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The effectiveness of directional microphone alignment in the Baha Divino

Kristi Ann Marie Oeding

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THE EFFECTIVENESS OF DIRECTIONAL MICROPHONE ALIGNMENT IN THE BAHÄ DIVINO

by

Kristi Ann Marie Oeding

A Capstone Project
submitted in partial fulfillment of the requirements for the degree of:

Doctor of Audiology

Washington University School of Medicine
Program in Audiology and Communication Sciences

May, 2011

Approved by:
Michael Valente, Ph.D., Capstone Project Advisor
Jessica Kerckhoff, Au.D., Second Reader

Abstract: The primary objective of this research study is to determine if off-vertical directional microphone alignments of the Baha Divino significantly impact the Reception Threshold for Sentences (RTS, in dB) using the Hearing in Noise Test (HINT) in a diffuse listening situation.
ACKNOWLEDGEMENTS

Thank you to Michael Valente, Ph.D., for his guidance on creating and conducting a research project as well as his insight into writing a research paper. I sincerely appreciate all of the time and effort he provided in reading weekly drafts of this paper, for always taking time out of his busy schedule to answer questions, and his constant support and encouragement throughout this study. I would also like to thank him for the wonderful photographs of each subject’s Baha in Appendix A and of the equipment utilized in this study. Thank you to Jessica Kerckhoff, Au.D. for training me on the R-Space™ system, helping me with the organization of my data, for all of her help with recruiting subjects for this study, and her support and insight into conducting a research project. Thank you to my R-Space™ helpers: Beth Baum Fernandez, Kristi Musser, Mary Rice, Noël Dwyer, and Kathy Swan for helping me train on the R-Space™. Thank you to all of the subjects for their support and willingness to drive great distances to be a part of my study. Thank you to all of the staff at the Center for Advanced Medicine for allowing me to utilize their space and equipment and for all of their kindness and support. Thank you to Cochlear America’s for allowing me to use the loaner Divinos for this study. Thank you to George Cire, Au.D. for providing information on the polar patterns of the Compact and Divino. Thank you to Larry Revit, M.S. for providing valuable information about the R-Space™ system. Finally, thank you to the Valente Award for supporting this project; it is greatly appreciated.
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### ABBREVIATIONS

<table>
<thead>
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<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baha</td>
<td>Bone Anchored Hearing Aid</td>
</tr>
<tr>
<td>BTE</td>
<td>Behind-the-ear hearing aid</td>
</tr>
<tr>
<td>DI</td>
<td>Directivity Index</td>
</tr>
<tr>
<td>DM</td>
<td>Directional microphone</td>
</tr>
<tr>
<td>HINT</td>
<td>Hearing in Noise Test</td>
</tr>
<tr>
<td>ITE</td>
<td>In-the-ear hearing aid</td>
</tr>
<tr>
<td>KEMAR</td>
<td>Knowles Electronics Manikin for Acoustic Research</td>
</tr>
<tr>
<td>OM</td>
<td>Omnidirectional microphone</td>
</tr>
<tr>
<td>OVP</td>
<td>Optimal Vertical Position (0º)</td>
</tr>
<tr>
<td>RTS</td>
<td>Reception Threshold for Sentences (dB)</td>
</tr>
<tr>
<td>USNHL</td>
<td>Unilateral Sensorineural Hearing Loss</td>
</tr>
</tbody>
</table>
INTRODUCTION

The Bone Anchored Hearing Aid (Baha) is a sound processor coupled to a surgically implanted titanium fixture and abutment placed in the mastoid that transmits amplified sound to the cochlea via bone conduction. The Baha was originally created for patients with conductive or mixed hearing losses where conventional air conduction amplification was contraindicated. Examples of conductive or mixed hearing loss contraindications include chronic otitis media or otorrhea, malformations of the external auditory meatus and pinna, conductive pathologies where surgery is not a viable option, and a conductive hearing loss in which insufficient gain could be provided by conventional air conduction hearing aids (Entific Medical Systems, 2005).

In 2002, the United States Food and Drug Administration (U.S. FDA, 2002) approved a new application of the Baha for treatment of patients with unilateral sensorineural hearing loss (USNHL) (caused by damage to the inner ear, auditory nerve, and/or auditory pathway). The FDA (2002) defines USNHL as normal hearing in one ear (pure-tone air conduction average (PTA) ≤ 20 dB HL at 500, 1000, 2000, and 3000 Hz) and sensorineural deafness in the other ear (defined as profound sensorineural hearing loss, poor word recognition, and/or an inability to tolerate amplified sounds) (Valente, 2007). This treatment option could provide benefit to patients with USNHL, particularly in noise, which is one of the most challenging listening environments for patients with USNHL due to the loss of binaural cues such as binaural summation and binaural squelch. As a result of this new application of the Baha, several studies have evaluated the efficacy and effectiveness of the omnidirectional and directional microphone performance of the Baha Compact, Classic, and Divino in patients with USNHL using objective and subjective measures. Tables 1 and 2 provide detailed summaries of the methods and results from these studies.
Omnidirectional Performance of the Baha

In 2003, Niparko et al compared unaided, contralateral routing of signal (CROS) (unknown model), and Compact performance in 10 adult subjects using the Hearing in Noise Test (HINT) (Nilsson et al, 1994), the Abbreviated Profile of Hearing Aid Benefit (APHAB) (Cox & Alexander, 1995) and the Glasgow Hearing Aid Benefit Profile (GHABP) (Gatehouse, 1999). Initially, subjects were fit using an undefined protocol with the CROS and allowed one month of acclimatization. All subjects perceived little benefit from the CROS during this trial period and elected to have surgery for the Baha. Three months after implantation, subjects were fit with the Compact processor using an undefined protocol and were allowed one month of acclimatization.

After the acclimatization period for the CROS and Compact, Niparko et al (2003) investigated differences in performance between unaided, CROS, and Compact using HINT sentences under four experimental conditions: a) quiet (HINT sentences presented at 0º), b) noise (HINT noise at 65 dBA) and signal (HINT sentences) presented from 0º, c) signal from 0º and noise presented on the side of the better ear, and d) signal from 0º and noise presented on the side of the poorer aided ear. An adaptive procedure was utilized to measure the presentation level (in dB) at which sentences could be repeated 50% of the time in quiet and the Reception Threshold for Sentences (RTS, in dB) was measured (also referred to as the signal-to-noise ratio (SNR)), which is the level required to correctly repeat sentences embedded in noise 50% of the time.

Results in quiet revealed statistically significant benefit for the Compact (3.2 dB) when compared to CROS and no significant difference for the unaided condition compared to Compact and CROS. In noise, the Compact performed significantly better than CROS and unaided when
Table 1. Summary of six studies comparing omnidirectional performance between unaided, CROS and Baha.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Subjects</th>
<th>Amplification</th>
<th>Acclimatization Period</th>
<th>Subjective Measure(s)</th>
<th>Objective Measure(s)</th>
<th>Signal/ Level</th>
<th>Signal Azimuth(s)</th>
<th>Noise/ Level</th>
<th>Noise Azimuth(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Niparko et al, (2003)</td>
<td>10</td>
<td>CROS Compact</td>
<td>CROS &amp; Compact: 1 month</td>
<td>APHAB &amp; GHABP</td>
<td>HINT</td>
<td>HINT Sentences/ Adaptive</td>
<td>0º</td>
<td>HINT Noise/ 65 dBA</td>
<td>0º/ BE or PE</td>
</tr>
<tr>
<td>Wazen et al, (2003)</td>
<td>18 (3)*</td>
<td>Telex CROS Baha</td>
<td>CROS &amp; Baha: 1-2 months</td>
<td>APHAB &amp; SSD</td>
<td>HINT</td>
<td>HINT Sentences/ Adaptive</td>
<td>0º</td>
<td>HINT Noise/ 60 dBA</td>
<td>BE or PE</td>
</tr>
<tr>
<td>Hol et al, (2005)</td>
<td>29 (20)*</td>
<td>CROS Compact &amp; Classic</td>
<td>CROS, Compact, &amp; Classic: 1 month</td>
<td>APHAB, GHABP, IOI-HA, &amp; SSD</td>
<td>Short, Everyday Dutch Sentences</td>
<td>Short, Everyday Dutch Sentences/ Adaptive</td>
<td>0º/  BE or PE</td>
<td>Spectrally Shaped/ 65 dBA</td>
<td>0º/ BE or PE</td>
</tr>
<tr>
<td>Andersen et al, (2006)</td>
<td>26</td>
<td>Baha Testband</td>
<td>Objective: day of fitting; Subjective: 1 hour</td>
<td>Hearing Handicap Questionnaire</td>
<td>DANTALE</td>
<td>DANTALE/ 65 dB SPL</td>
<td>0º</td>
<td>Cocktail Party/ Fixed 10 dB SNR</td>
<td>?</td>
</tr>
</tbody>
</table>

Note: CROS = contralateral routing of signal; Baha = bone anchored hearing aid; APHAB = Abbreviated Profile of Hearing Aid Benefit; GHABP = Glasgow Hearing Aid Benefit Profile; SSD = Single Sided Deafness questionnaire; IOI-HA = International Outcome Inventory for Hearing Aids; HINT = Hearing in Noise Test; DANTALE = Danish speech material; BE = better ear; PE = poorer ear; SNR = signal-to-noise ratio; * = contains (#) previously reported subjects.
### Table 2. Summary of six studies reporting omnidirectional speech recognition performance in quiet and noise between unaided, CROS, and Baha.

