# COMPARISON OF PERFORMANCE WITH BILATERAL BONE ANCHORED HEARING AID PROCESSORS WITH TEST BAND AND BINAURAL AIR CONDUCTION HEARING AIDS

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# CERTIFICATE

This is to certify that this dissertation entitled ***Comparison of performance with bilateral Bone Anchored Hearing Aid processors with test band and binaural air conduction hearing aids*** is a bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student Registration No.: 10AUD034. This has been carried out the under guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree

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# CERTIFICATE

This is to certify that this dissertation entitled ***Comparison of performance with bilateral Bone Anchored Hearing Aid processors with test band and binaural air conduction hearing aids*** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

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# DECLARATION

This is to certify that this master's dissertation entitled ***Comparison of performance with bilateral Bone Anchored Hearing Aid processors with test band and binaural air conduction hearing aids*** is the result of my own study under the guidance of Ms. N. Devi, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other university for the award of any diploma or degree.

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# Introduction

Hearing loss can greatly affect the quality of life of an individual. It can have an impact on employment, education, and general well-being, unless and until it is properly managed. Fitting of air conduction hearing aids is considered to be an efficient treatment option for (partially) compensating hearing loss for many individuals with hearing loss. However, it is contraindicated for patients with certain medical conditions such as recurrent otorrhoea, otitis media which is refractory to treatment, post operative anatomical deficits, congenital aural atresia or otitis externa (Bosman, Snik, Van der pouw, Mylanus & Cremers, 2001).

According to Spitzer, Ghossaini and Wazen (2002) the use of air-conduction hearing aids in persons with chronically draining ears entails risk of continuing or worsening infection caused by an earmold, which prevents adequate aeration of the ear. Even though venting is used in an effort to permit airflow and thus promote healing, often it results in feedback and inadequate gain. These venting efforts are often insufficient to allow substantial aeration, and thus the medical condition may be exacerbated. In addition, many persons with chronic otologic disease who have had prior ear surgery, such as a mastoidectomy, would have anatomical defects making air conduction hearing aid fitting a difficult task. The technical difficulties have been reported to include a challenging process of taking an impression in an ear with a mastoid bowl with risk of leaving material behind when the impression is removed. Having obtained an impression in such an ear, the fit may be problematic resulting in unmanageable feedback prohibiting significant hearing aid benefit. In these cases, one alternative option is the use of bone conduction devices for transmission of amplified sounds (Bosman et al., 2001).

Bone conduction hearing aids bypass the normal sound passage through middle ear by vibrating the structures within the cochlea. A vibrator known as bone conductor is used as an output transducer. To effectively couple the vibrations to the skull and hence to the cochlea, the bone conductor is usually mounted on one side of a head band, which uses spring tension to push the bone conductor against the head. It can also be mounted on the arms of a spectacle aid. The hearing aid can be in a spectacle frame, in a BTE case mounted on the transducer headband, or in a body aid (Dillon, 2001).

Although conventional bone-conduction hearing aids have been used successfully for many years, they are associated with a number of practical problems resulting in limited use or patient rejection. Since an oscillator is held on the head using a headband and driven by a powerful hearing aid, it can result in discomfort caused by pressure on the mastoid. The tension on the headband is crucial to deliver sufficient bone-conduction stimulation, but stretching of the band is common, leading to reduced sound quality and power. Frequent readjustments are usually required because of tension failures. Complaints of headache or ulcers involving the skin of the mastoid area may occur from the pressure against the skull (Spitzer et al. 2002). Maximum sound power output is limited due to acoustico-mechanical limitations of the transducer, to limited static pressure, and to damping in the transmission path to the skull bone. Clinical practice shows that, due to the attenuation of the high frequencies by the skin and underlying tissue, sound quality is often judged rather poor when compared to air conduction aids. Finally, the static pressure necessary for correct operation of the aid by counteracting reactive forces often results in complaints of discomfort (Bosman et al. 2001).

In order to overcome the problems associated with both air- and bone-conduction hearing aids, the bone anchored hearing aids (BAHA) offers a reasonable alternative. The BAHA takes advantage of the ability of bone to form a tight closure around a titanium implant. Attaching to a screw implanted into the mastoid, an abutment protrudes through the skin. The BAHA is snapped into place, eliminating the need for the headband and its side effects. Otological conditions and/or indications for BAHA as described by Spitzer et al. (2002) are described in Table 1.

Table 1

*Otologic conditions and/or indications for candidacy for BAHA*

| **Otologic Condition** | **Associated Problems with Traditional Hearing Aids** |
|---|---|
| Draining ear, unresponsive to treatment | Use of an ear mold with an air-conduction aid prevents adequate aeration of ear. |
| Maximal conductive component in only hearing ear | Risk of possible loss of remaining hearing prohibits surgical treatment; BAHA is an alternative to traditional aid. |
| Postoperative ear defect:<br>- Large mastoid bowl, as results from Mastoidectomy.<br>- Absence of auricle, closure of ear canal, as in temporal bone resection | Ill-fitting ear mold leads to unmanageable feedback. |
| Congenital aural atresia | Use of bone-conduction aid often results in discomfort, pressure sores, headache, or poor hearing caused by inadequate band pressure. |
| Discomfort caused by ear mold, including itching or moisture | There may be no solution to this problem using hypoallergenic ear mold materials. |
| Discomfort from sound quality, especially from sound of one’s own voice | Occlusion effect accompanies use of ear mold or custom aid that occupies ear canal. |

Osseointegration of titanium implants was first demonstrated in the late 1960s by Per-Invar Branemark (Tjellstrom & Hakansson, 1995). The first clinical application of osseointegrated titanium implants was in the oral cavity to anchor a fixed bridge in an edentulous jaw (Branemark et al., 1977). Later 1970s, Tjellstrom and his coworkers introduced the use of titanium implants outside the oral cavity for bone anchored hearing aids (cited in Spitzer et al., 2002).

Bone anchoring utilizes a natural process called osseointegration. Osseointegration is the development of a solid connection between living bone and an implanted material. Titanium is used for the implant screw, but research has also shown that some forms of stainless steel can also undergo osseointegration. In this procedure, a titanium screw is implanted into the temporal bone behind the ear. The osseointegration process takes approximately 3 months, after which the BAHA can be fitted on the patient. An external abutment is connected to the implanted screw, and the BAHA can be joined to this abutment with a simple bayonette connector (Chasin, 1999). The BAHA, consisting of microphone, amplifier and vibration transducer, can be connected and disconnected to the abutment by the wearer at will. Owing to the direct coupling to the temporal bone, BAHA has been proved to be superior in both wearer comfort and sound quality over conventional bone conduction hearing aids (Hakansson, Tjellstrom, Rosenhall & Carlsson, 1985).

Generally, for conductive or mixed hearing loss, the patient should have adequate sensorineural reserve measured by a bone-curve of at least 45 dB HL for the head level processor, and an unaided speech discrimination score (word recognition score) greater than or equal to 60% (Habal, Frans, Zelski, & Scheuerle, 2003)

A bilateral fitting of BAHA should be considered for candidates with binaural hearing loss, which may lead to binaural hearing and in turn improving speech understanding, sound localization, and general candidate satisfaction.

(Hakansson, Tjellström, & Rosenhall, 1984; Van der pouw, Snik, & Cremers, 1999; Gründer, Seidl, Ernst & Todt, 2008)

A preoperative assessment is recommended which includes sound field testing using a BAHA held in contact with the head by a special, bone-conduction-style headband or a soft, sweatband-style headband. Another measure is a test rod with a BAHA snapped into it. The test rod is held between the teeth with the mouth closed, allowing the patient to hear the conducted signal. In the use of test bands or test rod, there is some inefficiency of signal transduction, particularly in the high frequencies. Although none of these means of applying the BAHA mimic the post-implantation result precisely, this may assist in selecting the side to be implanted. Since it demonstrates the effectiveness of bone conducted stimulation, the experience is helpful to the patient in developing an understanding of the potential of the BAHA (Spitzer et al., 2002).

### Need for the study

Markides, (1977); Festen & Plomp, (1986); Day, Browning & Gatehouse, (1988); Bronkhorst & Plomp, (1990); Jerger, Darling & Florin, (1995) have reported on the advantages of binaural application of air conduction hearing aids. Brooks, (1984) assessed patient’s subjective preference for either monaural or binaural fitting have shown that, in general binaural fitting was preferred.

