Comparison of Bone Anchored Hearing Aid with Test Band and Air Conduction Hearing Aid

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Abstract

The aim of the present study was to compare the performance between the aided conditions with bilateral fitting of Bone Anchored Hearing Aid processors attached to test bands and binaural air conduction hearing aids, in bilateral conductive hearing loss. Fifteen individuals with bilateral symmetrical moderate to moderately severe degree of conductive loss were included in the study. Sound field warble tone thresholds, Speech Identification Scores in quiet as well as in the presence of noise and degrees of errors of horizontal localization were compared in the two aided conditions. Statistical analysis of data revealed that warble tone thresholds and Speech Identification Scores in quiet and noise were significantly better with bilateral Bone Anchored Hearing Aid processors attached to test bands compared to those with binaural air conduction hearing aids. There was no significant difference between the degrees of errors of horizontal localization in the two aided conditions.

Keywords: *Bone anchored hearing aid, Test band, Air conduction hearing aid.*

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 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 and 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. Eventhough 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), which 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 which 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, limited static pressure, and the 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 alter-

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native. 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 processor is snapped into place, eliminating the need for the headband and its side effects.

Bone anchoring utilizes a natural process called osseointegration. Osseointegration is the development of a solid connection between living bone and an implanted material (Chasin, 1999). 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 in 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).

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 processor can be fitted on the patient. An external abutment is connected to the implanted screw, and the BAHA processor can be joined to this abutment with a simple bayonette connector (Chasin, 1999). The BAHA processor, 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-conduction 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, Tjellstrom & Rosenhall, 1984; Van der pouw Snik & Cremers, 1999; Grunder, Seidl, Ernst & Todt, 2008).

A preoperative assessment is recommended which includes sound field testing using a BAHA processor 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 processor 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 BAHA (Spitzer et al., 2002).

Markides (1977), Festen and Plomp (1986), Day, Browning and Gatehouse (1988), Jerger, Darling and Florin (1995) have reported on the advantages of binaural application of air conduction hearing aids. Brooks (1984) assessed patient's subjective preference for monaural and binaural fitting and 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 than that with monaural application. However, any results on either sound localization or on speech recognition in noise was not included. Snik, Beynon, Van der 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 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 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. The aim of the present study was to compare the performance with bilateral fitting of BAHA processors with test band and binaural air conduction hearing aids in individuals with bilateral conductive loss. The specific objectives were to compare the a) sound field warble tone thresholds with bilateral fitting of BAHA processors with test band and binaural air conduction hearing aids b) speech perception abilities in quiet as well as in the presence of background noise with bilateral fitting of BAHA processors with test band and binaural air conduction hearing aids and c) the horizontal localization abilities with bilateral fitting of BAHA processors with test band and binaural air conduction hearing aids.

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 should be greater than or equal to 30 dB. Bone conduction thresholds should be less than or equal to 45dB. Air conduction thresholds and 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 2kHz). Word recognition should be greater than 60%. Age range was 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 (1999).

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 three 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 -45^0azimuth.

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 (BAHA).

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 1 kHz. The level adjustment was manipulated in such way that it coincides with the OdB 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, Aurora 16 and Aurora 8 AD/DA converters were used. The output of the loudspeaker was calibrated using a sound level meter (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

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. Speech babble in Kannada developed by Anitha (2003) was used as background noise for the measurement of speech identification in noise. 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.

Procedures

The study was carried out in three phases; Selection of participants who have conductive hearing loss in both ears, Programming the air conduction hearing aids and BAHA and Comparison of sound field warble tone thresholds, Speech Identification 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 250 Hz and 8 kHz and bone conduction thresholds at octave frequencies between 250 Hz and 4 kHz using modified Hughson Westlake method (Carhart& Jerger, 1959). Speech audiometry was administered for all the participants in which Speech reception threshold, Speech identification scores and Uncomfortable loudness level for speech were found out.

Immittance evaluation using 226 Hz probe tone was carried out for all the participants. Tympanograms, ipsilateral and contralateral reflexes for stimulus frequencies of 500 Hz, 1 kHz, 2 kHz and 4 kHz 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. It was intended to 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 of 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, namely aided condition with individually programmed air conduction hearing aids in both ears and aided condition with individually adjusted BAHA processors attached to test band on both the mastoids.

The following tests carried out in the above mentioned conditions were, Sound field thresholds for warble tones, 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 and Horizontal plane localization.

Sound field thresholds for warble tones: Sound field thresholds were obtained for warble tones at 500 kHz, 1 kHz, 2 kHz and 4 kHz. The warble tones were presented through loud speakers of the audiometer located at 0^o azimuth and at 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.

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 0^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: Speech front/noise front (SFNF), Speech front/noise left (SFNL) and Speech front/noise right (SFNR).