<table>
<thead>
<tr>
<th>Study</th>
<th>Comparisons</th>
<th>Loudspeaker Arrangement</th>
<th>Quiet</th>
<th>Noise &amp; Signal</th>
<th>Noise 0º</th>
<th>Noise 0º</th>
<th>Signal 0º</th>
<th>Signal 0º</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BE</td>
<td>BE</td>
<td>PE</td>
<td>PE</td>
</tr>
<tr>
<td>Niparko et al, (2003)</td>
<td>U vs. CROS</td>
<td>U (1.6 dB)</td>
<td>U</td>
<td>N/A</td>
<td>N/A</td>
<td>CROS*</td>
<td>U*</td>
<td>(4.1 dB)</td>
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<td></td>
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<tr>
<td></td>
<td>U vs. Baha</td>
<td>Baha* (1.5 dB)</td>
<td>Baha*</td>
<td>N/A</td>
<td>N/A</td>
<td>Baha*</td>
<td>U*</td>
<td>(2.4 dB)</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>CROS vs. Baha</td>
<td>Baha* (3.2 dB)</td>
<td>Baha*</td>
<td>N/A</td>
<td>N/A</td>
<td>Baha</td>
<td>Baha</td>
<td>(1.8 dB)</td>
</tr>
<tr>
<td>Wazen et al, (2003)¹</td>
<td>U vs. CROS</td>
<td>U (2.9 dB)</td>
<td>U</td>
<td>N/A</td>
<td>N/A</td>
<td>CROS</td>
<td>U</td>
<td>(3.7 dB)</td>
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<tr>
<td></td>
<td>U vs. Baha</td>
<td>U (2.6 dB)</td>
<td>Baha</td>
<td>N/A</td>
<td>N/A</td>
<td>Baha</td>
<td>U</td>
<td>(1.6 dB)</td>
</tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>CROS vs. Baha</td>
<td>Baha (0.2 dB)</td>
<td>Baha</td>
<td>N/A</td>
<td>N/A</td>
<td>Baha</td>
<td>Baha</td>
<td>(2.1 dB)</td>
</tr>
<tr>
<td>Bosman et al, (2003)¹</td>
<td>U vs. CROS</td>
<td>N/A</td>
<td>N/A</td>
<td>U (~0.7 dB)</td>
<td>CROS (~1.4 dB)</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td></td>
<td>U vs. Baha</td>
<td>N/A</td>
<td>N/A</td>
<td>Baha (~0.7 dB)</td>
<td>Baha (~2.3 dB)</td>
<td>N/A</td>
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<tr>
<td></td>
<td>CROS vs. Baha</td>
<td>N/A</td>
<td>N/A</td>
<td>Baha (~1.4 dB)</td>
<td>Baha (~0.9 dB)</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Hol et al, (2004)</td>
<td>U vs. CROS</td>
<td>N/A</td>
<td>U</td>
<td>(0.4 dB)</td>
<td>U (1.1 dB)</td>
<td>CROS (2.1 dB)</td>
<td>CROS (1.5 dB)</td>
<td>U* (2.4 dB)</td>
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<tr>
<td></td>
<td>U vs. Baha</td>
<td>N/A</td>
<td>U</td>
<td>(0.5 dB)</td>
<td>U (0.1 dB)</td>
<td>Baha* (2.2 dB)</td>
<td>Baha (1.3 dB)</td>
<td>U (0.8 dB)</td>
</tr>
<tr>
<td>Hol et al, (2005)</td>
<td>U vs. CROS</td>
<td>N/A</td>
<td>U</td>
<td>(~0.6 dB)</td>
<td>CROS* (~2.4 dB)</td>
<td>CROS (~1.1 dB)</td>
<td>U* (~2.7 dB)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>U vs. Baha</td>
<td>N/A</td>
<td>Baha</td>
<td>(~0.9 dB)</td>
<td>Baha* (~2.5 dB)</td>
<td>Baha (~1.2 dB)</td>
<td>U (~0.7 dB)</td>
<td></td>
</tr>
<tr>
<td>Andersen et al, (2006)</td>
<td>U vs.</td>
<td>Baha* (Signal 0º/Noise ?) (15%)</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

**Note:** CROS = contralateral routing of signal; Baha = bone anchored hearing aid; U = unaided; BE = better ear; PE = poorer ear; 0º = front speaker; N/A = not applicable; * indicates statistical significance; º indicates statistical analysis not reported.
the signal and noise arrived from 0° (1.5 dB and 1.2 dB, respectively), however no significant difference was noted between CROS and unaided. The CROS and Compact performed significantly better than unaided when the signal arrived from 0° and the noise was presented on the side of the better ear (2.8 dB and 4.4 dB, respectively) and no statistical significance was reported between the Compact and CROS. Finally, the unaided condition performed significantly better than Compact and CROS when the signal arrived from 0° and noise was presented on the side of the poorer aided ear (2.4 dB and 4.1 dB, respectively) and no significance was found between Compact and CROS. This result is expected as the noise was amplified by the CROS and Compact causing a possible interference with the signal to the good ear compared to the unaided condition, which had the 6 dB advantage of the head shadow effect, which caused the noise signal to attenuate by approximately 6 dB in comparison to the signal.

The subjective measures were administered pre and post intervention for CROS and Compact. Niparko et al (2003) reported a wide variability of responses for both subjective measures. APHAB scores revealed that Compact provided significantly better benefit scores (relative to the unaided problem score) compared to CROS based on a difference of 5% on all three speech communication subscales: Ease of Communication (EC) (mean benefit score of 6.7% versus 0.6%, respectively), Background Noise (BN) (mean benefit score of 21.2% versus 2.5%, respectively), and Reverberation (RV) (mean benefit score of 18.5% versus 5.9%, respectively). There were no significant differences on the Aversiveness of Sounds (AV) subscale for the Compact and CROS. The GHABP revealed no significant differences between the Compact and CROS, although the Compact revealed slightly better scores compared to CROS in all four categories (time worn, benefit, residual disability, and satisfaction).
The results from this study suggest that the Compact performed better in all noise conditions compared to unaided and CROS, except when the signal was from 0º and the noise was presented on the side of the poorer aided ear. There were, however, several errors in the experimental design of this study. First, it is unclear if the HINT sentence lists were counterbalanced to reduce learning effects. Second, the treatment order for CROS and Compact was not randomized increasing the chance of incurring an order effect, however, it is likely unethical to perform a surgical procedure (i.e. Baha) before trying a non-surgical treatment (i.e. CROS). The potential effects on the results of not randomizing the treatment levels should be noted, though, as they may have affected the subjective measures. Finally, subjects may have been biased towards the Compact because subjects included initially underwent a trial of the CROS, of which all perceived no benefit, and then elected to have Baha surgery hoping for a better outcome with this device.

A similar study was conducted by Wazen et al (2003) comparing differences in performance between unaided, Telex CROS, and Baha (unknown model) in 18 adult subjects, of which three were previously reported in Niparko et al (2003) (Baguley et al, 2006). All participants used a test rod or headband during a trial period and only those that had a positive response were included in the study. Each device was fit using an undefined protocol and subjects were allowed one to two months of acclimatization, with the CROS always evaluated prior to Baha surgery. Unaided, CROS, and Baha were investigated using HINT sentences, the APHAB (pre and post intervention), and the Single Sided Deafness questionnaire (Baha treatment level only after one month). After each acclimatization period, unaided, CROS, and Baha were tested utilizing HINT sentences under three experimental conditions: a) quiet (HINT sentences presented from 0º), b) noise (HINT noise at 60 dBA) and signal (HINT sentences)
presented from 0º, c) signal from 0º and noise presented on the side of the better ear, and d) signal from 0º and noise presented on the side of the poorer aided ear.

