to the better ear.

The participant was asked to sit comfortably on a chair at one meter distance from the loudspeaker. A list of 40 sets of Kannada bi-syllabic words developed by Sahgal and Manjula (2005) was used to find out the SNR 50. The speech material was presented at a constant intensity of 40 dB HL. The speech noise was started at an intensity 15 dB lower than the signal and manipulated systematically in one dB step. The patient was asked to reiterate the words comprehended. At each level of noise, a set of three words were presented to the participant. The level of noise was increased by one dB if the participant restated at least two out of three words correctly. If they failed to repeat at least two of the three words, then the level of noise was dropped by two dB. This procedure was carried on till the highest level of speech noise was reached in the presence of which the participant could repeat at least two out of the three words correctly. The difference between the signal and noise at this juncture was taken as the SNR-50.

d. Subjective quality rating

Subjective quality rating for speech was obtained only for Group I participants since it was assumed that children below age 14 years would not be able to reliably subjectively rate the quality of the hearing devices. The quality rating scale developed by Eisenberg and Dirks (1995) was modified and made use of for the project. The five-point rating scale used in the study had five parameters on which the devices were to be evaluated. They were loudness, fullness, clarity, naturalness and overall fidelity. Participants had to assign numbers towards each parameter from 1 to 5 where in 1 was worst and 5 was best.

The stimulus used for the subjective quality rating was a recorded Kannada passage developed by Sairam and Manjula(2002) which was directed through the auxiliary input of the audiometer to the loudspeaker placed at one meter distance from the participant at the side of the test ear. The passage was presented at 65 dB SPL.

Chapter 4

RESULTS & DISCUSSION

The aim of the present study was to compare the audiological performance of the individuals with unilateral hearing loss while wearing Bone Anchored Hearing Aid attached to the headband and Transcranial CROS hearing aid in adults and children. The study also aimed at comparing the subjective quality ratings of the BAHA attached to the headband and Transcranial CROS in adults.

The study was conducted on two groups of participants, Group I had 15 children with severe to profound unilateral hearing loss and Group II consisted of 24 adults with severe to profound unilateral hearing loss. For both the groups, data were collected in 4 conditions:

a. Unaided condition
b. With digitally programmable BAHA (BAHA1)
c. With trimmer digital BAHA (BAHA2)
d. With transcranial CROS (T-CROS)

The following measures were obtained in each of the above mentioned conditions:

a. Sound field warble tone thresholds at 500, 1000, 2000 and 4000 Hz with the better ear occluded by ear plug and ear muff.
b. Speech Identification Scores (SIS) in quiet condition with the better ear occluded by ear plug and ear muff.
c. Speech recognition threshold (SNR-50) in the presence of noise in two conditions, direct and indirect.

d. Subjective quality rating for a Kannada passage (Sairam & Manjula, 2002) with the better ear occluded by ear plug and ear muff. This was measured for the Group II participants and for the aided conditions alone.

The above obtained data were analysed using Statistical Package for Social Sciences (SPSS for windows, Version 17) software. The analysis was carried out separately for the Group I& II data. The following statistical tests were used in the present study:

- Descriptive statistics was taken up to obtain the mean and standard deviation of the above mentioned measures.
- Freidman test was carried out to find out whether the effects of the devices were significantly different from each other.
- Wilcoxon's signed rank test was used for pair-wise comparison of the devices whenever there was a significant difference obtained.

The results will be discussed under the following headings:

4.1 Functional measures

a. Group I (7-14 years)

b. Group II (15-50 years)

4.2 Subjective quality rating

4.3 Correlation between functional measures and subjective quality rating

4.1 Functional measures:

The mean and standard deviation values for each of the measures obtained in both the groups in each of the conditions have been calculated and tabulated in Table 4.1.

Table 4.1: *Mean and Standard deviation values for the sound field thresholds, SIS and SNR-50 scores obtained for both the groups in unaided and three aided conditions.*