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

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 and 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 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 binaural air conduction hearing aids). In each of the two aided conditions, 5 loudspeakers × 5 presentations, a total of 25, from each loud speaker were 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. DOE corresponds to the difference in degrees between the degrees of azimuth of the loudspeaker of actual presentation of the stimuli, to the degree of azimuth of the loudspeaker identified as the source of the stimulus by the participant. 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). 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 the unaided condition and in each of the two aided conditions. It is calculated using the formula (Ching, Incerti, & Hill, 2004).

$$rmsDOE = \sqrt{\frac{DOE_1^2 + DOE_2^2 + DOE_3^2 + \cdots + DOE_{25}^2}{25}}$$

Where, DOE$_n$= Degree of Error of the nth presentation in a set, and

$rmsDOE$ = *Root mean square degree of Error*

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

Results and Discussion

The results were tabulated and analyzed using the software SPSS version. 18.

Comparison of aided sound field threshold for warble tones in the two aided conditions

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 and the two aided conditions. The mean and SD of these data are shown in the Table 1. To compare the warble tone thresholds obtained in the unaided condition and aided condition with bilateral BAHA processors attached to test bands, across frequencies, paired t-test was done. The result of paired t-test is given in Table 2.

The results 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 bands.

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 and the result is given in Table 3.

To compare the warble tone thresholds obtained in the unaided condition and aided condition with bilateral

Table 1: 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) dB HL	1kHz Mean (SD) dB HL	2kHz Mean (SD) dB HL	4kHz Mean (SD) dB HL
Unaided	51.00 (6.32)	49.00 (5.07)	46.00 (5.73)	43.33 (6.73)
Bilateral BAHA with test band	16.33 (3.99)	19.00 (5.73)	24.33 (6.23)	29.67 (3.99)
Binaural air conduction hearing aids	28.33 (7.94)	25.33 (8.12)	27.67 (5.94)	34.67 (7.90)

Table 2: 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	**	-	-	-
	1kHz	-	**	-	-
	2kHz	-	-	**	-
	4kHz	-	-	-	**

*Note: - ** = Significantly Different at p < 0.05*

Table 3: 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	**	-	-	-
	1kHz	-	**	-	-
	2kHz	-	-	**	-
	4kHz	-	-	-	**

*Note: - ** = Significantly Different at p < 0.05*

BAHA processors attached to test bands, across frequencies, paired t-test was done. The result of paired t-test is given in Table 2.

The result 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.

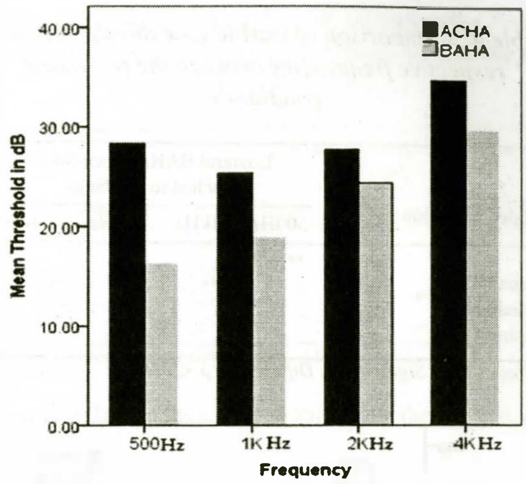

Figure 1: Mean warble tone thresholds obtained with bilateral BAHA processors attached to test bands and binaural air conduction hearing aids. Note: ACHA ? Binaural air conduction hearing aids BAHA ? Bilateral BAHA processors attached to test bands.

Figure 1 represents warble tone thresholds obtained with bilateral BAHA processors attached to test bands 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 bands and the aided condition with binaural air conduction hearing aids (the two aided conditions) is given in Table 4.

The results revealed that there was statistically significant difference in warble tone thresholds with the two aided conditions except at 2 kHz. 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 2 kHz.

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 binaural 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

Table 4: 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	** -	-	-	-
	1kHz	-	**	-	-
	2kHz	-	-	**	-
	4kHz	-	-	-	**

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

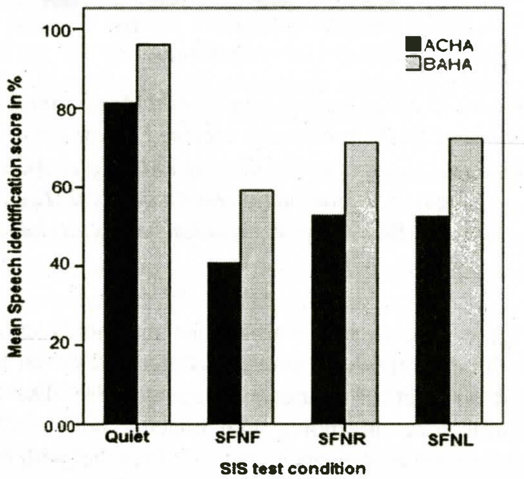

Figure 2: Mean warble tone thresholds obtained with bilateral BAHA processors attached to test bands and binaural air conduction hearing aids.

(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 & Clark, 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 in the Two Aided Conditions

Speech Identification Scores were obtained 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 5.

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 6.

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 7.

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 the four SIS test conditions at $p < 0.05$. Pair wise comparison was done using Bonferroni: Adjustment for multiple comparisons and the results of the test are given in Table 8.