Results were nearly identical to those reported in Niparko et al (2003). Unaided performed better than CROS and Baha in quiet (2.9 dB and 2.6 dB, respectively) and Baha and CROS performed equally well (0.2 dB difference). The unaided treatment level also performed better than CROS and Baha when the signal was from 0º and noise was presented on the side of the poorer aided ear (3.7 dB and 1.6 dB respectively) and Baha reported a better RTS (dB) than CROS (2.1 dB) for this condition. Baha performed better than CROS and unaided when the noise and signal were presented from 0º (1.5 and 1.3 dB, respectively) and unaided and CROS performed equally well (0.1 dB difference) for this condition. Baha also performed better than CROS and unaided when the signal was from 0º and noise was presented on the side of the better ear (1.1 dB and 3.5 dB, respectively) and CROS performed better than unaided (2.4 dB) for this condition. It is unclear, however, if any of these HINT results were statistically significant, as the statistical analysis was not reported. APHAB results revealed that Baha had better APHAB benefit scores, relative to the unaided condition, when compared to CROS, but results were not statistically significant (EC = 6.5% versus 4.9%; RV = 15.5% versus 9.4%; BN = 18.9% versus 8.9%; AV = 9.2% versus –18.1%, respectively).

Fifteen of the eighteen subjects completed the SSD questionnaire. The SSD questionnaire reported 12 subjects wore the Baha on a daily basis and 16 reported wearing the Baha for more than eight hours a day. Twelve subjects reported the Baha improved quality of life, one stated the Baha had no impact, and four subjects reported they were unsure. Overall satisfaction with the Baha was rated as eight, with a range from 5-10, on a 10-point scale, with zero representing unsatisfied and 10 very satisfied. Fifteen subjects reported that the Baha
improved listening in quiet, talking to one person in a small group, and at a dinner table with someone talking on the deaf side. Fourteen reported improvement for listening to the TV and radio and 12 reported improvement when listening to music. These results provide further evidence that the Baha provides improved speech recognition in noise and perceived user benefit. However, it must be noted that there were errors in the experimental design similar to the previous study with participant selection bias, no reported counterbalancing of the objective measures, and there was no report of the statistical analysis, making interpretation of the results difficult.

In a study by Bosman et al (2003), nine adult subjects were evaluated in the unaided, CROS (unknown model), and Baha (unknown model) conditions using short, everyday Dutch sentences (Plomp and Mimpen, 1979) and the APHAB. The CROS and Baha were fit using an undefined protocol and subjects were allowed one month of acclimatization for each device, with the CROS trial period always occurring before the Baha. After acclimatization, the short, everyday Dutch sentences were utilized to measure subjects’ speech recognition in noise using an adaptive procedure for two experimental conditions: a) noise (unknown type and level) from 0° and signal (short, everyday Dutch sentences) presented on the side of the better ear and b) noise from 0° and signal presented on the side of the poorer aided ear.

Results revealed that Baha performed better than unaided and CROS (~0.7 dB and ~1.4 dB, respectively) and unaided performed better than CROS (~0.7 dB) when the sentences were presented on the side of the better ear. Baha also performed better than unaided and CROS (~2.3 dB and ~0.9 dB, respectively) and CROS performed better than unaided (~1.4 dB) when sentences were presented on the side of the poorer aided ear. It is unknown, however, if these results are statistically significant as the statistical analysis of these results was not reported.
APHAB results revealed better benefit scores, relative to the unaided condition, for Baha on the EC, BN, RV, and AV subscales (5.8%, 27.6%, 17.6%, and 11.4%, respectively) compared to CROS (4.7%, 19.6%, 7.2%, and –1.3%, respectively), however these results were not significantly different from each other. Results are similar to the previous studies and suggest that Baha performance is better than unaided and CROS. However, the experimental design had similar errors to those previously reported (no reported counterbalancing of outcome measures, no report of the statistical analysis of the results, etc.).

Hol et al (2004; 2005) expanded on Bosman et al’s study (2003) and published two subsequent studies in 2004 and 2005. In 2004, Hol et al recruited 11 adult subjects and compared their results with the nine subjects from Bosman et al’s study (2003) (Baguley et al, 2006). It should be noted that 27 subjects were originally recruited, however, six subjects did not continue due to a lack of perceived benefit during a Baha headband trial and one subject could not continue due to reduced mental abilities. CROS (unknown model) and the Compact (three subjects) or Classic (17 subjects) were fit using an unspecified fitting protocol and subjects were allowed one month of acclimatization before testing (CROS trial period always occurred before Baha). Subjects were tested in unaided, CROS, and Baha conditions with the same subjective and objective measures utilized by Bosman et al (2003) and with three additional experimental conditions a) signal (short, everyday Dutch sentences) and noise (spectrally shaped speech noise at 65 dBA) presented from 0°, b) signal from 0° and noise presented on the side of the better ear, and c) signal from 0° and noise presented on the side of the poorer aided ear. It should be noted that CROS and Baha were compared only to the unaided condition and not each other for all five experimental conditions.
Results (reported for only 11 CROS and 12 Baha users) on the short, everyday Dutch sentences revealed no statistically significant differences between the CROS and Baha versus the unaided condition with the signal and noise presented from 0°, noise from 0° and signal presented on the side of the better ear, and signal from 0° and noise presented on the side of the better ear. The Baha performed significantly better than the unaided condition when noise was from 0° and the signal was presented on the side of the poorer aided ear (2.2 dB) and no significant difference was reported between CROS and unaided for this condition. The unaided condition performed significantly better compared to CROS when the signal was from 0° and noise was presented on the side of the poorer aided ear (2.4 dB), but no significance was reported between unaided and Baha for this condition. APHAB results revealed significantly better benefit scores, relative to the unaided condition, for Baha compared to CROS based on a difference of 5% between all three speech communication subscales (BN = 34.4% versus 18.4%, RV = 18.1% versus 6.9%, EC 14.4% versus 7.6%, and AV = -12.4% versus 2.7%, respectively). This study reiterates the greater benefit provided by the Baha relative to the unaided condition, but it has the same experimental design errors as mentioned previously.

In 2005, Hol et al re-investigated the original 20 subjects from the 2004 study with nine newly recruited subjects using the same objective measures in Hol et al (2004) in addition to the APHAB, GHABP, International Outcome Inventory for Hearing Aids (IOI-HA) (Cox and Alexander, 2002) and the SSD questionnaire. It should be noted that originally 39 subjects were recruited, however nine did not continue due to a lack of perceived benefit from a trial with the Baha headband and one subject could not continue due to reduced mental abilities. Subjects were fit using an undefined protocol initially using the CROS (unknown model) and then, following one month of acclimatization and objective and subjective testing, with the Compact
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(five subjects) or Classic (24 subjects). Results on the objective measures (comparing only the unaided condition with CROS and Baha and not with each other) were similar to Hol et al (2004), except for two test conditions. The results for the signal and noise presented from 0° condition were not mentioned, although Hol et al (2005) listed it as an experimental condition. Also, CROS performed significantly better than the unaided condition when noise was from 0° and the signal was presented on the side of the poorer aided ear (~2.4 dB).

APHAB benefit scores were also similar in this study as those reported by Hol et al (2004). The only difference was CROS performed significantly poorer than unaided on the AV subscale (12.7%). In addition to the pre and post intervention (six weeks) scores, the APHAB was also administered at one year post Baha intervention, however, no significant differences in scores were noted at one year when compared to the results obtained at six weeks, suggesting that benefit was maintained over time. The GHABP was administered four weeks after fitting the CROS and at six weeks and one year after fitting the Baha. The Baha was worn more (88% at six weeks and 78% at one year) than CROS (65%), was judged to provide greater satisfaction (Baha: 51% at six weeks and 44% at one year; CROS: 32%), perceived disability was lower for Baha (Baha: 32% at six weeks and 37% at one year; CROS: 42%), and Baha provided increased benefit (Baha: 52% at six weeks, 49% at one year; CROS: 39%), however, these results were not reported to be statistically significant.