Sl. no	**Group**	**Condition**	**Sound field thresholds** (dB) Mean (S.D.)				**SIS** (Max=25)	**SNR50** Mean (S.D.)	
			500 Hz	1000 Hz	2000 Hz	4000 Hz	Mean (S.D.)	D	ID
1.	I	Unaided	58.33 (14.47)	61.00 (12.84)	53.00 (8.19)	61.00 (6.87)	0.00	-3.20 (5.29)	5.73 (4.76)
		BAHA 1	25.67 (11.00)	26.00 (10.38)	21.67 (10.96)	28.00 (5.28)	22.07 (1.94)	0.20 (6.80)	6.40 (3.62)
		BAHA 2	28.33 (15.08)	26.00 (14.29)	25.00 (10.52)	45.67 (12.80)	21.73 (2.60)	-3.07 (4.79)	6.53 (4.27)
		T-CROS	44.33 (9.98)	32.00 (13.47)	23.00 (10.99)	40.33 (12.31)	16.93 (5.26)	-4.00 (4.12)	5.80 (4.69)
2.	II	Unaided	53.12 (10.61)	51.87 (7.34)	51.46 (11.56)	64.37 (10.03)	0.00	-5.67 (6.80)	3.12 (6.01)
		BAHA 1	15.42 (9.43)	20.21 (11.08)	19.37 (11.64)	30.21 (14.70)	23.08 (2.28)	-4.87 (6.40)	1.17 (5.48)
		BAHA 2	17.29 (9.89)	17.92 (12.42)	26.25 (13.53)	49.17 (16.26)	22.46 (3.20)	-6.37 (5.39)	2.33 (6.25)
		T-CROS	38.33 (9.40)	20.42 (10.62)	22.71 (10.93)	43.96 (19.72)	18.29 (4.51)	-6.37 (5.45)	3.04 (6.15)

Note: D = Direct condition, ID = Indirect condition

The description of the trend observed in the mean data is as follows:

1. The mean data for the sound field thresholds show that the aided thresholds were considerably better than the unaided. It can be observed that the thresholds were lowest for the BAHA 1 as compared to other devices and that the thresholds were slightly better at the lower frequencies for all the devices.
2. The SIS in the quiet condition remarkably improved from the unaided condition to the aided and BAHA 1 obtained higher scores compared to other devices.
3. Better performance on the SNR-50 test would yield lower SNR scores. The direct SNR-50 values were seen to be lower than indirect and the T-CROS hearing aid seemed to interfere less with the speech perception and hence had better SNR than the other devices. No observable differences were seen across the devices in terms of the indirect SNR-50 values.

The data displayed in Table 4.1 shows vast variability indicating the group lacked homogeneity, hence non-parametric statistics was considered for the analysis. Freidman test was applied on the sound field thresholds, SIS obtained in the quiet condition and the SNR-50 values to find out whether the hearing devices were significantly different from each other. Further, Wilcoxon's Signed Rank test was utilized for the pair wise comparison wherever a significance was seen in the Friedman test. The analysis was carried out separately for Group I and Group II.

a. Group I:

The sound field thresholds, SIS measured in quiet condition and the SNR-50 values obtained in direct and indirect conditions obtained in

Group I were analysed using Freidman test and the results have been tabulated in Table 4.2.

Table 4.2: *Comparison of the unaided and aided conditions on the basis of sound field thresholds, SIS and SNR-50 values in Group I.*

Sl. No.	**Measures**	**χ^2 (df)**	**p**
1.	500 Hz	40.41 (3)	0.000
2.	1000 Hz	33.19 (3)	0.000
3.	2000 Hz	32.60 (3)	0.000
4.	4000 Hz	36.10 (3)	0.000
5.	SIS	41.60 (3)	0.000
6.	SNR-50 Direct	14.03 (3)	0.003
7.	SNR-50 Indirect	3.94 (3)	0.267

It can be inferred from the above table that the listening conditions were significantly different ($p < 0.05$) from each other as measured in terms of sound field thresholds, SIS obtained in quiet condition and SNR-50 direct. However, the listening conditions did not differ significantly in terms of SNR-50 indirect measure. This indicates that the aided condition was not significantly different from the unaided condition and there was no significant benefit from the hearing devices for Group I in the presence of noise. Further, Wilcoxon's Signed Rank test was applied wherever significant differences were obtained across the listening conditions. The results of the Wilcoxon's Signed Rank test for the sound field thresholds have been displayed in the Table 4.3.

Wilcoxon's Signed Rank test for the sound field thresholds revealed that the unaided sound field thresholds were significantly different from those of aided condition for all the measures with the aided scores being better. However, the results varied across frequencies for the aided condition. It was observed that at 500 Hz, both the BAHA devices performed better than the T-CROS device. Similar results were obtained by Shastri (2010) who compared the performance of BAHA attached to a headband and AC hearing aid in individuals with conductive and mixed hearing loss. At 1000 and 2000 Hz, all the devices performed more or less to the same extent and at 4000 Hz, BAHA 1 scored better than the BAHA 2 and T-CROS.