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 signifi-

Table 5: 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 (13.81)	0.00 (0.00)	2.67 (4.70)	2.93 (4.65)
Bilateral BAHA with test band	95.60 (5.57)	59.20 (15.28)	70.93 (10.85)	72.27 (15.15)
Binaural air conduction hearing aids	81.33 (17.93)	40.80 (16.98)	52.27 (17.92)	52.00 (17.70)

Table 6: Comparison of warble tone threshold across respective frequencies between the two aided conditions

Aided condition		Bilateral BAHA processors attached to test band			
		Quiet	SFNF	SFNR	SFNL
Unaided	500Hz	** -	-	-	-
	1kHz		**	-	-
	2kHz	-	-	**	-
	4kHz	-	-	-	**

*Note: ** = Significantly Different at $p < 0.05$*

Table 7: Comparison of Speech Identification Scores across the four SIS test conditions, in the unaided condition and the aided condition with binaural air conduction hearing aids

Aided condition		Binaural air conduction hearing aids			
		Quiet	SFNF	SFNR	SFNL
Unaided	Quiet	**	-	-	-
	SFNF	-	**	-	-
	SFNR	-	-	**	-
	SFNL	-	-	-	**

*Note: ** = Significantly Different at $p < 0.05$*

Table 8: Pair wise Comparison across different SIS test conditions in the aided condition with bilateral BAHA processors

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

*Note: ** = Significantly Different at $p < 0.05$*
*Note: * = Not Significantly Different at $p > 0.05$*

Table 9: Pair wise Comparison across different SIS test conditions with binaural air conduction hearing aids

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

*Note: ** = Significantly Different at $p < 0.05$*
*Note: * = Not Significantly Different at $p > 0.05$*

cant 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

Table 10: 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
Bilateral BAHA processors	Quiet	**	-	-	-
	SFNF	-	**	-	-
	SFNR	-	-	**	-
	SFNL	-	-	-	**

*Note: ** = Significantly Different at $p < 0.05$*

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 the four SIS test conditions at $p < 0.05$. Pair wise comparison was done using Bonferroni: Adjustment for multiple comparisons and the results of the test are given in Table 9.

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.

Figure 2 represents the mean Speech Identification Scores in percentage, across four SIS test 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 10

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 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 (Mylanus, van der Pouw, Snik & Cremers, 1998). 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 Horizontal Localization Skills in the Two Aided Conditions

The rms 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 11.

Paired t-test was done to compare the rms DOE in the unaided condition and that in the two aided conditions. The result showed that there was significant difference between the DOE of localization in the unaided condition and that with bilateral BAHA processors as well as with binaural air conduction hearing aids. Subjectively, participants reported that they felt more confusion in localization after wearing the aids, especially with 45^0 and 90^0azimuth. The mean data in Table 12 shows that, the mean rms 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 et al. (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 reported that the localization performance by individuals with hearing loss was good with binaural postaural hearing aids. But 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 Differ-

Table 11: The Mean and Standard Deviation (SD) of rms Degrees of Error (DEO) of localization obtained in the unaided and the two aided conditions

Condition	rms Degrees of Error Mean (SD)
Unaided	15.47 (18.89)
Bilateral BAHA with test band	32.45 (18.63)
Binaural air conduction hearing aids	32.65 (12.87)

ence by compression. Another possible explanation can be the microphone positions. For, both BAHA processors and air conduction hearing aids, the microphone position is behind the pinna resulting in obscured spectral information. This also might have led to localization confusions (Groth & Laureyns, 2011).

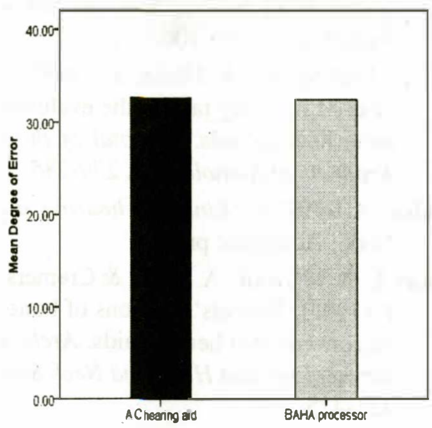

Figure 3: Mean rms Degrees of error of localization obtained with bilateral BAHA processors attached to test bands and binaural air conduction hearing aids.

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.

Figure 3 represents the mean rms DOE of localization obtained in the two aided conditions. Paired t-test was done to compare the rms DOE values in the two aided conditions. The result showed that there was no significant difference in rms 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 (Beynon et al., 1998), 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.

Conclusions

From the present study it can be concluded that, the bilateral BAHA processors provide significantly better warble tone thresholds than binaural air conduction hearing aids. Also, the Speech identification Scores obtained with bilateral BAHA processors will be significantly better than that with binaural hearing aids, both in quiet and in the presence of noise. The Speech Identification Scores will be significantly better when speech and noise will be from different directions (SFNR and SFNL conditions) than when both were from the same directions in both the aided conditions. Further, no significant difference will be obtained in the rms degrees of errors of localization between the two aided conditions.

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

Also, it 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.Further,the results of the present study resolved the conflicts related to expected localization difficulties with bilateral BAHA due to the reduced intracranial attenuation.

Here are some 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 and also localization experiments can be done 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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