The IOI-HA was administered only for the Baha at six weeks and one-year post fitting, with 23 of the 29 subjects completing the questionnaire. This outcome measure examines hours of use, benefit, residual activity limitations, satisfaction, residual participation restrictions, impact on others, and quality of life. For 23 subjects, six out of seven items (unspecified) on the IOI-HA at six weeks and one year were not statistically different from each other, except for
satisfaction, which was reported to be significantly poorer after one year. Hol et al (2005) attributed this decrease in satisfaction to initially high expectations for the Baha, due to a failed CROS trial, which may have inflated subjective scores. Interestingly, in spite of the reported decrease in perceived satisfaction, 23 of the 26 subjects stated they would recommend the Baha to a friend with USNHL. Finally, 24 of the 29 subjects completed the SSD questionnaire for the Baha at six weeks and one-year post fitting. Nineteen subjects used the Baha every day for more than eight hours a day and rated the Baha an average of 7.6 out of 10 on the 10-point satisfaction scale. Twenty subjects stated the Baha improved listening in situations such as music, when talking to a single person in a group, or when watching television relative to when not wearing amplification. Twenty-two subjects reported that the Baha improved listening situations in which the signal arrived to the poorer ear, while two subjects did not. Twenty-one subjects stated the Baha improved their quality of life. Results at six weeks and at one year were not significantly different from each other. These results further reinforce the evidence base of improved objective and subjective scores with the Baha over CROS and unaided conditions, however, there are still experimental design errors that are similar to those previously reported.

Andersen et al (2006) investigated perceived handicap caused by USNHL and objective and subjective benefit of a Baha coupled to a testband compared to an unaided condition. The researchers initially mailed a Hearing Handicap Questionnaire to 59 adults with USNHL, receiving 53 (90% return rate) responses. Fifty-two subjects reported a handicap due to their USNHL (24 perceived a significant handicap, 23 perceived a moderate handicap, and eight perceived a mild handicap). Eleven percent reported difficulty in a quiet situation, while all respondents reported difficulty in noise, with 94% reporting significant difficulty. Twenty-eight of the respondents had previously tried CROS, and nine still used CROS. After receiving the
returned surveys, the investigators offered a trial of the Baha coupled to a testband to these respondents. Thirty-eight subjects responded with interest, but only 26 arranged for a test trial of the Baha coupled to a testband. The Baha was adjusted to the maximum power output that was comfortable for each subject and the Danish speech material test (DANTALE) (Keidser, 1993) was utilized to measure speech recognition in noise with the signal from 0º at 65 dB SPL with cocktail party noise presented from an unspecified loudspeaker location at a 10 dB SNR (unspecified if a + or – SNR was utilized).

Results revealed that the Baha performed significantly better (median=87%; range=32-99%) than the unaided condition (median=72%; range=24-95%). The subjects were also given an opportunity to wear the Baha for one hour in the “real-world” and return to complete a questionnaire created by Andersen et al (2006) concerning their experiences. Most (65%) subjects reported the Baha performed better than unaided, that the Baha made it easier to hear signals from the side of their poorer ear (77%), the Baha helped in noisy situations (62%), and the sound quality of the Baha was natural (88%). At the end of the study, 14 out of 26 subjects chose to be implanted with the Baha, while the other subjects reported a lack of perceived benefit with the trial of the Baha on a testband. The results suggested a perceived improvement over unaided for both objective and subjective measures, however, only 14 chose to be implanted. Andersen et al (2006) hypothesized that this may be due to unwillingness to undergo a surgical procedure as well as a decrease in perceived handicap over time as patients with USNHL learn to compensate for their hearing loss.

A meta-analysis conducted by Baguley et al (2006) examining the studies of Bosman et al (2003), Niparko et al (2003), Wazen et al (2003), and Hol et al (2004) reported that the Baha performed significantly better on speech recognition measures in noise than CROS and unaided
conditions (except when noise was presented on the side of the poorer aided ear). The Baha also performed significantly better on subjective measures with the Baha having better overall scores compared to CROS and unaided. However, there are many shortcomings to these studies. Baguley et al (2006) reported that the studies had small subject sample sizes and that a sample size of 70 would be required for a power of .80, however, Baguley et al (2006) did not specify which study(s) this power analysis was conducted for. Some other problems included the presence of subject selection bias due to inclusion of previous CROS users (Bosman et al, 2003; Hol et al, 2004), only selecting subjects with perceived benefit from a testband trial of the Baha (Bosman et al, 2003; Hol et al, 2004; Wazen et al, 2003), and the studies often reported subjects that had already been included in previous studies (Wazen et al, 2003; Hol et al, 2004). In addition, treatment levels were not randomized as the unaided, CROS, and Baha were always tested in this order for all four studies. Also, many studies did not provide information about testing procedures, as reported in Table 1 (Bosman et al, 2003; Andersen et al 2006), or even statistical analysis of the results, as reported in Table 2 (Bosman et al 2003; Wazen et al, 2003). This lack of documentation makes it difficult for researchers to interpret and replicate these studies.

There are consistent findings, however, across these studies. First, Baha and CROS alleviated the head shadow effect and improved the ability of subjects to receive the signal on the side of the poorer ear. Results were also consistent in reporting that the unaided condition performed better than Baha and CROS when the signal was from 0º and the noise was presented on the side of the poorer aided ear. This is expected as Baha and CROS amplify the noise from the poorer aided side and send this signal via bone conduction to the better ear, which could interfere with the signal (speech) that the subject wants to hear. In this case, subjects with
USNHL benefit from the head shadow effect as it attenuates the unwanted signal (noise). There is, however, a technological advance that could help patients with USNHL in this challenging listening situation by attenuating the noise and therefore improving the SNR. The addition of a directional microphone could reduce the background noise presented to the poorer aided side and therefore decrease interference with the wanted signal arriving at the better ear. A couple of studies have examined objectively and subjectively the addition of a directional microphone to the Baha and are investigated in the following section.

**Directional Performance of the Baha**

The Compact, introduced in 2000, was the first bone anchored hearing aid to offer a directional microphone (Figure 1) as an accessory that connected at the bottom of the Compact via an electrical input (Entific Medical Systems, n.d.a). The directional microphone for the Compact (Microtronic, model 6003) utilized a fixed hybrid bidirectional-hypercardioid polar pattern (nulls at 110° and 260° and an attenuated lobe at 180°) (Figure 2) with a Directivity Index
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(DI) of 6 dB to 4000 Hz decreasing to 5.7 dB at 6000 Hz (Figure 3) (Microtronic, 2000). This polar pattern could help patients with USNHL in difficult listening environments, especially when background noise arrives either to the side or behind the patient. One study has evaluated the performance of the directional microphone accessory for the Compact in patients with USNHL.

![Figure 2. Hybrid bidirectional-hypercardioid polar pattern of the directional microphone in the Baha Compact. Figure from Microtronic (2000).](image1)

![Figure 3. Directivity Index (DI) as a function of frequency (Hz) of the directional microphone in the Baha Compact. Figure from Microtronic (2000).](image2)
Lin et al (2006) recruited 28 adults with USNHL, 10 of which were from the Niparko et al (2003) study. Twenty-three subjects had normal hearing and five had a mild to moderate SNHL in the better ear. Five of the 23 subjects with normal hearing were lost at follow-up, leaving a total of 23 subjects completing the study. Four treatment levels: unaided, Telex CROS ACTII BTE, Compact with omnidirectional microphone (Compact OM), and Compact with directional microphone (Compact DM) were compared to determine differences in performance utilizing HINT sentences and the APHAB. Each of the 23 subjects was initially fit with CROS programmed with the low-cut and saturation sound pressure level (SSPL) potentiometers adjusted to full-on with the volume control fixed at 2.5. Each subject was allowed one month of acclimatization before objective and aided subjective measurements were obtained. All 23 subjects perceived little benefit with the CROS after this trial period and elected to have Baha surgery. Subjects were fit with the Compact OM three months post surgery using an undefined protocol and were allowed one month of acclimatization before objective and aided subjective measurements were obtained.

After measurements were obtained for Compact OM, only 14 of the 23 subjects agreed to continue on with the study to examine performance with the directional microphone and were fit with the Compact DM using an undefined protocol and were allowed one month of acclimatization before objective and aided subjective measurements were obtained. HINT sentences were utilized to investigate possible differences between the unaided, CROS, Compact OM, and Compact DM treatment levels under four experimental conditions: a) quiet (HINT sentences presented from 0º), b) signal (HINT sentences) and noise (white noise at 65 dBA) presented from 0º, c) signal from 0º and noise presented on the side of the better ear, and d)
signal from 0° and noise presented on the side of the poorer aided ear. All results of the aided treatment levels were compared to the unaided treatment level rather than to each other.