Table 4.3: *Pairwise-comparison of the unaided and aided conditions for sound field thresholds in Group I.*

Measure	Condition	Unaided	BAHA 1	BAHA 2	T-CROS
500 Hz	Unaided	-	SD	SD	SD
	BAHA 1	SD	-	NSD	SD
	BAHA 2	SD	NSD	-	SD
	T-CROS	SD	SD	SD	-
1000 Hz	Unaided	-	SD	SD	SD
	BAHA 1	SD	-	NSD	SD
	BAHA 2	SD	NSD	-	NSD
	T-CROS	SD	SD	NSD	-
2000 Hz	Unaided	-	SD	SD	SD
	BAHA 1	SD	-	NSD	NSD
	BAHA 2	SD	NSD	-	NSD
	T-CROS	SD	NSD	NSD	-
4000 Hz	Unaided	-	SD	SD	SD
	BAHA 1	SD	-	SD	SD
	BAHA 2	SD	SD	-	NSD
	T-CROS	SD	SD	NSD	-

Note: SD-Significantly Different ($p<0.05$), NSD-Not Significantly Different ($p>0.05$)

The results of the Wilcoxon's Signed Rank test for the SIS obtained in the quiet condition and for the SNR-50 obtained in the direct condition for the Group I are as displayed in the Table 4.4.

Table 4.4: *Pairwise-comparison of the unaided and aided conditions for SIS and SNR-50 direct values in Group I.*

Measure	Condition	Unaided	BAHA 1	BAHA 2	T-CROS
SIS	Unaided	-	SD	SD	SD
	BAHA 1	SD	-	NSD	SD
	BAHA 2	SD	NSD	-	SD
	T-CROS	SD	SD	SD	-
SNR-50 Direct	Unaided	-	SD	NSD	NSD
	BAHA 1	SD	-	SD	SD
	BAHA 2	NSD	SD	-	NSD
	T-CROS	NSD	SD	NSD	-

Note: SD-Significantly Different (p<0.05), NSD-Not Significantly Different (p>0.05)

Table 4.4 represents the finding that the unaided SIS scores were significantly different from the aided scores. It is also evident that the scores with both the BAHA devices were significantly different than those with the T-CROS hearing aid, with BAHA scoring better. Niparko, Cox, and Lustig (2003) also obtained significantly higher scores with the BAHA compared to the conventional CROS in individuals with unilateral hearing as measured in quiet condition.With respect to the SNR-50 measured in direct condition, only BAHA 1 made a significant difference from the unaided condition. Also, BAHA 1 differed significantly from the BAHA 2 and T-CROS, however, there was no significant difference between BAHA 2 and T-CROS. From Table 4.1 it can be inferred that the Group I participants required higher SNR with BAHA 1 to achieve the 50% score compared to the unaided and the other aided conditions. This means that the BAHA 1 was having a significant adverse effect on the speech perceptionwhen the signal was given to the better ear and noise towards the poorer ear.

b. Group II:

The sound field thresholds, SIS measured in quiet condition and the SNR-50 values obtained in direct and indirect conditions in Group II were analysed using Freidman test and the results have been tabulated in Table 4.5.

Table 4.5 indicates that listening conditions were significantly different ($p < 0.05$) from each other as measured in terms of sound field thresholds, SIS obtained in quiet condition and SNR-50 indirect. However, it can be seen that the listening conditions did not differ significantly in terms of SNR-50 direct measure. This shows that the aided condition was not significantly different from the unaided condition and neither of the devices had any adverse effects on the speech perception as evident in Table 4.1. However, this result is in contradiction to that reported by Niparko, Cox, and Lustig (2003), who measured speech perception in noise using HINT in ten adults with unilateral hearing loss. They compared the speech perception performance in the presence of noise in unaided and while the individuals were aided with the conventional CROS and the BAHA. They reported that in the direct condition, there was significant difference between the unaided and both the aided conditions and that BAHA performed better than the conventional CROS. The significance of difference seen in the SNR-50 indirect condition shows that the aided condition was significantly different from the unaided, and from the Table 4.1, it can be inferred that the aids were beneficial to the individuals with unilateral hearing loss.

Table 4.5: *Comparison of the unaided and aided conditions on the basis of sound field thresholds, SIS and SNR-50 values in Group II.*

Sl. No.	**Measures**	**χ^2 (df)**	**p**
1.	500 Hz	65.48 (3)	0.000
2.	1000 Hz	47.88 (3)	0.000
3.	2000 Hz	49.14 (3)	0.000
4.	4000 Hz	53.62 (3)	0.000
5.	SIS	57.08 (3)	0.000
6.	SNR-50 Direct	6.28 (3)	0.090
7.	SNR-50 Indirect	10.89 (3)	0.010

Further, Wilcoxon's Signed Rank test was applied wherever significant differences were obtained across the listening conditions. The results of the Wilcoxon's Signed Rank test for the sound field thresholds have been displayed in the Table 4.6.