In contrast to air conduction hearing aids, only a few studies have been published on the advantage of binaural bone conduction device fitting. It has often been argued that the binaural application of any bone conduction device may not be effective due to the very less intracranial attenuation of skull vibrations leading to the stimulation of both the cochleae almost to the same extent (Beynon, Van der pouw, Mylanus, & Cremers, 1998). However, Hamann, Manach and Roulleau (1991) reported that with bilateral application of bone anchored hearing aid, the speech reception threshold (SRT) in quiet was, on average, 4dB better with the bone anchored aids than with monaural application. However, any results on either sound localization or on speech recognition in noise was not included. Snik, Beynon, Pouw, Mylanus and Cremers (1998) studied sound localization and speech recognition in quiet as well as noise. The results revealed that there was an improvement in directional hearing for binaural bone anchored hearing aid application, but less directional hearing, or even none at all, for monaural application. Speech recognition threshold in quiet was found to be 3 to 6dB better with binaural bone anchored hearing aid and in the presence of noise there was an improvement of 2.9dB to 6dB with binaural fitting over monaural.

However, there is a dearth of studies on direct comparison between bilateral application of air conduction hearing aid and bone anchored hearing aids. Browning and Gatehouse (1994) suggested that pre-implantation evaluation of the difference in performance between the air-conduction hearing aid and a temporary conventional bone-conduction hearing aid might have value in predicting how patients who are advised to stop using their air conduction hearing aids will perform with a BAHA. A point that must be noted here is that on average patients perform significantly better with a BAHA than with a conventional bone-conduction hearing aid (Hakansson, Liden, Tjellstrom, et al. 1990; Cooper, Burrell, Powell, Proops & Bickerton, 1996; Mylanus, Snik, Cremers, Jorritsma & Verschuure, 1994).

Thus the present study makes an attempt to compare the benefits of bilateral fitting of bone anchored hearing aid using test band and binaural fitting of air conduction hearing aid.

## Aim

To compare the performance with bilateral fitting of BAHA with test band and air conduction hearing aids in individuals with bilateral conductive loss.

## Objectives

- To compare the sound field warble tone thresholds with bilateral fitting of BAHA with test band and binaural air conduction hearing aids
- To compare the speech perception abilities in quiet as well as in the presence of background noise with bilateral fitting of BAHA with test band and binaural air conduction hearing aids
- To compare the localization abilities with bilateral fitting of BAHA with test band and binaural air conduction hearing aids

# Chapter 2

## Review of literature

Surgical correction of conductive hearing loss is considered to be the principal and preferred treatment by most patients. But it may not be successful in all patients because of medical, anatomic or personal reasons. Although most who undergo an otologic operation achieve socially adequate hearing [i.e., speech recognition threshold of 25dBHL or less], some do not, and these patients can generally obtain additional benefit from amplification. In some cases where conductive hearing loss is there in the only hearing ear, the surgeon recommends amplification to avoid risk of surgical complications that might increase the hearing loss, provided that the conductive hearing loss is not the result of progressive disorder, such as cholesteatoma (Goebel, Valente, Valente, Enrieto, Layton, & Wallace, 2002).

### Overall strategies for amplification in conductive hearing loss

Hearing restoration requires an individualized approach based on many factors. Medical or surgical control of active infection of the external ear canal, tympanic membrane or middle ear must be obtained before amplification is prescribed. Surgical correction of dry tympanic membrane perforations, ossicular discontinuity, or ossicular fixation is recommended with amplification reserved for residual conductive or mixed losses after surgery. One exception would be the poor surgical candidate where amplification is the only alternative. In cases of severe aural atresia or uncontrolled chronic otitis media with an open mastoid cavity, surgical implantation of electromagnetic bone-anchored devices may not be a good option. In many instances patients may progress through their disease process that includes all medical, surgical, and rehabilitative options (Goebel et al. 2002).

Options for selecting and fitting hearing aids for conductive hearing loss can generally be divided into three categories. Patients can be fitted with air conduction hearing aids, bone-conduction hearing aid(s) or an implanted hearing device which can be either a bone anchored hearing aid (BAHA) or a Middle Ear Implant (MEI).

## 1. Conventional Air Conduction hearing aids

Determining which air-conduction hearing aid is most appropriate is usually based on; The magnitude of hearing loss, the magnitude of the air-bone and patient preference (Goebel et al., 2002). Age and Dexterity are the other factors which need to be considered.

As a general rule, as the hearing loss and magnitude of the air-bone gap increases, the need to fit a BTE or body hearing aid increases. Finally, air-conduction hearing aids, should be considered the most appropriate fitting for chronic conductive hearing loss when medical contraindications have been ruled out.

### Fitting Strategies for Air-Conduction Hearing Aids

Regardless of the type of air-conduction hearing aid, the appropriate real-ear gain for patients with conductive or mixed hearing loss can be determined by using many of the prescriptive procedures. That is, prescribed real-ear gain for hearing aids providing linear amplification is based on the air-conduction thresholds. Additional gain prescribed to compensate for the magnitude of the air-bone gap in conductive hearing loss.

Additional gain of 25% of the air-bone gap to the amplification requirements for patients with sensorineural hearing loss is recommended (Lybarger, 1955, 1963; Byrne, 1983; Byrne & Dillon, 1986). Whereas, Berger, Hagberg and Ranel (1984) recommended that 20% of the air-bone gap should be added with the maximum additional gain limited to 8 dB at any frequency.

Other than prescriptive formulae given by Berger et al (1984) and Byrne and Dillon (1986), no prescriptive formula has specified guidelines for providing additional gain to compensate for the air-bone gap. It has been recommended that audiologists should always consider adding between 20% and 25% of the air-bone gap to the prescribed gain even if the selected prescriptive procedure (Cox, 1983, 1988; McCandless, & Lyregaard, 1983; Libby, 1986) does not specifically provide such guidelines.

### Verification Strategies for Air-Conduction Hearing Aids

The verification process for air-conduction hearing aids can either be real-ear gain using probe tube or functional gain measures, paired comparisons, and/or subjective evaluations.

## 2. Bone-Conduction Hearing aids

Bone-conduction hearing aids are available in BTE and in eyeglass and body configurations. Bone-conduction aids are considered the most appropriate hearing aid fitting when there are contraindications to use air conduction hearing aids such as atresia, severe stenosis of the ear canal, chronic middle ear drainage, and chronic allergic reaction to the materials used to manufacture ear molds. In addition, it is important that bone-condition thresholds should be within normal limits or only minimally affected in order to achieve success with this type of amplification (Goebel et al., 2002).

Bone-conduction hearing aids deliver the amplified sound to a bone vibrator that is held in place over the mastoid process using a headband or eye-glass frame. The most frequently used bone-conduction hearing aids are eyeglass and body designs. The major limitations of bone-conduction hearing aids are the minimal available gain at 3000 to 4000 Hz and difficulties involved in achieving the precise placement and tension of the vibrator on the mastoid process. In addition, many patients using bone-conduction hearing aids complain of headaches and soreness around the mastoid process due to the pressure of the bone vibrator on the mastoid process (Bosman et al., 2001; Spitzer et al., 2002).

### Fitting strategies for Bone Conduction hearing aids

Lybarger (1963) suggested that if the air-bone gap is less than 25dBHL, then a conventional air-conduction hearing aid is the appropriate fitting. If the air-bone gap is between 25 and 40dBHL, then either an air-conduction or bone-conduction fitting may be sitable. Finally, if the air-bone gap is greater than 40dB HL, then a bone-conduction fitting may be the most appropriate.

A preferred practice of fitting bone conduction hearing aids is that it should initially be selected and adjusted based on the hearing aid specifications, followed by measurement of functional gain or the use of other subjective techniques (Dillon, 2001). He suggested that, to convert any prescription formula for air conduction hearing aids into one for prescription of bone conduction hearing aids, acousto-mechanical sensitivity level, A, should be found out. Acousto-mechanical sensitivity level is a measure which, on average, results in a sensation level equal to that provided by air conduction hearing aids. It can be calculated from the following equation

Acousto-mechanical sensitivity level, A = IG + (RETFL - MAF) – C, where RETFL is the Reference Equivalent Threshold Force Level referred to an artificial mastoid, MAF is the Minimum Audible Field for normal hearing and C is the conductive component of the person's hearing loss, as quantified by the air-bone gap.

The equation is derived based on the fact that the bone conductor acousto-mechanical sensitivity must be different from the insertion gain by the amount that, for normally hearing individual the force level at threshold exceeds the sound pressure level at threshold. In addition prescription of bone conduction hearing aids does not need to account for the conductive component of the hearing loss in its gain, because the bone-conduction path bypasses the middle ear and that is why the term C is subtracted in the equation.