Results for HINT sentences in quiet revealed that CROS performed better than unaided for 3/23 subjects, which was significantly poorer than unaided, and no statistically significant differences were seen between Compact OM and Compact DM (14/23 and 4/14 had improved thresholds, respectively) compared to unaided. Results for the noise condition at which the signal and noise were presented from 0° revealed no significant differences between the three aided conditions compared to unaided (CROS 11/23, Compact OM 13/23, and Compact DM 8/14). CROS and Compact OM (2/23 and 5/23, respectively) performed significantly poorer compared to unaided when the signal was from 0° and noise was presented on the side of the poorer aided ear. There was no statistically significant difference between the unaided and Compact DM (3/14 had improved thresholds relative to unaided) for this condition. CROS and Compact OM, however, performed significantly better than unaided when the signal was from 0° and noise was presented on the side of the better ear (20/23 and 18/23 had improved thresholds relative to unaided, respectively). There was no statistically significant difference between Compact DM and unaided for this listening condition (9/14 had improved thresholds relative to unaided). HINT RTS (dB) differences between subjects with normal hearing versus sensorineural hearing loss in the better ear were not stated to be significantly different from each other.

Results from the APHAB were divided into two groups, those with normal hearing and those with a mild to moderate sensorineural hearing loss in the better ear. Results for the group with normal hearing in the better ear revealed that CROS provided significantly less benefit (only 2/16 had significant benefit scores) compared to unaided and no statistically significant
differences between Compact OM and Compact DM relative to unaided (6/14 and 3/9 had significant benefit scores, respectively) were reported using the 5% difference between EC, BN, and RV subscales. No statistically significant differences were reported for CROS, Compact OM, and Compact DM relative to unaided (1/5, 4/5, and 3/4 had significant benefit scores, respectively) for the group with a mild to moderate sensorineural hearing loss in the better ear.

At the end of this study, all subjects were followed up at an average of 30 months, and 22 of the 23 still wore the Compact on a regular basis, however it was not stated whether the directional microphone accessory was being used at this time.

This study provides evidence that the Compact OM and CROS provided greater benefit relative to unaided when the signal was from 0° and noise was presented to the better ear, which is consistent with the previously reported omnidirectional studies. CROS and Compact OM performed statistically poorer, relative to unaided, when the signal was from 0° and noise was presented to the poorer aided ear, which again is consistent with the previously reported omnidirectional studies. However, although Compact DM did not perform significantly better when the signal was from 0° and noise was presented to the better ear, Compact DM did not perform significantly poorer than unaided like CROS and Compact OM when the signal was from 0° and noise was presented to the poorer aided ear. This result suggests that the directional microphone could help improve listening in situations in which background noise is presented to the poorer aided ear relative to CROS and Compact OM.

Lin et al (2006) noted that the experimental test conditions that were examined (signal from 0° and noise arriving either from 0°, on the side of the good ear, or on the side of the poorer aided ear) may not have been favorable for the directional microphone accessory because of its polar pattern. However, the hybrid bidirectional-hypercardioid polar pattern should have
provided some benefit due to the nulls being close to where the noise was presented at 90° and 270° (110° and 260°). In the future, a study using a more “real-world” listening environment, such as a diffuse listening situation (signal from 0° and noise surrounding the subject), could better determine if the Compact DM provides benefit relative to the unaided and omnidirectional conditions. Studies in the future should also randomize treatments to prevent order effects, counterbalance test materials to prevent learning effects, and define fitting protocols in order for the studies to be replicated.

In 2005, the Baha Divino was introduced which was the first Baha with a built-in directional microphone (Figure 4). The directional microphone in the Divino (Sonion, model 6950) utilizes a fixed hybrid bidirectional-hypercardioid polar pattern (nulls at 100° and 260° along with an attenuated lobe at 180°) (Figure 5) with a DI of 5.9 dB to 4000 Hz decreasing to 5.4 dB at 6000 Hz (Sonion, 2005). With the Divino, a patient can switch between an omnidirectional program (up) and a directional program (down) via a toggle switch. The
potential benefit of the integrated directional microphone in the Divino has not been extensively studied, particularly in subjects with USNHL.

Figure 5. Hybrid bidirectional-hypercardioid polar pattern of the directional microphone in the Baha Divino. Figure from Sonion (2005).

Figure 6. Directivity Index (DI) as a function of frequency (Hz) of the directional microphone in the Baha Divino. Figure from Sonion (2005).
Kompis et al (2007) compared unaided, Compact (omnidirectional), Divino in the omnidirectional mode (Divino OM), and Divino in the directional mode (Divino DM) using objective measurements, including Freiburger numbers and monosyllabic words (Lehnhardt & Laszig, 2000) and the Basler sentence test (Tschopp & Züst, 1994), and subjective measures, including the APHAB and a custom questionnaire. Seven experienced Baha users (five wore Compact and two wore Classic 300) with bilateral conductive or mixed hearing losses were recruited. If the subject did not currently wear the Compact, the subject was initially fit with the Compact, with settings matching those of the subject’s Classic 300, and was allowed three months of acclimatization before aided objective and subjective measures were obtained. Then subjects were fit with the Divino and allowed three months of acclimatization before aided objective and subjective measures were obtained. After each acclimatization period, speech recognition in quiet was tested using Freiburger numbers and Freiburger monosyllabic words, presented at 50, 65, and 80 dB SPL. The Basler sentence test was utilized for testing in noise under two experimental conditions: a) signal (Basler sentences fixed at 70 dB SPL) and noise (type and input level undefined) presented from 0° and b) signal from 0° and noise presented from 180°. All experimental conditions and sentence lists were counterbalanced to prevent order and learning effects.

Results revealed that the Compact and Divino OM (Divino DM not measured) performed significantly better in quiet compared to unaided on Freiburger numbers (average combined improvement of 29-30 dB) and Freiburger monosyllabic words (average combined improvement of 52%), with no statistically significant differences between Compact and Divino OM. All aided conditions performed significantly better than unaided when the signal and noise were presented from 0° (Compact = ~8 dB; Divino OM = ~9 dB; Divino DM = ~8 dB) and when the
signal was from 0° and noise was presented from 180° (Compact = ~6 dB; Divino OM = ~7 dB; Divino DM = ~8 dB). No significant differences were reported between the Compact, Divino OM, and Divino DM when the signal and noise arrived from 0° or between Compact and Divino OM when the signal was from 0° and noise was presented from 180°. However, a significant difference of 2.3 dB was reported between Compact and Divino DM when the signal arrived from 0° and noise was presented from 180°. A statistically significant difference of 1.9 dB was also reported between the Divino DM when the signal and noise were presented from 0° compared to the Divino DM when the signal was from 0° and the noise was presented from 180°. No other within-treatment level statistically significant differences were reported. Interestingly, no significant difference was noted between the Divino OM and Divino DM for the 180° condition.

Results from the APHAB revealed no significant differences between the user’s current Baha (Compact or Classic 300) and the Divino (OM and DM combined). Results on the investigators’ questionnaire, which examined differences between the subjects’ own Baha versus the Divino (OM and DM combined) in different listening situations, revealed significant benefit using the Divino for sound quality and one-on-one conversations in quiet. No significant differences were reported between the user’s Baha and the Divino for listening in noise with one or many speakers or for listening to the television and radio. Four of the subjects reported using the directional microphone in difficult listening situations, one reported no benefit, and two did not use the directional microphone due to a perceived decrease in volume.

Interestingly, no significant differences were reported between the Divino OM and Divino DM. This contrasts with previous studies that have examined differences between omnidirectional and directional microphones in conventional in-the-ear (ITE) and behind-the-ear
(BTE) hearing aids. In these studies, a directional advantage of 3.2–3.7 dB (Valente et al, 2000) for a front-to-back listening situation (signal arriving from 0° and noise from 180°) and a directional advantage of 2.7–3.5 dB (Valente et al, 2000) to 3.3 dB (Pumford et al, 2000) for a diffuse listening situation (0°, 45°, 135°, 225°, and 315° and 0°, 72°, 144°, 216°, and 288°, respectively) with respect to the omnidirectional condition was reported for ITEs. A directional advantage of 7.4–8.5 dB (Valente et al, 1995) for a front-to-back listening situation and a directional advantage of 5.8 (Pumford et al, 2000) in a diffuse listening situation (0°, 72°, 144°, 216°, and 288°) with respect to the omnidirectional microphone was reported for BTEs. This study, however, may not have been ideal for the directional microphone in the Divino, as the noise was presented from 0° and 180° and the major nulls of the directional microphone used in the Divino are at 100° and 260° along with a lobe at 180° (5 dB of attenuation). A more “real-world” diffuse listening situation would provide a more accurate estimate of the performance of the directional microphone in the Divino.