Table 4.6: *Pairwise-comparison of the unaided and aided conditions for sound field thresholds in Group II.*

Measure	Condition	Unaided	BAHA 1	BAHA 2	TCROS
500 Hz	Unaided	-	SD	SD	SD
	BAHA 1	SD	-	NSD	SD
	BAHA 2	SD	NSD	-	SD
	T-CROS	SD	SD	SD	-
1000 Hz	Unaided	-	SD	SD	SD
	BAHA 1	SD	-	NSD	NSD
	BAHA 2	SD	NSD	-	NSD
	T-CROS	SD	NSD	NSD	-
2000 Hz	Unaided	-	SD	SD	SD
	BAHA 1	SD	-	SD	NSD
	BAHA 2	SD	SD	-	NSD
	T-CROS	SD	NSD	NSD	-
4000 Hz	Unaided	-	SD	SD	SD
	BAHA 1	SD	-	SD	SD
	BAHA 2	SD	SD	-	NSD
	T-CROS	SD	SD	NSD	-

Note: SD-Significantly Different ($p<0.05$), NSD-Not Significantly Different ($p>0.05$)

From the Table 4.6, it can be deduced that the unaided sound field thresholds are significantly different from those of aided condition for all the frequencies, aided scores being better. However, the results vary across frequencies for the aided condition. Like the results for Group I participants, even in Group II participants, it was observed that at 500 Hz, both the BAHA devices performed better than the T-CROS device. At 1000 and 2000 Hz, all the devices performed more or less to the same extent and at 4000 Hz BAHA 1 scored better than the BAHA 2 and T-CROS.

The results of the Wilcoxon's Signed Rank test for the SIS obtained in the quiet condition and for the SNR-50 obtained in the indirect condition for the Group II participants are as displayed in the Table 4.7.

Table 4.7: *Pairwise-comparison of the unaided and aided conditions for SIS and SNR-50 indirect values in Group II.*

Measure	Condition	Unaided	BAHA 1	BAHA 2	T-CROS
SIS	Unaided	-	SD	SD	SD
	BAHA 1	SD	-	NSD	SD
	BAHA 2	SD	NSD	-	SD
	T-CROS	SD	SD	SD	-
SNR-50 Indirect	Unaided	-	SD	NSD	NSD
	BAHA 1	SD	-	SD	SD
	BAHA 2	NSD	SD	-	NSD
	T-CROS	NSD	SD	NSD	-

Note: SD-Significantly Different (p<0.05), NSD-Not Significantly Different (p>0.05)

The above table, Table 4.7 depicts that the unaided SIS scores were significantly different from the aided scores. On comparison of the unaided condition and the T-CROS aided condition, it is seen in Table 4.1 that the T-CROS was beneficial for the participants in quiet condition when the better ear was blocked with ear plugs and ear muffs. This is not in agreement with Niparko, Cox, and Lustig (2003), who reported that the participants scored higher in the unaided condition when compared to the conventional CROS aided condition. This discrepancy must be due to the methodological differences between the studies, where they have measured speech perception in quiet condition without blocking the better ear. It was also seen that the BAHA was beneficial for speech perception in quiet condition for the participants of the present study when compared to the unaided condition. The same has been reported by Niparko, Cox, and Lustig (2003).

It is also evident from Table 4.7 that the SISmeasured in quiet with both the BAHA devices were significantly different than those with the T-CROS hearing aid, with no difference between BAHA 1 and BAHA 2. From Table 4.1, both the BAHAs yielded higher scores than the T-CROS. This is in agreement with the Niparko, Cox, and Lustig (2003) study where they also found that the participants performed well with the BAHA when compared to the conventional CROS.

With respect to the SNR-50 measured in indirect condition, only BAHA 1 made a significant difference from the unaided condition while BAHA 2 and CROS were similar to the unaided condition. Also, BAHA 1 differed significantly from the BAHA 2 and T-CROS, however, there was no significant difference between BAHA 2 and T-CROS. This indicates that only BAHA 1 was beneficial for the individuals with unilateral hearing loss in noisy condition. This can be speculated to be due to an additional feature named positional compensation present only in BAHA 1 when compared to BAHA 2 along with better fine tuning facility. Niparko, Cox, and Lustig (2003) reported that the unaided condition was significantly different from both the BAHA and CROS aided conditions and that the aided scores were better than the unaided scores. Similar to the current study, Niparko, Cox, and Lustig (2003) and Hol, Bosman, Snik, Mylanus, and Cremers (2004)also reported that the participants scored higher with the BAHA when compared to the conventional CROS.

4.2 Subjective Quality Rating

The subjective quality rating was obtained only from the Group II participants, since it was believed that children below 14 years would not be able to reliably subjectively rate the quality of the hearing devices. The five-point rating scale used in the study had five parameters on which the devices were to be evaluated. They were loudness, fullness, clarity, naturalness and overall fidelity. Participants had to assign numbers towards each parameter from 1 to 5 where in 1 was worst and 5 was best. The mean and standard deviation of the ranks for each of the five parametersfor each of the devices have been calculated and tabulated in Table 4.8.