Alternatively, if one starts from a prescription for real ear aided gain (REAG) rather than insertion gain, then the required acousto-mechanical sensitivity level can be calculated from the following equation

Acousto-mechanical sensitivity level, A = REAG + (RETFL - MAP) – C, where MAP is the minimum audible pressure for normal threshold of hearing for air conducted sound, referred to the average ear canal.

Similarly the maximum output for the bone conductor, OFL90, in terms of the maximum output that would be prescribed for an air conduction hearing aid, OSPL90 for the same person;

OFL90 = OSPL90 + (RETFL - RETSPL) – C, where RETSPL is the Reference Equivalent Threshold SPL (for normal hearing) in a 2cc coupler

According to Dillon (2001), after the prescription of gain frequency response, target acousto-mechanical sensitivity level should be compared to the published specification for the hearing aid being considered and the appropriate tone control and gain settings can then be deduced.

### Verification strategies

The verification process for bone conduction fitting is primarily limited to measures of functional gain. Real ear probe tube measures are not commonly used as a means to verify bone-conduction fittings.

## 3. Implantable hearing devices

Implantable hearing aid options for conductive hearing loss include middle ear implants (MEIs) bone-anchored hearing aids (BAHAs).

### 3.1 Midlle ear implants

Middle Ear Implants are devices that are either wholly or partially implanted in the middle ear. The first clinically wearable device was designed by Drs. Suzuki and Yanagihara for patients with chronic middle ear dysfunction. All other MEIs that are being marketed, other the one developed by Drs. Suzuki and Yanagihara, are for those patients with completely normal middle ear function. Therefore, the ideal candidate is one who has a completely sensorineural hearing loss, with limited success from conventional hearing aids related to chronic acoustic feedback (Chasin, 1999).

## 3.2 Bone anchored hearing aids (BAHA)

BAHAs are useful for people who have primarily conductive (or mixed) hearing losses and who are not optimally fitted with more conventional hearing aids, especially those who have either congenital atresia or chronic middle ear dysfunction that has prevented optimal use of air-conduction hearing aids.

### Fitting Strategies for the BAHA

Assuming that all criteria have been met, the audiologist would determine the processor; that appears most appropriate for the client. This decision is primarily based on the bone-conduction thresholds and the subjective judgments of the patient. A test headband is available to determine which ear would be the best candidate for surgical placement of the titanium fixture. Additional information may include onset of the hearing loss (i.e., congenital vs. acquired) and prior experience with amplification. The processor is fit after 3 to 4 months of surgery in adults and 6 months in children to allow for complete osseointegration of the titanium fixture and abutment.

Tjellstrom and Grantstrom (1977) reviewed over 100 BAHA cases and reported that over 68% had no skin reactions (e.g. swelling or redness around the abutment; granulation; removal /revision), 21% had one or two episodes of adverse reactions, five of the patients lost their abutment due to direct trauma (e.g., hitting a doorway; blow to the ear; taking off an apron), and an additional five patients lost osseointegration of the implant. That is, in 90% of the patients (90/100), the BAHA was still intact following surgery over an 8-year time frame.

Hakansson et al (1990) reported that out of 24 Subjects considered for their study, 22 reported fewer ear infections, 16 subjects reported better sound quality with the BAHA than with their previous air-conduction hearing aids. 19/27 other subjects who were experienced bone-conduction hearing aid users reported greater comfort with the BAHA (four reported no difference and four reported poorer comfort with the BAHA). Thus BAHA gives better sound quality and greater comfort compared to conventional air and bone conduction hearing aids.

Tjellstrom and Granstrom (1995) reported on a follow up study of 214 patients over a 5-year period using a two-stage (titanium screw implanted first and then titanium abutment attached at a second surgery) or one-stage (titanium screw and titanium abutment implanted at the same time) surgical procedure and reported that the success rates for both procedures were the same. In the two-stage group, nearly 68% had no adverse reactions to the implant, whereas in one stage group nearly 75% of the one-stage group did not have any.

Tjellstrom and Hakansson (1995) reported on 122 cases from nine sites on a questionnaire for unaided, BAHA, and bone conduction hearing aid listening conditions. On the questionnaire, 86.6% reported they use the BAHA 8 or more hours per day. Improved wearing comfort, improved speech intelligibility, better sound comfort, less pressure on the head, less skin irritation, easy handling and greater cosmetic appearance were reported by the subjects with BAHA compared to bone conduction hearing aid. In addition, 44 of 51 subjects (86%) reported a general improvement of their ear infections after they switched to the BAHA in comparison to those who previously had worn air conduction hearing aids.

The authors compared sound field warble tone thresholds (500 to 3000Hz), SRTs and word recognition at +6dB SPL (signal at 63dB SPL; speech noise at 57dB SPL) also using BAHA and bone conduction hearing aid. The mean improvement for the BAHA over the unaided hearing was 29.4dB HL whereas the mean improvement for the bone conduction hearing aid was 27.3dB HL. The advantage of BAHA over the bone conduction hearing aid ranged between 1.6 and 9.1 dB, where the mean improvement for the bone conduction hearing aid was better than the BAHA at 500 Hz. For the SRT, the BAHA and the bone conduction hearing aid reported a mean improvement over unaided performance by 26.5dB HL. For word recognition in noise, the BAHA improved word recognition, on average by 41.8%, whereas the bone conduction hearing aid improved word recognition, on average, by 35.5%. Thus BAHA was better than the bone conduction hearing aids by 6.2% and found to be statistically significant, $p < 0.001$).

Mylanus, Snik, and Cremers (1995) studied unilateral BAHA fittings in 13 patients who were formerly bilaterally fitted with conventional bone conductors in spectacles. Six patients preferred the conventional bilateral fitting with regard to sound localization, but, quite unexpectedly, five patients preferred monaural BAHA fitting.

Usually patients with symmetrical hearing loss prefer bilateral amplification to unilateral amplification when fitted with air conduction hearing aids. Depending on the hearing configuration and on the integrity of the (peripheral) auditory system, bilateral amplification may be more or less successful in restoring binaural hearing (Markides, 1977).

As the interaural attenuation of sounds is on the order of a few decibels, the premise of restoring binaural hearing is not trivial when bilaterally fitting bone conduction aids, (Katz, 1994; Vanniasagaram, 1994). It has even been shown that in some conditions, especially at the lower frequencies, stimulation via bone conduction may result in higher stimulus levels at the contralateral cochlea than at the ipsilateral cochlea (Brandt, 1989). But the results of localization experiments conducted by Beynon, Van der pouw, Mylanus & Cremers (1998) with binaural application of bone anchored hearing aids, showed that the results of 500Hz and 2KHz noise bursts were comparable. Since at 500Hz, directional hearing depends on the detection of interaural phase differences, while above 1KHz, on the detection of interaural intensity differences, their results proved that the detection of both interaural phase differences and interaural intensity differences was adequate with binaural fitting.

Even though patients do seem to benefit from this type of bilateral fitting; it is not clear whether this is based on an improvement in binaural hearing or on an increase in stimulus level rendered possible by utilizing two sound transducers (Brandt, 1989; Stenfelt, Hakansson & Tjellstorm, 2000).

Hamann, Manach, and Roulleau (1991) found a 4-dB improvement in the speech reception threshold in quiet with bilaterally fitted BAHAs. However, any test results on sound localisation or on speech perception in noise were not included in the study.

Pouw, Snik, and Cremers (1998) reported that, in four patients with bilateral congenital aural atresia, improvements both in sound localisation and in speech recognition in quiet with bilateral BAHA fittings relative to unilateral fittings. Three out of four patients showed improved speech recognition in noise with bilaterally fitted BAHAs. This suggests that patients with congenital symmetrical conductive loss may also benefit from bilateral fitting of BAHAs.

There are many ways of predicting how patients will perform with BAHA. Test rod and tension headband offer the patient a preoperative impression of their postoperative hearing. Browning and Gatehouse (1994) suggested that comparison of performance between their air-conduction hearing aid and a temporary bone conduction hearing aid might have predictive value. But on an average, patients perform significantly better with a BAHA than with a conventional bone conduction hearing aid. This is due to the limited power output of the bone conduction hearing aids due to transducer limitations and high frequency sound attenuation by the skull and skin (Bosman, Snik, Van der pouw, Mylanus & Cremers, 2001) and all these problems are overcome by implantation of BAHA.