A similar study by Hodgetts (2005) investigated the performance of the directional microphone in the Divino (Divino DM) compared to the Divino’s omnidirectional microphone (Divino OM) and the Classic. Five subjects were recruited with bilateral conductive or mixed hearing loss. All subjects previously wore the Classic and were fit with the Divino, with the omnidirectional program matched as closely as possible to user settings on the Classic. Acclimatization periods for each condition were not stated. Four listening conditions were examined utilizing HINT sentences: a) quiet (HINT sentences from 0°), b) signal (HINT sentences) and noise (HINT noise fixed at 65 dBA) presented from 0°, c) signal from 0° and noise presented on the Baha side, and d) signal from 0° and noise presented on the unaided side.
Results revealed no significant differences between Classic, Divino OM, and Divino DM in the quiet condition or when the signal and noise were presented from 0°. Differences were reported, however, for Divino DM compared to Classic and Divino OM when the signal was from 0° and noise was presented on the Baha side (benefit of ~8 and 7 dB, respectively) and when the signal was from 0° and noise was presented on the unaided side (benefit of ~3 and 4 dB, respectively). It is unknown whether these results are statistically significant, as statistical analysis was not reported. These results do, however, provide some evidence of benefit with the Divino’s directional microphone when noise is presented on either side of the subject compared to the Divino’s omnidirectional microphone.

In another study, Blackmore et al (2007) examined the directional microphone in the Divino using the Glasgow Benefit Inventory (GBI) (Robinson et al, 1996) with 11 adults having either a conductive or mixed hearing loss that were current users of the Baha (model undefined). The GBI measures quality of life after otolaryngological procedures in three areas: general, social, and physical subscales. Each question is rated on a five-point scale, with one representing the lease favorable outcome (-100), three representing no change (0), and five representing the most favorable outcome (+100). The GBI was mailed to subjects before being fit and three months after being fit with the Divino, using an undefined fitting protocol, and a response rate of 82% was reported.

Sixty-six percent of subjects reported an improvement in GBI scores, with an overall perceived quality of life increase of ~9 points (+49.7) relative to omnidirectional (~+41). An improvement was seen on each of the three subscales for the directional microphone compared to the omnidirectional microphone (general health = +57.4 versus ~+46, ~11 point benefit; physical health = +42.6 versus ~+33, ~10 point benefit; and social health = +25.9 versus ~+22, ~4 point
benefit). It is uncertain, however, if these results are statistically significant as the statistical analysis was not reported. Also, the editors and statistical advisor of the journal were hesitant to publish the study due to the uncertainty of using the GBI to measure benefit in users of Bahas, however they wanted to draw attention to the new technology (directional microphone).

These initial studies demonstrate some evidence of the potential benefit of the directional microphone of the Divino in subjects with conductive or mixed hearing loss. However, more research is needed examining the benefits of a directional microphone for subjects with USNHL, utilizing more “real-world” listening situations, and using a larger subject sample size to evaluate the effectiveness and efficacy of the directional microphone in the Divino. Numerous studies have shown that directional microphones in conventional air conduction hearing aids can provide significant benefit for patients in noisy situations, however, great care must be taken to properly fit the hearing aids and to counsel patients on the potential benefits and in which environments to use the directional microphone. An important aspect of achieving maximum benefit from the directional microphone is directional microphone alignment.

In a study by Ricketts (2000), directional microphone alignment was examined in three different BTE hearing instruments using five directional microphone alignment conditions: a) optimal horizontal position (O = 0°), b) non-optimal Condition 1 (NO1 = -24°, -26°, -22°), with negative alignment indicating that the rear port of the microphone was above the optimal horizontal position, c) non-optimal Condition 2 (NO2 = -12°, -13°, -11°), d) non-optimal Condition 3 (NO3 = 12°, 13°, 11°), and e) non-optimal Condition 4 (NO4 = 24°, 26°, 22°). DIs were measured for each of these five directional microphone alignment conditions on the Knowles Electronics Manikin for Acoustic Research (KEMAR) in the horizontal plane. Results revealed that the DI was significantly affected at all frequencies for NO1 and at 500 and 2000 Hz
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for NO4. Ricketts (2000) concluded that DI was significantly affected, most notably in the high frequencies, when directional microphone alignment deviated by ±20° from the optimal horizontal position (+20° = 2.9 dB and -20° = 1.2 dB versus optimal = 3.4 dB, -10° = 3.2 dB, and +10° = 3.4 dB) (Figure 7). Ricketts (2000) also noted that for NO1, the hearing aid was close to the back of the pinna, which created a “sound shadow” causing an approximate 3 dB decrease in the DI in the high frequencies compared to the other three non-optimal directional microphone alignment conditions.

![Figure 7. Directivity Indexes (DIs) of five directional microphone alignment conditions on KEMAR. O=optimal horizontal position (0°); NO1=non-optimal condition 1 (-24°, -26°, -22°); NO2=non-optimal condition 2 (-12°, -13°, -11°); NO3=non-optimal condition 3 (12°, 13°, 11°); NO4=non-optimal condition 4 (24°, 26°, 22°). Figure from Ricketts (2000).](image)

In a similar study conducted by Mueller and Wesselkamp (1999), three different directional microphone alignments (0°, 10°, and 20°) were evaluated for an ITE hearing aid. Similar results to Ricketts (2000) study were noted in that a deviation within ±10° did not significantly impact the DI, however, a deviation of ±20° resulted in a 0.5 dB decrease in the DI.
Ricketts (2001) also reported that even with the significant decrease in the DI for directional microphone alignment conditions that were ±20°, the resulting DIs were still better for the directional microphone for ITEs and BTEs compared to the DI for the omnidirectional microphone. In order to obtain maximum benefit from directional microphones, certain considerations must be taken into account for each style of hearing aid in order to achieve the optimal horizontal position. BTE optimal directional microphone alignment is largely determined by the patient’s ear anatomy and tubing length, while ITE optimal directional microphone alignment can vary with the patient’s ear anatomy and by the proper marking of the horizontal plane at the time earmold impressions are made to determine placement of the directional microphones (Mueller and Wesselkamp, 1999; Ricketts, 2000; Ricketts, 2001).

![Figure 8](Image)

Figure 8. Photo from the Divino User’s Manual showing how to properly align the directional microphones on the Divino. Photo from Entific Medical Systems (n.d.b.).

The Divino presents a unique problem in maintaining directional microphone alignment at the optimal vertical position (OVP 0°). The Divino snaps onto a titanium abutment and can rotate 360°, therefore, due to the lack of control, the patient could place the Divino in many
different directional microphone alignment positions each time it is worn. Another problem that could affect directional microphone benefit is surgical placement of the Baha. The Baha is optimally placed at a distance of 50-55 mm and at an angle of 45° from the external auditory meatus (Brenner et al, 2007), however, the Baha could be surgically implanted in a different position due to the anatomy and integrity of the mastoid, causing different proximities of the Baha to the pinna. This theoretically could cause a “sound shadow” for the Baha, as was noted by Ricketts (2000). The Divino user’s manual states “For the best performance of the directional microphone the sound processor should be positioned vertically with the microphone at the bottom”, but there is no data to support or refute this recommendation for the Baha as there is for conventional air conduction hearing aids (Figure 8) (Entific Medical Systems, n.d.b.).

The primary objective of this study is to determine:

1. If directional microphone alignments of the Divino at -10°, 0°, +10°, +20°, and +30° significantly impact the RTS (dB) using HINT sentences in a diffuse listening situation (with HINT sentences presented at 0° and uncorrelated restaurant noise fixed at 65 dBA presented from eight loudspeakers separated by 45° from each other surrounding the subject). It is hypothesized that no significant differences in the RTS (dB) will be found between the five directional microphone alignment conditions.

2. If the implanted anatomical position of the Divino affects the directional advantage of the Divino. It is hypothesized that different anatomical placements will not negatively affect the RTS (dB).

3. If subjects, when arriving to the clinic, wear the Baha at OVP. If directional microphone alignment deviations from OVP negatively impact RTS (dB)
performance, it is important to know whether patients are wearing the Baha at these non-optimal directional microphone alignment positions.