Table 4.8: *Mean and standard deviation of the ranksacross the devices for each of the parameters of the subjective rating scale.*

Sl. No.	**Parameter**	**BAHA 1** Mean (S.D.)	**BAHA 2** Mean (S.D.)	**T-CROS** Mean (S.D.)
1.	Loudness	4.71 (0.46)	4.54 (0.58)	3.62 (1.01)
2.	Fullness	4.71 (0.46)	4.54 (0.77)	3.66 (1.04)
3.	Clarity	4.66 (0.56)	4.71 (0.55)	3.37 (1.13)
4.	Naturalness	4.45 (0.72)	4.41 (0.65)	3.25 (1.07)
5.	Overall Fidelity	4.58 (0.50)	4.50 (0.65)	3.41 (0.77)

From Table 4.8, it can be deduced that both the BAHAs scored higher than the T-CROS and that there was no noticeable difference across the parameters. Freidman test was administered to find out whether any significant difference existed across the hearing devices in terms of the quality perceived by the participants. The results of the test have been tabulated in the Table 4.9.

Table 4.9: *Comparison of the unaided and aided conditions on the basis of subjective quality rating in Group II.*

Sl. No.	Parameter	χ^2 (df)	p
1.	Loudness	26.16 (2)	0.000
2.	Fullness	21.12 (2)	0.000
3.	Clarity	26.00 (2)	0.000
4.	Naturalness	27.43 (2)	0.000
5.	Overall Fidelity	28.03 (2)	0.000

It can be understood from the Table 4.9 that the hearing devices were significantly different ($p < 0.05$) from each other in terms of their perceived sound quality. Consequently, Wilcoxon's Signed Rank test was applied wherever significant differences were observed across the hearing devices. The results of all the parameters has been presented in the Table 4.10.

Table 4.10: *Pairwise comparison of the aided conditions for all the parameters of Subjective quality rating in Group II.*

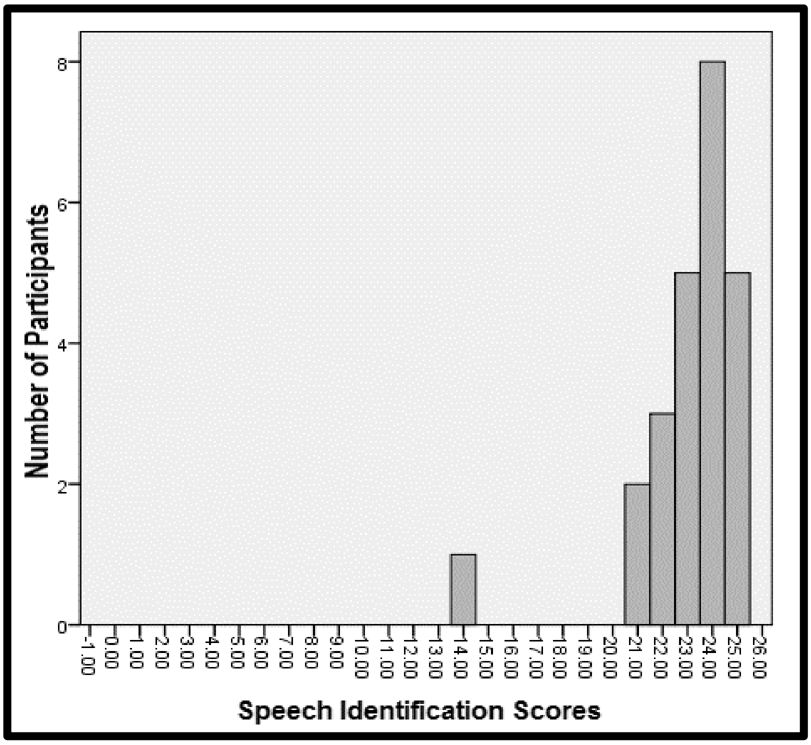
Sl. No.	Parameter	Condition	BAHA 1	BAHA 2	T-CROS
1.	Loudness	BAHA 1	-	NSD	SD
		BAHA 2	NSD	-	SD
		T-CROS	SD	SD	-
2.	Fullness	BAHA 1	-	NSD	SD
		BAHA 2	NSD	-	SD
		T-CROS	SD	SD	-
3.	Clarity	BAHA 1	-	NSD	SD
		BAHA 2	NSD	-	SD
		T-CROS	SD	SD	-
4.	Naturalness	BAHA 1	-	NSD	SD
		BAHA 2	NSD	-	SD
		T-CROS	SD	SD	-
5.	Overall Fidelity	BAHA 1	-	NSD	SD
		BAHA 2	NSD	-	SD
		T-CROS	SD	SD	-

Note: SD-Significantly Different ($p<0.05$), NSD-Not Significantly Different ($p>0.05$)