Another approach to decide about the BAHA might be to consider the width of the air-bone gap. In patients with an air-bone gap, the gain of an air conduction hearing aid has to be increased significantly to compensate for the air-bone gap. Whereas, in a bone conduction device (eg, the BAHA), this is not required as it bypasses the air conduction path. So in patients with a significant air-bone gap, the amplification and output levels of air conduction hearing aids are limited, owing to increased susceptibility to feedback and possible saturation of the amplifier. Accordingly as the width of air-bone gap increases patients perform better with BAHA compared to air-conduction hearing aids (Mylanus, Van der pouw, Snik & Cremers, 1998).

# Chapter 3

# Method

## Participants

A total of 15 individuals with bilateral conductive hearing loss were included in the study. Age range of the participants was from 18 to 40 years. All participants had post-lingually acquired conductive hearing loss ranging from moderate to moderately severe degree with adequate speech and language. All the participants were oriented about the study and written consent was taken regarding their willingness to participate in the study. The participant selection criteria were as follows;

- Air-bone gap > or =30 dB.
- Bone conduction thresholds should be < or =45dB
- Bone conduction thresholds must be symmetrical (defined as less than 10 dB difference on average or less than 15 dB at individual frequencies) in both ears.
- Speech Recognition Threshold should be ±12 dB (re. PTA of 0.5, 1 and 2 KHz ).
- Word recognition should be proportional to Pure tone average.
- Age range: 18 to 40 years.
- Presence of middle ear pathology indicated by immittance evaluation.
- No indication of Retrocochlear Pathology (RCP).
- No history of neurological problems.
- No illness on the day of testing.

## Testing Environment

All testing was carried out in a sound treated two room situation as per the standards of ANSI S3.1 (1991).

## Instrumentation

A calibrated dual channel diagnostic audiometer, Madsen Orbiter 922 with TDH 39 headphones encased in MX 41AR ear cushion was used for performing the Pure Tone Audiometry (air-conduction and bone-conduction) and Speech Audiometry in the unaided condition. The same audiometer with Madsen loud speakers was used for performing speech identification tests in different aided conditions. One channel of the audiometer was connected to the loudspeaker placed at $0^0$ azimuth. A toggle switch was used to route the signal of the other channel of the audiometer to any of the two speakers placed at $+45^0$azimuth or $-45^0$azimuth**.**

A calibrated GSI Tympstar (Version 2.0) middle ear analyzer was used to evaluate middle ear problems.

For evaluating the performance in aided conditions, four hearing aids were used; two digitally programmable air conduction hearing aids and two digitally programmable bone anchored hearing aids attached to head bands.

A personal computer with NOAH-3 and hearing aid specific software and the Hearing Instrument Programmer (HiPro) interface were used to program the digital Behind The Ear (BTE) air conduction hearing aids and digital bone anchored hearing aids.

A laptop computer, installed with Adobe Audition software (version 3.0) was used to route the speech babble through the auxiliary input of the audiometer. Before the presentation of the stimuli, the level of the presentation was monitored with the calibration tone of 1KHz. The level adjustment was manipulated in such way that it coincides the 0dB in the audiometer's VU meter. The presentation level of the stimuli was monitored with the calibration tone. The same laptop was used to generate the stimulus for localization task. i.e, A train of white noise pulses, using Adobe Audition software (version 3.0).

For localization task five Genelec 8020B loudspeakers mounted on Iso-Pod$^{TM}$ (Isolation positioned/ Decoupler$^{TM}$) vibration insulating table stands were used. The loudspeakers were mounted at head level at five different angles. ie., at $-90^0$, $-45^0$, $0^0$, $+45^0$ and $+90^0$ keeping a distance of one meter from the patient's seat. Cubase 6 software was used to present the localization stimulus from a personal computer. To route the stimulus to loudspeakers The Aurora 16 and Aurora 8 AD/DA converters were used. The output of the loudspeaker was calibrated using a sound level meter (SLM) (Larson-Davis system 824, model no. 2540) with a 1/2" free-field microphone fitted to its preamplifier. The microphone of the sound level meter was placed at the position of the head of the participant, during calibration, at a distance of one meter. This process was carried out by presenting the stimuli through the loudspeakers, one at a time, and measuring the output for calibration.  Thus, the loud speakers were calibrated to emit the output that would result in equal dB HL at the microphone at a distance of one metre.

## Stimuli

The following test materials were used in the study

1. Phonemically balanced (PB) word list in Kannada developed by Yathiraj and Vijayalakshmi (2005) was used for the measurement of Speech identification scores(SIS) in quiet and in the presence of noise. It consists of 4 lists, each having 25 words.
2. Speech babble in Kannada developed by Manjula and Anitha (2003) was used as background noise for the measurement of Speech identification in noise.
3. A train of four white noise pulses with duration of 200 ms separated by 200 ms of silence (Tyler et al., 2002) was generated for the purpose of localization task. A calibration tone of 1000 Hz was recorded prior to the train of white noise pulses. Stimulus was generated and normalized using Adobe Audition 3.0 software.

## Procedure

The study was carried out in three phases.

1. Selection of participants who have conductive hearing loss in both ears.

II. Programming the air conduction hearing aids and BAHA

III. Comparison between sound field thresholds, speech reception scores in quiet and noise and localization abilities.

### Phase I. Selection of participants who have either conductive/ mixed hearing loss in both ears

Pure tone audiometric thresholds were estimated for air conduction at octave frequencies between 250Hz and 8KHz and bone conduction thresholds at octave frequencies between 250Hz and 4KHz using modified Hughson Westlake method (Carhart& Jerger, 1959). Speech audiometry was administered for all the participants in which Speech reception threshold (SRT), Speech identification scores (SIS) and Uncomfortable loudness level for speech were found out.

Immittance evaluation using 226Hz probe tone was carried out for all the participants. Tympanograms, ipsilateral and contralateral reflexes for stimulus frequencies of 500Hz, 1KHz, 2KHz and 4KHz were measured. Those individuals who met the participant selection criteria were included in the study.

### Phase II. Programming the air conduction hearing aids and BAHA

Both air conduction hearing aids and digitally programmable BAHA processors were programmed using a personal computer and a HiPro interface unit using NOAH-3 and hearing aid specific fitting software.

The air conduction hearing aids were programmed to fit the hearing loss of the participant. NAL-NL1 fitting formula was used to prescribe the gain of the air conduction hearing aid according to the first fit.

BAHAs were programmed using specific fitting software for BAHA. The gain calculation was based on bone conduction thresholds. Additional gain at high frequencies was given as the present study assesses the pre-implantation evaluation of BAHA. This will better approximate post-implantation results.

The hearing aid settings were optimized depending on participant's listening needs. Loudness normalization was done to make sure equal loudness in both ears in the aided conditions.

### Phase III. Comparison between sound field thresholds, speech reception scores in quiet and noise and localization abilities.

Testing was done in two aided conditions for each of the participants.

A. Aided condition with individually programmed air conduction hearing aids in both ears
B. Aided condition with individually adjusted BAHA processors attached to test band on both the mastoids.

The following tests were carried out under the above mentioned conditions.

1. Sound field thresholds for warble tones
2. Speech Identification Scores in four test conditions; quiet condition, Sound Front/Noise Front (SFNF) condition, Sound Front/Noise Right (SFNR) condition and Sound Front/Noise Left (SFNL) condition
3. Horizontal plane localization

### 1. Sound field thresholds for warble tones

Sound field thresholds were obtained for warble tones at 500HZ, 1KHz, 2KHz and 4KHz. The warble tones were presented through loud speakers of the audiometer located at O$^o$ azimuth and one meter distance from the participant. The minimum intensity at which the participant heard the warble tone 50% of the time were considered as the threshold. This procedure was carried out with the air conduction hearing aids in both the ears as well as with the BAHA processors attached to test band on both the mastoids which were individually programmed.

### 2. Speech identification scores in quiet and in the presence of noise at 0dBSNR

#### Speech Identification Scores in quiet

Speech Identification Scores in quiet were measured using PB word list in Kannada (Yathiraj & Vijayalakshmi, 2005). The participants were seated at a distance of one meter and at 0$^o$ azimuth from the front loud speaker of the audiometer. The word list was presented using monitored live voice through microphone of the audiometer at 40dBHL. Speech identification score was measured for 25 words under each aided condition. The participants were instructed to repeat the words. A score of 1 was given for correct word repetition and a score of 0 was given for incorrect word repetition. The raw scores were converted to percentage scores by giving a weightage of 4% for each correct answer.