METHODS

Subjects

Fourteen subjects were recruited from Washington University’s Center for Advanced Medicine (CAM) and surrounding St. Louis area clinics by telephone utilizing scripts and letters approved by Washington University’s Human Research Protection Office (WUHRPO). Each subject signed a Consent Form that was approved by the WUHRPO either prior to the initial visit (those who received letters) or at the initial visit. In order to qualify for entrance into the study, each subject was required to: a) have worn the Baha for at least four weeks, b) have a USNHL, and c) be a native English speaker. Otoscopy, pure-tone air conduction audiometry (at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz), and word recognition testing (WRS) were performed to determine if he/she qualified and met the USNHL guidelines. USNHL was defined as a profound hearing loss with no measurable word recognition score in the poorer ear and a pure-tone air conduction average threshold of $\leq 20$ dB HL at 500, 1000, 2000, and 3000 Hz with word recognition scores of 90-100% at the subject’s Most Intelligible Level (MIL) in the better ear. The MIL was determined using monitored live voice presentation (voice peaking at 0 dB on the VU meter) by talking to the subject and asking the subject to indicate when the presentation level was comfortably loud and most intelligible. Two potential subjects could not participate due to hearing thresholds that were poorer than the requirements in the better ear, leaving a total of 12 subjects that participated in this study.

The mean and error bars representing one standard deviation of the hearing thresholds for the subjects’ better and poorer ear are displayed in Figures 9 and 10, respectively. The mean
PTA (at 500, 1000, 2000, and 3000 Hz) for the better ear was 11.8 dB HL (SD = 4.6 dB HL) and 105.9 dB HL (SD = 24.1 dB HL) for the poorer ear. WRSs were obtained using the compact disc (CD) recording of the female version of the Northwestern University Test Number 6 (NU-6) word list at the subject’s MIL. A half list was utilized only if the subject scored 92% (two incorrect words) or better for the first 25 words; otherwise a full list was completed. The mean WRS for the better ear was 97.3% (SD = 3.1%) and 13.0% (SD = 18.4%) for the poorer ear. WRSs could not be obtained in the poorer ear for ten of the subjects due to the magnitude of hearing loss. It should also be noted that Subject 7 had hearing thresholds within the moderate to severe range for the poorer ear and Subject 11 had hearing thresholds within the mild sloping to severe range. However, Subjects 7 and 11 exhibited poor WRSs of 26% and 0%, respectively, qualifying them for the study.

Figure 9. Audiogram displaying the mean (●) and error bars representing ± one standard deviation of the hearing thresholds for the better ear.
The 12 subject characteristics as well as their current Baha settings are reported in Table 3. The mean age of subjects was 52.9 years (SD = 13.9 years). There were five males and seven females. The etiologies of hearing loss in the poorer ear included one subject with progressive Ménière’s disease with gentamicin injections, six with an acoustic neuroma, one subject of which had NFII, two subjects had congenital deafness, one was idiopathic, one had a sudden sensorineural hearing loss, and one subject had hearing loss due to a petroclival meningioma. Six subjects wore the Divino, four the Intenso, and two the Compact, one of which had a D-mic. The mean years of experience with the subjects’ Baha was 1.6 years (SD = 1.4 years). Five subjects wore the Baha on the right side and seven wore the Baha on the left side. If a subject did not currently use the Divino, he/she was fit with a loaner Divino that was provided by

Figure 10. Audiogram displaying the mean (●) and error bars representing ± one standard deviation of the hearing thresholds for the poorer ear. *Note: * indicates that the error bar representing one standard deviation from the mean was greater than 130 dB HL.
Table 3. Individual subject characteristics and Baha settings.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Gender</th>
<th>Model of Baha</th>
<th>Years of Experience with Baha</th>
<th>Ear/Diagnosis of Hearing Loss</th>
<th>Worn in OM/DM Mode</th>
<th>Volume Control Setting</th>
<th>Tone Control Setting</th>
<th>AGCo Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48</td>
<td>M</td>
<td>Intenso</td>
<td>0.6</td>
<td>R Acoustic Neuroma</td>
<td>OM</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>44</td>
<td>F</td>
<td>Divino</td>
<td>2.5</td>
<td>R Congenital Deafness</td>
<td>OM</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>70</td>
<td>F</td>
<td>Divino</td>
<td>1.5</td>
<td>L Idiopathic</td>
<td>OM</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>65</td>
<td>M</td>
<td>Intenso</td>
<td>0.5</td>
<td>R Sudden SNHL</td>
<td>OM</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>58</td>
<td>M</td>
<td>Divino</td>
<td>0.5</td>
<td>L Acoustic Neuroma</td>
<td>OM</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>46</td>
<td>F</td>
<td>Compact with D-mic</td>
<td>4.3</td>
<td>L Acoustic Neuroma</td>
<td>OM</td>
<td>3</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>75</td>
<td>M</td>
<td>Intenso</td>
<td>0.6</td>
<td>L Ménière’s Disease with Gentamicin Injections</td>
<td>OM</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>45</td>
<td>F</td>
<td>Compact</td>
<td>3.5</td>
<td>R Acoustic Neuroma</td>
<td>OM</td>
<td>3</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>9</td>
<td>58</td>
<td>F</td>
<td>Divino</td>
<td>3</td>
<td>L Acoustic Neuroma</td>
<td>OM</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>47</td>
<td>F</td>
<td>Divino</td>
<td>0.8</td>
<td>L Acoustic Neuroma NF II</td>
<td>DM</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>56</td>
<td>F</td>
<td>Intenso</td>
<td>1</td>
<td>L Petroclival Meningioma</td>
<td>OM</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>23</td>
<td>M</td>
<td>Divino</td>
<td>0.08</td>
<td>L Idiopathic (Congenital-Sepsis)</td>
<td>OM</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cochlear Americas for another study that all, but one subject in the current study completed.

The Divino was adjusted using the potentiometers so that the tone control and automatic gain...
control output were adjusted to full-on. These settings remained constant throughout the study. The subject returned one week later or was called (due to travel limitations) for fine-tuning, if necessary, and to address any concerns or questions. Subjects then had four weeks to acclimatize to the Divino before HINT testing.

Two photographs were taken of each subject’s current Baha device (see Appendix A). One was close up and the other was taken further away showing the entire pinna. Photographs were obtained to illustrate the angle at which the subject wore his/her Baha and to illustrate the proximity of the Baha to the pinna. These photographs were analyzed in PowerPoint® using a technique described by Jones et al (2008) (see Appendix B for description of methodology). Finally, for each subject, measurements were made to document four anatomical positions of the titanium abutment. These measures included the angle of the abutment to the tragus, the distance (mm) from the abutment to the tip of the nose, from the abutment to the shoulder, and from the abutment to the tragus.

**TU-1000 Skull Simulator**

The TU-1000 skull simulator (Figure 11) allows for an objective measure of the output force level of the Baha over the frequency range of 250-8000 Hz (Stenfelt and Håkansson, 1998). The skull simulator simulates the properties of the average mastoid bone and overlying tissues. The impedance of the TU-1000 skull simulator adheres to the IEC 373 (1990) standard. The Baha is connected to the TU-1000 skull simulator via an abutment similar to the implanted titanium abutment in the subjects’ mastoid. The reader is referred to Håkansson and Carlsson (1989) and Stenfelt and Håkansson (1998) for a more detailed description of the TU-1000 skull simulator.
Figure 11. The directional microphone of the Baha being verified using the TU-1000 skull simulator in the Audioscan Verifit system. The calibrated reference microphone sits close to the Baha that is placed equidistant from the front and rear facing loudspeakers.

**Measuring Differences Between Omnidirectional and Directional Performance**

The TU-1000 skull simulator was utilized to verify and quantify omnidirectional versus directional microphone performance before HINT testing was performed. Prior to measuring differences in performance between the omnidirectional and directional microphones, the Divino was dehumidified and the microphone ports cleaned with a MedRx Ultra Vac to remove any debris that could potentially deteriorate directional microphone performance. The #13 zinc air battery was checked to ensure the battery was fully charged for testing. Initially, the reference microphone of the Audioscan Verifit was calibrated according to the Audioscan Verifit User’s Guide version 3.0 (Audioscan Verifit, 2007). After the Divino was cleaned and dehumidified, the Baha was coupled to the TU-1000 skull simulator (Figure 11) connected to the Audioscan Verifit and the volume control of the Divino was adjusted to “three” for electroacoustic testing.
Figure 12 illustrates an example of the response of the omnidirectional and directional microphone of the Divino. The Divino was placed in omnidirectional mode via the program switch (up position) to measure the omnidirectional performance (see upper curve in Figure 12) using “dual noise” (broadband noise comprised of 500 pure tones separated by 16 Hz) at 70 dB SPL (Audioscan, 2004). Then, the Divino was switched to the directional microphone mode (down position) and was moved slightly to the left or right to find the best directional response and the test was repeated (see lower curves in Figure 12). This measurement was performed to verify that the directional microphone was working properly before HINT testing. The dual noise from each speaker is unique to that speaker due to the 16 Hz of separation, allowing the magnitude of separation between the two signals to be examined (Audioscan, 2004).
directional microphone in Figure 12 is working properly as the front measure is providing more output than the back measure. The frequency output force response was also examined to determine if differences in the magnitude of the front-to-back ratio existed between the 12 Divinos utilized in this study.