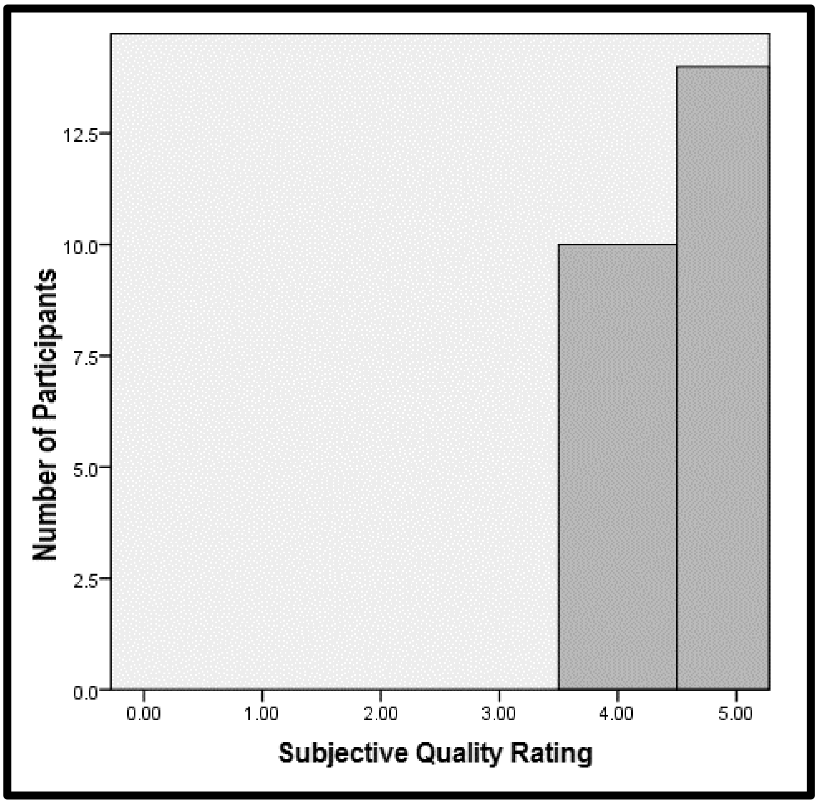
It is evident from Table 4.10, that the subjective quality in terms of all the parameters of both the BAHA 1 and BAHA 2 did not differ significantly, however a difference was observed between the two BAHAs and the T-CROS. It was also seen that the BAHAs obtained a higher quality rating than the T-CROS. The same was reported by Bosman, Hol, Snik, Mylanus and Cremers (2003) and also by Hol, Bosman, Snik, Mylanus and Cremers (2004), who compared the performance of conventional CROS and BAHA in individuals with unilateral hearing loss using the Abbreviated Profile of Hearing Aid Benefit (APHAB).

4.3 Correlation between the functional and subjective measures:

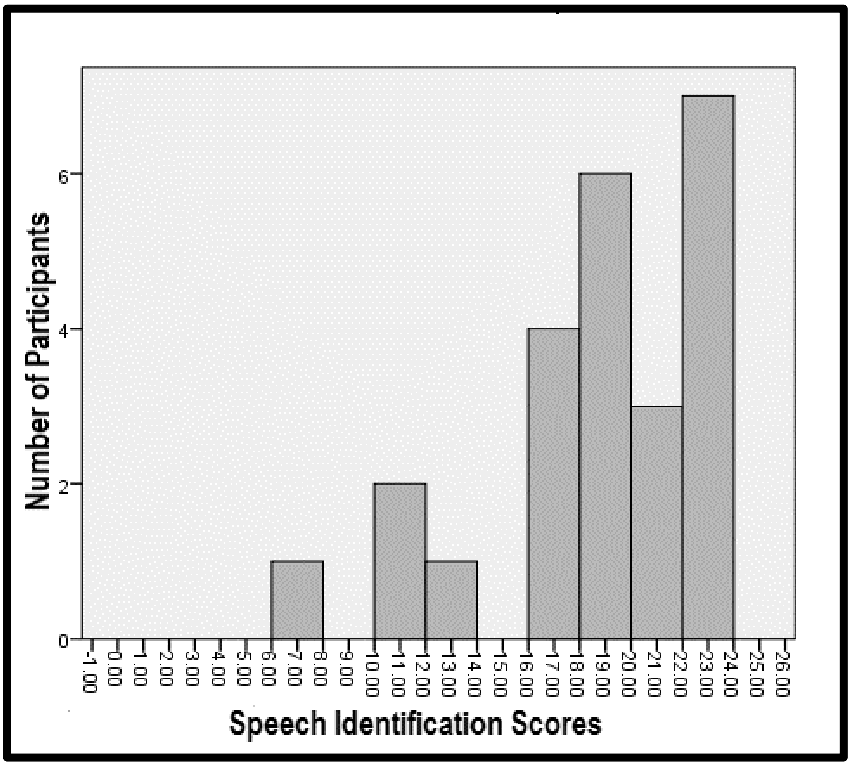
From the previous section it is understood that the BAHA 1 did not significantly differ from BAHA 2 in terms of the subjective quality rating. Additionally, both BAHA 1 and BAHA 2 were not significantly different from each other in terms of the SIS measured in quiet as shown in Table 4.7. Therefore, only BAHA 1 and T-CROS were subjected to correlational analysis, omitting BAHA 2, since results of BAHA 1 would apply to BAHA 2 as well.Furthermore, Table 4.10 conveys that the hearing devices differed among themselves in a similar fashion for all the parameters. Hence, only the overall fidelity parameter was considered for correlational analysis and the result was generalised across the other parameters of the rating scale. The correlation between the aided SIS obtained in the quiet condition with the BAHA 1 and the T-CROSand the overall fidelity parameter in the subjective quality rating was checked using Spearman’s Correlation. The results showed no significant correlation between the two measures with both BAHA 1 and T-CROS. However, this can be speculated to be due to the reduced range of both the SIS and the subjective quality rating with the BAHA 1 as depictedin Graphs 4.1 and 4.2 and also with the T-CROS as shown in Graphs 4.3 and 4.4 respectively.