#### Speech Identification Scores in noise at 0dBSNR

To find out speech identification scores at 0dBSNR, the participants were seated at one meter distance at O$^o$ azimuth from the front loud speaker and one loudspeaker each was placed at 45$^o$azimuth on two sides. PB word list in Kannada (Yathiraj &

Vijayalakshmi, 2005) was presented using monitored live voice at 40dBHL through front loudspeaker and speech babble was presented at the same level, through either the front, left or right loud speaker.

There were three experimental conditions;

a) Speech front/noise front (SFNF)

b) Speech front/noise left (SFNL)

c) Speech front/noise right (SFNR)

25 words were presented and the participants were instructed to repeat the words. A score of 1 was given for correct word repetition and a score of 0 was given for incorrect word repetition. The raw scores were converted to percentage scores by giving a weightage of 4% for each correct answer.

### 3. Horizontal plane localization

The participant was seated in the centre of the array of five loudspeakers. One loud speaker was placed in front of the patient at $0^o$ azimuth and two loudspeakers each to the right and left of the patient at $45^0$ and $90^o$ azimuth .

A train of white noise pulses recorded on a compact disk was presented from a personal computer using cubase 6 audio software using Aurora 16 and Aurora 8 AD/DA converters. Twenty five bursts of white noise were presented through the loudspeakers in a random order.  The output of the loudspeaker was calibrated using a sound level meter (SLM) with a free-field microphone fitted to its preamplifier.

A set of stimuli consisting of 25 similar trains of white noise pulses, five times from each loudspeaker, was presented in each of the two aided conditions (Bilateral

BAHA with test band and bilateral air conduction hearing aids). In each of the two aided conditions, 5 loudspeakers*5 presentations, a total of 25, from each loud speaker will be made.  The stimuli were presented at 40 dBHL. During the test, the participants were instructed to maintain the designated position/orientation of the head. The order of 25 stimuli was randomized. The participants were instructed that he/she would be hearing a train of noise stimuli from any one of the five speakers at a time. Each time, he or she had to report the loudspeaker from which the stimulus was heard. The response mode from the participant was through a pointing task. The location of the loudspeaker to which participants pointed was noted down in terms of azimuth.

For the purpose of the study, degree of error (DOE) was measured for the localization task. Degree of error corresponds to the difference in degrees between the degrees of azimuth of the loudspeaker of the actual presentation of the stimuli to the degree of azimuth of the loudspeaker identified as the source of the stimulus by the participant.  For example, if the stimulus was presented from a loudspeaker at $+45^0$ azimuth and the participant reported the sound to be arriving from loudspeaker at $-45^0$, then the degree of error would be $90^0$ i.e., $45^0-(-45^0) = 90^0$.  This DOE was obtained for 25 trials in each aided condition. Thus, in each of the two different aided conditions, there was one set of degrees of errors consisting of 25 items.

A single representation of degree of errors in each aided condition was done by the calculation of root mean square degree of error (rms DOE) (Ching, Incerti, & Hill, 2004; Deun et al. 2009). The rms DOE is defined as the square root of the average of squared degrees of errors in each set. Thus, each participant had three rms

DOEs, representing the localization abilities of the participants in each of the two aided conditions.

It is calculated using the formula (Ching, Incerti, & Hill, 2004);

$$\text{rms DOE} = \sqrt{\frac{DOE_1^2 + DOE_2^2 + DOE_3^2 + \ldots\ldots\ldots\ldots + DOE_{25}^2}{25}}$$

Where, $DOE_n$= Degree of Error of the $n^{th}$ presentation in a set; and

rms DOE = Root mean square degree of Error.

The above data were tabulated and subjected to appropriate statistical analyses.

# Chapter 4

## Results and Discussion

The present study aimed at the comparison of performance with bilateral bone anchored hearing aid processors attached to test bands and binaural air conduction hearing aids in individuals with conductive hearing loss. The data were collected from 15 individuals with bilateral moderate to moderately severe conductive hearing loss.

For each participant, Sound field warble tone thresholds, Speech identification scores in quiet and Speech identification scores the presence of noise and Localization skills were compared in two aided conditions, namely bilateral bone anchored hearing aid processors attached to test bands and binaural air conduction hearing aids.

### Comparison of aided sound field threshold for warble tones with binaural air conduction hearing aids and bilateral BAHA processors attached to the headband (two aided conditions)

### Mean and standard deviation of aided sound field threshold for warble tones

The mean and standard deviation (SD) of the sound field thresholds at 500, 1000, 2000 and 4000 Hz warble tones were obtained in the unaided condition and the two aided conditions. The mean and SD of these data are shown in the Table 2.

Table 2

*Mean and Standard Deviation (SD) of the Sound Field Thresholds for Warble Tones at Different Frequencies in the Unaided Condition and the Two Aided Conditions*

| **Condition** | **Warble tone detection thresholds across frequencies in dB** | | | |
|---|---|---|---|---|
| | **500Hz Mean (SD)** | **1KHz Mean (SD)** | **2KHz Mean (SD)** | **4KHz Mean (SD)** |
| **Unaided** | 51.00<br>(6.32) | 49.00<br>(5.07) | 46.00<br>(5.73) | 43.33<br>(6.73) |
| **Bilateral BAHA with test bands** | 16.33<br>(3.99) | 19.00<br>(5.73) | 24.33<br>(6.23) | 29.67<br>(3.99) |
| **Binaural air conduction hearing aid** | 28.33<br>(7.94) | 25.33<br>(8.12) | 27.67<br>(5.94) | 34.67<br>(7.90) |

To compare the warble tone thresholds obtained in the unaided condition and aided condition with bilateral BAHA processors attached to test band, across frequencies, paired t-test was done. The result of paired t-test, between the unaided condition and the aided condition with bilateral BAHA processors attached to test bands is given in Table 3.

Table 3

*Comparison of Warble Tone Threshold across Respective Frequencies between the Unaided Condition and the Aided Condition with Bilateral BAHA Processors Attached to Test Bands*

| **Condition** | | **Bilateral BAHA processors attached to test bands** | | | |
|---|---|---|---|---|---|
| | | 500Hz | 1KHz | 2KHz | 4KHz |
| **Unaided** | 500Hz | SD | - | - | - |
| | 1KHz | - | SD | - | - |
| | 2kHz | - | - | SD | - |
| | 4KHz | - | - | - | SD |

Note: - SD = Significantly Different at $p < 0.05$

The results of paired t-test revealed that the warble tone thresholds obtained in the unaided condition were significantly different from that obtained in the aided condition with bilateral BAHA processors attached to test band.

Similarly, to compare the warble tone thresholds obtained in the unaided condition and the aided condition with binaural air conduction hearing aids, across frequencies, paired t-test was done. The result of paired t-test, between the unaided condition and the aided condition with binaural air conduction hearing aids is given in Table 4.

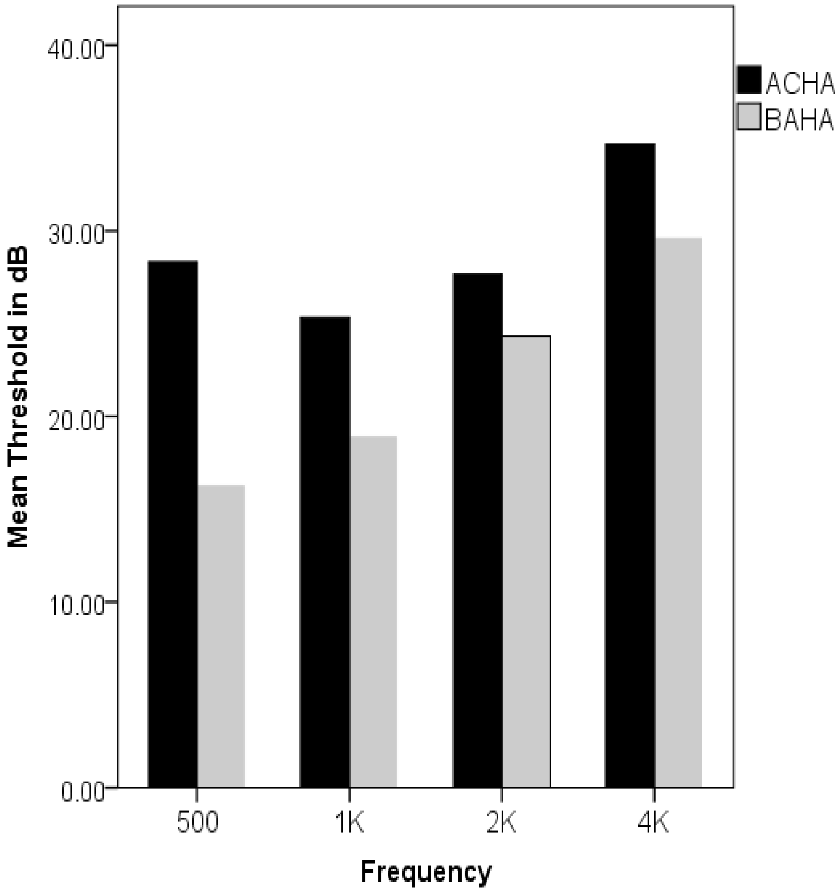
Table 4

*Comparison of Warble Tone Threshold across Respective Frequencies, between the Unaided Condition and the Aided Condition with Binaural Air Conduction Hearing Aids*

| **Condition** | | **Binaural air conduction hearing aids** | | | |
|---|---|---|---|---|---|
| | | 500Hz | 1KHz | 2KHz | 4KHz |
| **Unaided** | 500Hz | SD | - | - | - |
| | 1KHz | - | SD | - | - |
| | 2kHz | - | - | SD | - |
| | 4KHz | - | - | - | SD |

Note: - SD = Significantly Different at $p < 0.05$

The results of paired t-test revealed that the warble tone thresholds obtained in the unaided condition were significantly different from that obtained in the aided condition with binaural air conduction hearing aids.