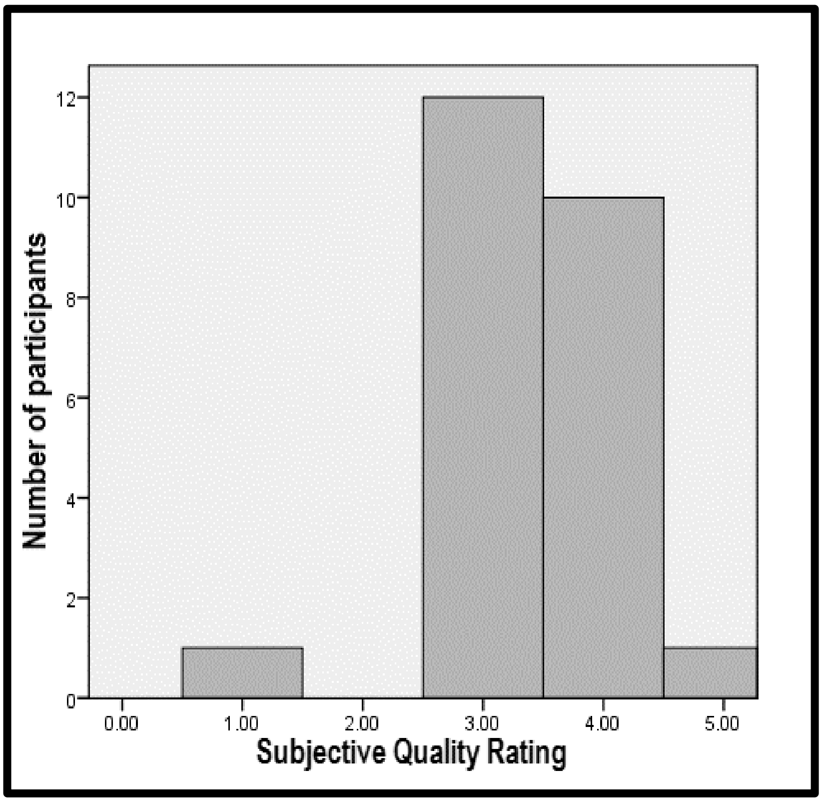
*Graph 4.1:*Depiction of the range of SISacross number of participants with the BAHA 1



Graph 4.2: Depiction of the range of subjective quality rating across number of participants with the BAHA 1



Graph 4.3: Depiction of the range of SIS across number of participants with the T-CROS



Graph 4.4: Depiction of the range of subjective quality rating across number of participants with the T-CROS

As can be seen in Graph 4.1 and 4.3, the speech identification scores measured in quiet in the aided condition were all clustered towards the higher end. Similarly in Graph 4.2 and 4.4, the overall fidelity parameter in the subjective quality rating, reveals that the ratings were cornered towards the higher scores. Hence, due to the reduced range of the variables, the results of the correlation analysis can be considered to be less reliable.

Chapter 5

SUMMARY AND CONCLUSION

The current study was taken up with the aim of comparing the sound field thresholds, speech perception performancein quiet and noise and the subjective quality rating of speech, while the participants with unilateral hearing loss were aided with either T-CROS or BAHA attached to the headband. The study was carried out on two groups of participants, Group I consisted of child participants and Group II had adult participants. All the participants were naïve users of hearing amplification devices.

The study was carried out in three phases:

Phase I: Participants who had unilateral hearing loss with either severe or profound hearing loss in the poorer ear and normal or near normal hearing sensitivity (PTA < 25 dBHL) in the better ear were selected. Group I had 15 children and Group II consisted of 24 adults.