*Graph 1.*

*Warble Tone Thresholds Obtained with Bilateral BAHA Processors Attached to Test Band and Binaural Air Conduction Hearing Aids*

*Note: ACHA – Binaural air conduction hearing aids*
*BAHA – Bilateral BAHA processors attached to test bands*

Graph 1 represents warble tone thresholds obtained with bilateral BAHA processors attached to test band and binaural air conduction hearing aids. The mean warble tone thresholds with bilateral bone anchored hearing aid processors were lesser than that with binaural air conduction hearing aids. Paired t-test was done to find out whether these differences in mean threshold were statistically significant. The result of paired t-test, between the aided condition with bilateral BAHA processors attached to test band and the aided condition with binaural air conduction hearing aids (the two aided conditions) is given in Table 5.

Table 5

*Comparison of Warble Tone Threshold across Respective Frequencies between the Two Aided Conditions*

| ***Aided condition*** | | ***Bilateral BAHA processors attached to test band*** | | | |
|---|---|---|---|---|---|
| | | *500Hz* | *1KHz* | *2KHz* | *4KHz* |
| ***Binaural air conduction hearing aids*** | *500Hz* | SD | - | - | - |
| | *1KHz* | - | SD | - | - |
| | *2kHz* | - | - | SD | - |
| | *4KHz* | - | - | - | SD |

Note: - SD = Significantly Different at $p < 0.05$

The results revealed that there was statistically significant difference in warble tone thresholds with the two aided conditions except at 2KHz. In other words, the warble tone thresholds obtained with Bilateral BAHA processors were significantly better than those with binaural air conduction hearing aids at all frequencies except at 2KHz.

Even though there was significant improvement with the aided condition with bilateral BAHA processors attached to test bands as well with binaural air conduction hearing aids compared to the unaided condition, the improvement with bilateral BAHA processors was significantly more in majority of the frequencies than with bilateral air conduction hearing aids. This can be due to the greater loudness summation with bone conduction mode compared to that with air conduction mode. A possible reason for this is the differences in the interaural attenuation for these two modes of conduction, which varies from 0 to 15dB for bone conducted signals for octave frequencies from 250Hz to 4KHz. Whereas, the minimum interaural attenuation for air conduction signal is considered to be 40dB (Studebaker, 1967).

Another reason for the reduced threshold with BAHA processors at least in the low frequency can be the occlusion effect. Since the population considered for the present study is individuals with bilateral conductive hearing loss, the occlusion effect associated with the middle ear pathology, might have caused the louder perception of the bone conducted sounds (Roeser, Valente & Dunn, 2007) through BAHA processors compared to the air conducted sound through air conduction hearing aids, leading to lower thresholds with binaural BAHA processors.

### Comparison of speech identification scores in quiet and in the presence of noise

Speech identification tests were done in four SIS test conditions. i.e, Quiet condition, Speech Front/Noise Front (SFNF) condition, Speech Front/Noise Right (SFNR) condition and Speech Front/Noise Left (SFNL condition. The mean and SD of Speech identification scores in the four SIS test conditions are given in Table 6.

Table 6

*The Mean and SD of Speech Identification Scores across the Four SIS Test Conditions, in the Unaided Condition and the Two Aided Conditions*

| ***Condition*** | ***Speech Identification Scores across the four SIS test conditions in %*** | | | |
|---|---|---|---|---|
| | *Quiet Mean (SD)* | *SFNF Mean (SD)* | *SFNR Mean (SD)* | *SFNL Mean (SD)* |
| ***Unaided*** | 14.93<br>(13.81) | .00<br>(.00) | 2.67<br>(4.70) | 2.93<br>(4.65) |
| ***Bilateral BAHA with test band*** | 95.60<br>(5.57) | 59.20<br>(15.28) | 70.93<br>(10.85) | 72.27<br>(15.15) |
| ***Binaural air conduction hearing aids*** | 81.33<br>(17.93) | 40.80<br>(16.98) | 52.27<br>(17.92) | 52.00<br>(17.70) |

To compare the Speech Identification Scores obtained in the unaided condition and aided condition with bilateral BAHA processors attached to test band, across the four SIS conditions, paired t-test was done. The result of paired t-test, between the unaided condition and the aided condition with bilateral BAHA processors attached to test band is given in Table 7.

Table 7

*Comparison of Speech Identification Scores across the Four SIS Test Conditions, in the Unaided Condition and the Aided Condition with Bilateral BAHA Processors Attached to Test Bands*

| **Condition** | | **Bilateral BAHA processors attached to test band** | | | |
|---|---|---|---|---|---|
| | | Quiet | SFNF | SFNR | SFNL |
| **Unaided** | Quiet | SD | - | - | - |
| | SFNF | - | SD | - | - |
| | SFNR | - | - | SD | - |
| | SFNL | - | - | - | SD |

Note: - SD = Significantly Different at $p < 0.05$

The results showed that the Speech Identification Scores obtained in the unaided condition were significantly different from that obtained in the aided condition with bilateral BAHA processors attached to test band.

Similarly, to compare the Speech Identification Scores obtained in the unaided condition and the aided condition with binaural air conduction hearing aids, across the four SIS test conditions, paired t-test was done. The result of paired t-test, between unaided condition and the aided condition with binaural air conduction hearing aids is given in Table 8.

Table 8

*Comparison of Speech Identification Scores across the Four SIS Conditions, in the Unaided Condition and the Aided Condition with Binaural Air Conduction Hearing Aids*

| **Condition** | | **Binaural air conduction hearing aids** | | | |
|---|---|---|---|---|---|
| | | Quiet | SFNF | SFNR | SFNL |
| **Unaided** | Quiet | SD | - | - | - |
| | SFNF | - | SD | - | - |
| | SFNR | - | - | SD | - |
| | SFNL | - | - | - | SD |

Note: - SD = Significantly Different at $p < 0.05$

The results of paired t-test revealed that the Speech Identification Scores obtained in the unaided condition were significantly different from that obtained in the aided condition with binaural air conduction hearing aids.

To compare the speech identification scores obtained in the four different SIS test conditions using bilateral BAHA processors, one-way repeated measure ANOVA was done. The results revealed that there is significant difference in Speech Identification Scores across different SIS test conditions at $p < 0.05$. Pair wise comparison was done using Bonferroni: Adjustment for multiple comparisons. The results of the test are given in Table 9.

Table 9

*Pair wise Comparison across Different SIS Test Conditions in the Aided Condition with Bilateral BAHA Processors*

| **Aided condition - Bilateral BAHA processors** | | | | |
|---|---|---|---|---|
| **SIS test condition** | Quiet | SFNF | SFNR | SFNL |
| **Quiet** | - | SD | SD | SD |
| **SFNF** | SD | - | SD | SD |
| **SFNR** | SD | SD | - | NSD |
| **SFNL** | SD | SD | NSD | - |

Note: - SD = Significantly Different at $p < 0.05$, NSD = Not Significantly Different at $p > 0.05$

The results showed that, with binaural BAHA processors attached to test band, there was no significant difference in speech identification scores between SFNR and SFNL conditions. That is, there was no significant difference between the speech identification scores when the noise came from left or right.

Speech identification scores were found to be significantly different between all other pairs of speech and noise conditions. From the mean data, it can be concluded that Speech identification scores obtained in quiet was better than that obtained in the presence of noise.

In the presence of noise, scores obtained in SFNR and SFNL were significantly better than that obtained in SFNF condition. In other words, better speech identification scores were obtained when speech and noise came from different directions i.e, Speech from front and noise from either right or left direction, compared to the condition in which both speech and noise came from the same direction.

Similarly, to compare the speech identification scores obtained in the four different SIS test conditions using binaural air condition hearing aids, one-way repeated measure ANOVA was done. The results revealed that there is significant difference in Speech Identification Scores across different the four SIS test conditions at $p < 0.05$. Pair wise comparison was done using Bonferroni: Adjustment for multiple comparisons. The results of the test are given in Table 10.

Table 10

*Pair wise Comparison across Different SIS Test Conditions with Binaural Air Conduction Hearing Aids*

| **Aided condition - Bilateral air conduction hearing aids** | | | | |
|---|---|---|---|---|
| **SIS test condition** | Quiet | SFNF | SFNR | SFNL |
| **Quiet** | - | SD | SD | SD |
| **SFNF** | SD | - | SD | SD |
| **SFNR** | SD | SD | - | NSD |
| **SFNL** | SD | SD | NSD | - |

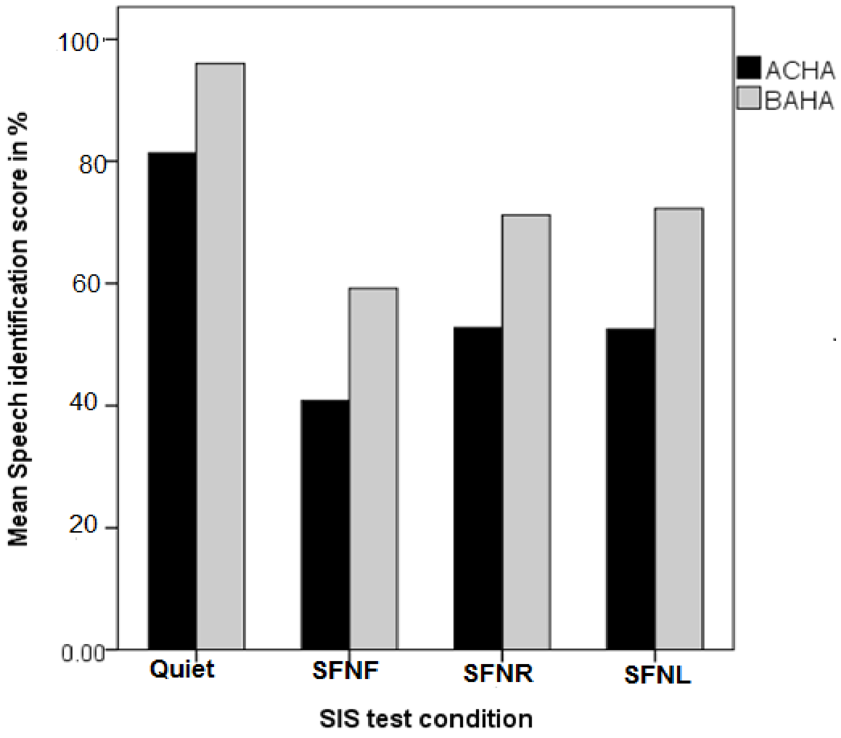
Note: - SD = Significantly Different at $p < 0.05$, NSD = Not Significantly Different at $p > 0.05$

The results showed that, with binaural air condition hearing aids, there was no significant difference in speech identification scores between SFNR and SFNL conditions. That is, there was no significant difference between the speech identification scores when the noise came from left or right.

Speech identification scores were found to be significantly different between all other pairs of different SIS test conditions. From the mean data, it can be concluded that Speech identification scores obtained in quiet was better than that obtained in the presence of noise.

In the presence of noise, scores obtained in SFNR and SFNL were significantly better that that obtained at SFNF condition. In other words, better speech identification scores were obtained when speech and noise came from different directions i.e, Speech from front and noise from either right or left direction, compared to the condition in which both speech and noise came from the same direction.

Thus, across four different SIS test condition, both bilateral BAHA attached to test band and binaural air conduction hearing aids showed the same trend. That is, as expected the Speech Identification Scores obtained in quiet condition were significantly better than that obtained with any other SIS test conditions. In the presence of noise, scores obtained with SFNR and SFNL were significantly better than that obtained in SFNF condition. This is because, in the SFNF condition, since both the speech and noise came from the same direction, it would be very difficult to separate speech and noise. In SFNR and SFNL conditions, binaural unmasking might have played a role. It is due to binaural unmasking, a signal is detected in noise when interaural difference cues help the listener to isolate the signal from the noise (such as when the signal and the noise originate from different locations), as opposed to when there are no useful interaural difference cues (such as when only one ear is used or when the signal and noise originate from the same location). Since the speech came from front and noise came from right and left for the SFNR and SFNL conditions respectively (speech and noise came from different directions), the participants could make use of interaural cues to separate speech and noise. This finding is in accordance with the study done by Bronkhorst and Plomp (1988), in which they reported an improvement in intelligibility of speech as the interfering noise was moved away from the target speech location. They attributed to the fact of binaural unmasking and better ear listening.



*Graph 2*

*Mean Speech Identification Scores obtained with Bilateral BAHA processors and Binaural air conduction hearing aids in the four SIS test conditions*

*Note : ACHA – Binaural air conduction hearing aids*

*BCHA – Bilateral BAHA processors attached to test bands*

Graph 2 represents the mean Speech Identification Scores in percentage, across four SIS conditions. The mean Speech identification scores with bilateral bone anchored hearing aid processors were better than that with bilateral air conduction hearing aids. Paired t-test was done to find out whether these differences in mean were statistically significant. The result of paired t-test is given in Table 11

Table 11

*Comparison of Speech Identification Scores Obtained with the Two Aided Conditions across the Four SIS Test Conditions*

| **Aided condition** | | **Binaural air conduction hearing aids** | | | |
|---|---|---|---|---|---|
| | | Quiet | SFNF | SFNR | SFNL |
| **Bilatearal BAHA processors** | Quiet | SD | - | - | - |
| | SFNF | - | SD | - | - |
| | SFNR | - | - | SD | - |
| | SFNL | - | - | - | SD |

Note:- SD = Significantly Different at $p < 0.05$

The results revealed that there was significant difference in Speech identification scores obtained with the two aided conditions across different SIS test conditions. From the mean data given in Table 4.5, it can be understood that Speech identification scores obtained with bilateral BAHA processors were significantly better in all conditions compared to binaural air conduction hearing aids.

The better speech perception in noise with bilateral BAHA processors can be due to the lesser distortion, because the BAHA processors as they bypasses the outer and middle ear and directly stimulate cochlea, very less gain is required. Whereas, additional gain had to be given for air conduction hearing aids so as to compensate for the conductive component or air-bone gap. As the amount of air-bone gap increases the amount of gain for air conduction hearing aids also has to be increased. Since all the participants considered for the present study had bilateral conductive hearing loss of more than 40dB, significantly more gain had to be increased for air conduction hearing aids compared to the very little gain needed for BAHA processors. The lesser distortion associated with the lesser gain and better loudness summation might have helped the participants to perform better with binaural BAHA processors.

### Comparison of localization skills with binaural air conduction hearing aids and bilateral BAHA processors attached to the headband (two aided conditions)

The degrees of error (DOE) of localization in the unaided condition and in the two aided conditions were found out and the mean and standard deviation (SD) was calculated. The mean and SD of this data are shown in the Table 12.