Phase II: The amplification devices, T-CROS, BAHA 1 and BAHA 2 were optimized for each of the participants in both the groups.

Phase III: Measurement of the sound field thresholds, speech perception performance in quiet and noise and subjective quality rating for speech was conducted while the participants were aided with either of the hearing amplification devices. The following assessments were carried out in unaided and three aided conditions:

1. Aided and unaided sound field thresholds for warble tones of frequencies 500, 1000, 2000 and 4000 Hz for both groups with the better ear occluded by ear plug and ear muff.

2. Aided and unaided SIS in quiet for both groups with the better ear occluded by ear plug and ear muff.
3. Aided and unaided SNR50 in direct and indirect conditions for both the groups.
4. Aided subjective quality rating for Group II participants with the better ear occluded by ear plug and ear muff.

The data obtained by the above measurements were analysed separately for both the groups using descriptive statistics, Friedman's test, Wilcoxon's signed rank test and Spearman's Correlation.

5.1 Functional measures:

a. Sound field thresholds: In Group I participants, aided thresholds were significantly better than those of unaided condition at all frequencies. Participants performed better with both the BAHAs at 500 Hz when compared to the T-CROS. At 1000 and 2000 Hz, all the devices performed more or less to the same extent and at 4000 Hz BAHA 1 scored better than the BAHA 2 and T-CROS. Same results were obtained in Group II as well.
b. SIS in quiet condition: Aided SIS in quiet was significantly better than unaided with both the BAHA devices being more beneficial than the T-CROS. No significant difference was observed between the two BAHA devices.This result was true for both the groups.
c. SNR-50: In terms of SNR-50 direct measure in Group I participants, only BAHA 1 was significantly different from the unaided condition. Whereas, the listening conditions did not differ significantly in Group II participants. In case of SNR-50 indirect measure in Group I participants, the listening conditions did not differ significantly. With respect to Group II participants, only BAHA

1 made a significant difference from the unaided condition while BAHA 2 and CROS were similar to the unaided condition.

5.2 Subjective quality rating:BAHA 1 and BAHA 2 did not differ significantly among themselves, however both the BAHAs obtained a higher quality rating than the T-CROS.

5.3 Correlation between the functional and subjective measures: No significant correlation was seen between SIS obtained in the quiet condition and the subjective quality rating. However, this can be speculated to be due to the reduced range of both the SIS and the subjective quality rating and hence, the results of the correlation analysis to be less reliable.

From the results of the current study, it can be concluded that both BAHA attached to the headband and the T-CROS provide significant benefit for both adults and children with unilateral hearing loss. However, the participants performed better with the BAHA than the T-CROS in both quiet and noise for most of the measures, with both the digitally programmable and the trimmer digital BAHA performing more or less to the same extent. Furthermore, BAHA can be expected to provide greater improvements after implantation as it was reported by Verstraeten et al., (2009) that implanted BAHA yields 5 to 20 dB better thresholds compared to pre-implant BAHA. In terms of speech perception, this post implant increment can lead to a bettering of the speech reception threshold by up to 4 to 7 dB, which in turn improves the SIS by about 20 to 40% as reported by Verstraeten et al., (2009).

5.4 Clinical Implications:

1. The current study helps in prioritizing the hearing amplification devices for the trial and also helps in arriving at the appropriate hearing amplification device for the individuals with unilateral hearing loss.
2. The present study provides a comparisonof thedigitally programmable BAHA, the trimmer digital BAHA and the T-CROS, which will help in the counsellingof the individuals with unilateral hearing concerning the available rehabilitation options and their comparative performance.
3. The current study confirms that there are rehabilitation options for the individuals with unilateral hearing loss which prove to be beneficial compared to the performance without amplification.
4. The results of the current study show that both the T-CROS and BAHA provided significant benefit when compared to the unaided condition with BAHA being better than T-CROS. From this, it can be deduced that,if the individuals with unilateral hearing loss cannot afford the higher cost of the BAHA, they can opt the T-CROS, which is also beneficial to some extent.

5.5 Future research directions:

1. Comparison of the rehabilitation options in individuals with asymmetrical hearing loss with severe to profound hearing loss in the poorer ear and minimal hearing loss in the better ear.
2. Comparison of the rehabilitation options in individuals with unilateral hearing loss of severe and profound degree in the poorer ear.

3. Correlationof the academic performance and speech and language development before and after rehabilitation in children with unilateral hearing loss.
4. Subjective evaluation of the rehabilitation options in daily listening environments in adults with unilateral hearing loss.
5. Longitudinal evaluation of the benefit of BAHA in individuals with unilateral hearing loss in various listening conditions.
6. Comparison of speech perception performance with the pre-implanted BAHA and the osseo-integrated implant.

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