Table 12

*The Mean and Standard Deviation (SD) of Degrees Of Error (DEO) of Localization Obtained in the Unaided and the Two Aided Conditions*

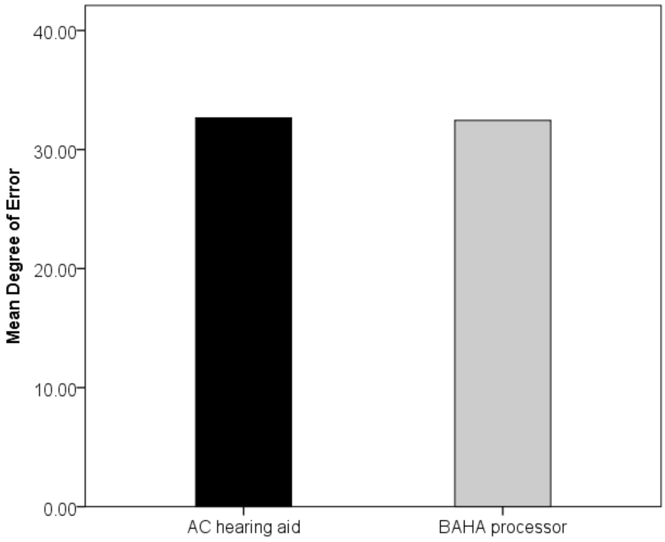
| **Condition** | **Degrees of Error Mean (SD)** |
|---|---|
| **Unaided** | 15.47<br>(18.89) |
| **Bilateral BAHA with test band** | 32.45<br>(18.63) |
| **Binaural air conduction hearing aids** | 32.65<br>(12.87) |

Paired t-test was done to compare the DEO in the unaided condition and that in the two aided conditions. The result showed that there was significant difference between the Degrees of errors of localization in the unaided condition and that with bilateral BAHA processors as well as with binaural air conduction hearing aids. The mean data in Table 12 shows that, the mean Degrees of error (DOE) in the unaided condition was lesser than that in either of the aided conditions. This finding is similar to the findings by Van den Bogaert, Klasen, Moonen, Van Deun and Wouters, (2006). They reported that the localization ability of hearing-impaired listeners wearing hearing instruments has been shown to be worse than when not wearing hearing instruments.

Heyes and Ferris (1975) also that the localization performance by individuals with hearing loss was good with binaural postaural hearing aids; it was still much inferior to the localization abilities of individuals with normal hearing.

The poorer performance in localization in both the aided conditions compared to the unaided conditions might be due to the disruption of Interaural Time Difference cues by small differences in signal processing on bilaterally worn devices, and distortion of Interaural Level Difference by compression. Another possible explanation can be the microphone positions. For, both BAHA processors and air conduction hearing aids, the microphone position are behind the pinna resulting in obscured spectral information. This also might have led to localization confusions (Groth & Laureyns, 2011).

Subjectively, participants reported that they felt more confusion in localization after wearing the aids, especially with $45^0$ and $90^0$ azimuth. The stimuli used for localization experiment were white noise bursts presented at 45dBHL which were audible to all of the participants even in the unaided condition. Since all of them had bilateral symmetrical hearing loss, significant localization difficulties were not present in the unaided condition.



Graph 3

*Degrees of Error of localization obtained with bilateral BAHA processors and binaural air conduction hearing aids*

Graph 3 represents the Degrees of error of localization obtained in the two aided conditions. Paired t-test was done to compare the DOE values in the two aided conditions. The result showed that there was no significant difference in DOE obtained in the two aided conditions with $p > 0.05$. Thus, even though the localization skills with BAHA was under debate, because of the very less interaural attenuation of sounds leading to very limited interaural cues, the results of the present study shows that the localization abilities with bilateral BAHA processors and that with binaural air conduction hearing aids are not significantly different.

# Chapter 5

## Summary and conclusions

The primary mode of management of conductive hearing loss is medical or surgical treatment. But medical or surgical management may not always restore the hearing completely. In such cases hearing aids can be considered as a secondary mode of management. Hearing aids can be the primary mode of treatment when the medical or surgical management is not possible due to medical, anatomical or physiological reasons.

Under the category of amplification devices air conduction hearing aids, bone conduction hearing aids or surgically implanted Bone Anchored Hearing Aids (BAHA) can be chosen based on the individual needs.

Fitting of air conduction hearing aids is an efficient treatment option; it may not be successful in cases with severe aural atresia or chronic ear discharge. In individuals with chronic ear discharge, fitting of air conduction hearing aids worsens the condition further as it occludes the ear canal. The next option for management in such cases is bone conduction hearing aids. But with bone-conduction hearing aids the gain available at high frequencies is minimal. Another difficulty is achieving the precise placement and tension of the vibrator on the mastoid process. In addition, many patients using bone-conduction hearing aids complain of headaches and soreness around the mastoid process due to the pressure of the bone vibrator on the mastoid process (Bosman et al., 2001; Spitzer et al., 2002).

Bone Anchored Hearing Aids are proved to be efficient in cases where air conduction and bone conduction hearing aids failed to show an improvement Hakansson et al. (1990). In general, as the air-bone gap increases the benefit with air conduction hearing aids decreases due to the increasing requirement of gain. As the air-bone gap increases beyond 25 to 30dB, BAHA becomes a better treatment option. BAHAs are recommended for in individuals with conductive or mixed hearing loss with adequate bone conduction reserve.

Test bands and test rods are available to determine possible benefit with BAHA after surgery, in the pre-surgical period itself. Both the pre-implantation evaluation method are not efficient in transmitting high frequencies. So after the surgery a better outcome is expected compared to that obtained during the pre-implantation evaluation.

There are many studies comparing outcomes with unilateral and bilateral BAHA fittings as well as that air conduction hearing aids and BAHA. But there is a dearth of literature on direct comparison of bilateral BAHA with binaural air conduction hearing aids. Bilateral fitting of BAHA is of concern because of the very less intracranial attenuation of the bone conducted sounds and the possible simultaneous activation of the two cochlea. Thus the present study aimed at the comparison of performance with bilateral BAHA processors attached to test band and binaural air conduction hearing aids.

A total of 15 individuals with bilateral conductive hearing loss ranging from moderate to moderately severe degree were included in the study. Sound field warble thresholds at 500Hz. 1KHz, 2KHz and 4KHz, Speech identification scores in four SIS test conditions; In Quiet, Sound Front/ Noise front (SFNF) condition, Sound Front/

Noise Right (SFNR) condition and Sound Front/Noise Left (SFNL) condition and localization abilities were measured in the unaided and the two aided conditions namely, the aided condition with bilateral BAHA processors attached to test bands and the aided condition with binaural air conduction hearing aids. The results were tabulated and analysed using the software SSPS version. 18.

There was significant improvement in warble tone thresholds with both the aided conditions, compared to the unaided condition. The thresholds were significantly better with bilateral BAHA processors attached to test bands compared to that with binaural air conduction hearing aids. The greater loudness summation and occlusion effect for the bone conducted sound through BAHA processors can be the possible reasons.

Similarly, there was significant improvement in the Speech Identification Scores in all the four SIS test conditions with the two aided conditions compared to that in the unaided condition. There was significant main effect for the SIS conditions. That is, Speech Identification scores obtained in quiet were significantly better than that obtained in any other SIS conditions. In the presence of noise, the Speech Identification Scores obtained in SFNR and SFNL conditions were significantly better than that obtained in SFNF condition due to the binaural unmasking and better ear listening in the SFNR and SFNL conditions. Both the aided conditions showed the same trend across the SIS conditions. But the Speech Identification Scores obtained with bilateral BAHA processors attached to test bands were significantly better than that with binaural air conduction hearing aids. This can be due to the lesser distortion through BAHA processors as lesser gain is required since it directly stimulates cochlea. Whereas air conduction hearing aids require more gain is required so as to compensate for the amount of conductive component or air-bone gap leading to amplifier saturations and distortions.

Localization experiments were done to find out the Degrees of error (DEO) localization in the unaided condition and in the two aided conditions. The DEOs were more with both the aided conditions compared to the unaided condition. This can be possibly due to the confusions caused by distortion created by the hearing aids and the difference in the sound receiving (microphone) positions. There was no significant difference in the localization skills with Bilateral BAHA processors and binaural air conduction hearing aids.

Thus, the following conclusions were drawn from the study

1. The warble tone thresholds with bilateral BAHA processors were significantly better than that with binaural air conduction hearing aids
2. The Speech identification Scores obtained with bilateral BAHA processors were significantly better than that with binaural hearing aids, both in quiet and in the presence of noise.
3. In the presence of noise, The Speech Identification Scores were significantly better when speech and noise were from different directions (SFNR and SFNL conditions) than when both were from the same directions in both the aided conditions
4. There was no significant difference in the Degrees of errors of localization between the two aided conditions

**Implications of the study**

- The study provides a support for bilateral implantation of BAHA in individuals with bilateral conductive hearing loss

- The study highlighted the better speech perception abilities with bilateral BAHA processors compared to bilateral air conduction hearing aids, both in quiet and in the presence of noise
- The results of the present study resolved the conflicts related to expected localization difficulties with bilateral BAHA due to the reduced intracranial attenuation

## Future directions for research

- Comparative study can be done with bilateral BAHA processors and binaural air conduction hearing aids in individuals with mixed hearing loss.
- The same study can be done grouping individuals with different amounts of air-bone gap.
- Localisation experiments can be with a low frequency and a high frequency stimulus as the effects of interaural time difference and interaural level differences can be studied.

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