**Recording the R-Space™ Restaurant Noise**

Restaurant noise was utilized during HINT testing to simulate a “real-world” listening situation. The recording was taken from a known noisy restaurant (noise floor of 58 dBA at the recording position, but the level of the noise created by the assemblage of people was significantly higher), with carpeted floors, wooden walls, and a wooden cathedral ceiling secured for a private party. The dimensions of the room where the recording was made was 36 feet (length) x 36 feet (width) x 8.5 to 17.5 feet (height with a sloping roofline). Thus, the volume of the room was 22,000 cubic feet. The reverberation time was unknown, but is probably of limited interest here, because the test materials (HINT sentences) were not spoken in the restaurant, and therefore were not subject to any possible masking effects of reverberation. Finally, it was determined that the critical distance for the recording was about 5 feet. Some of the tables (those nearest the recording position) were partially at or within the critical distance of the recording microphones, but many of the tables were beyond. Therefore, the restaurant simulation was a combination of direct and diffuse elements (Revit, personal communication).

About 45 people were seated and served breakfast in the main seating area of the restaurant, which, when completely full, could accommodate over 100 customers. A table at the center of the main seating area had been removed, replaced by an array of recording microphones. The eight, main recording microphones were of the highly directional, “shotgun” (interference-tube) variety, typically used in the movie-making industry to record sounds from a
distance. Because each shotgun microphone had a frontal pick-up pattern spanning approximately 45° (+/- 22.5°) around its axis, the eight microphones, when placed in an equally spaced, horizontal, circular array, picked up sounds arriving from all horizontal directions around the center of the array. The presumed pick-up points (diaphragms) of the shotgun microphones were located two feet from the center of the array. A ninth, omnidirectional microphone was placed at the center of the array for calibration purposes.

Each microphone was connected via a preamplifier to a separate track of a multi-track, digital audiotape (DAT) recorder (Tascam DTRS system). In this way, direct and reverberated sounds were captured (recorded) from around the restaurant “on their way” to the center of the two-foot-diameter microphone array. Later, using the R-Space™ playback system in the laboratory, these “captured” sounds were then released by the eight loudspeakers of the two-foot-diameter playback array. In this way, the sounds that had been captured at two feet from the center of the array in the restaurant would now complete their paths toward the central listening position, although now in a different time and place.

**Calibration of the R-Space™ Restaurant Noise**

Before the recording of the breakfast party, calibration signals were recorded individually through each of the eight microphones, so that playback levels could later be established to reflect the sound levels recorded in the restaurant. Separately, for each shotgun microphone, an equalized loudspeaker (flat from 100 - 16,000 Hz in 1/3-octave bands, +/− 3 dB) was held at a distance of two feet in front of the diaphragm, along the center of the pickup axis of the microphone. A pink-noise signal was delivered to the loudspeaker and adjusted to produce 84 dB SPL at the center of the array. For each shotgun microphone, the individual, pink-noise calibration signal was recorded onto the corresponding tape channel. In subsequent playback,
the gain of the amplifier for each of the eight R-Space™ loudspeakers was adjusted to produce 84 dB SPL at the center of the loudspeaker array, thus mirroring the calibration recording condition. On average, the sound-pressure level of the breakfast party, as measured at the calibration point in the restaurant, was 75 dBC, or 72 dBA. Therefore, when properly calibrated, the playback system created corresponding average sound-pressure levels.

The HINT materials (sentences) and the “R-Space™ restaurant noise” were transferred to a Macintosh hard drive using Toast 5.0 software, before being imported into AudioDesk software. Then, in AudioDesk, the right track was separated from the left track and the two tracks were digitally spliced end-to-end to form one long “sound bite.” This concatenated sound bite was then repeated as many times as was necessary to provide noise long enough for the longest presentation for the first HINT sentence. For subsequent HINT lists, the same noise sound bite was used, but with the starting time differing from that of the previous list by several seconds. Offset times of several seconds were digitally edited and placed in the appropriate channels thus producing uncorrelated noise. Compton-Conley et al (2004; Figure 4, p. 447) reported that the long-term speech spectrum of the R-Space™ restaurant noise was very similar to the long-term speech spectrum of the HINT sentences and noise.

Figure 13 illustrates the signal presentation system consisting of eight Boston Acoustics CR-65 loudspeakers (dimensions: 257 mm x 162 mm x 200 mm; frequency response (+/- 3 dB): 65-20,000 Hz; crossover frequency: 4200 Hz; woofer: 135 mm copolymer; tweeter: 20 mm dome; nominal impedance: 8 ohms) placed in an equally spaced array at ear level, two feet from the test subject in a 1.97 x 2.54 x 2.73 meter double-walled sound suite (volume = 14.05 m³) with a reported reverberation time of 0.19 seconds (personal communication with Industrial Acoustics Company). The loudspeakers were placed 45º apart from each other. The radius of the
Directional Microphone Alignment  Oeding

circle was two feet plus the depth of the loudspeaker (200 mm). The two signals (sentences and noise) were fed from a Macintosh-driven digital audio workstation, using MOTO AudioDesk software and a MOTU Model 828 8-channel FireWire A/D-D/A converter. The 0° loudspeaker and the remaining seven loudspeakers were driven by the individual channels of a QSC CX168 professional amplifier.

Figure 13. R-Space™ eight loudspeaker array. (Valente & Mispagel, 2008).

To ensure that the overall presentation level was 65 dBA, a 1” microphone connected to a Quest 1900 precision sound level meter and OB-300 1/3-1/1 octave band (OB) filter was placed at ear level, with the subject absent, two feet from the loudspeakers. Before calibration of the loudspeaker array, a QC-20 calibrator was coupled to the 1” microphone and a 1000 Hz tone at 94 dB SPL was presented. The measured output was read through the Quest 1900 precision sound level meter. The output was within +/- 0.5 dB of the targeted 94 dB SPL each time this measurement was taken to ensure that the 1” microphone was calibrated before calibrating the R-
Space™ loudspeaker array. Because the noise from each loudspeaker was uncorrelated to each other in the diffuse condition, the output level of each loudspeaker can be easily adjusted via the individual channels of the QSC CX168 amplifier to yield the same overall output for each test-loudspeaker condition. Calibration of the loudspeakers was completed before each test session utilizing “nearly” pink noise emitted and measured individually from each loudspeaker. The measured output was within +/- 0.5 dB of the targeted 84 dBA. The purpose for using this continuous noise rather than the gated noise provided by the HINT recording was that the noise approximates more closely many “real-world” noisy situations. Finally, a lavaliere microphone was placed near the subject’s mouth so the examiner could hear the subject’s response to the HINT sentences.

**Hearing in Noise Test (HINT)**

The HINT (Nilsson et al, 1994) consists of 250 sentences (25 lists of 10 sentences per list) read by a male speaker. The first 200 sentences (20 lists) were utilized in this study. The sentences are of approximately equal length (six to eight syllables) and difficulty (first-grade reading level) and have been digitally recorded for standardized presentation. The HINT estimates the RTS (dB) at which the sentences, embedded in uncorrelated restaurant noise, can be repeated correctly 50% of the time. This type of measure is useful because it enables accurate, reliable estimation of speech recognition in noise for context-rich speech materials.

The administration of the HINT requires two lists to be presented (10 sentences per list) for each of the five experimental conditions. The first sentence was presented at +8 dBA SNR with the noise at 65 dBA. This presentation level was determined from average starting levels of three of the twenty-five subjects that participated in a pilot study prior to this study. The first sentence was repeated, increasing the level of presentation by 4 dB, until repeated correctly by
the subject. Subsequently, the intensity level was decreased by 4 dB and the second sentence was presented. The stimulus level was raised (incorrect response) or lowered (correct response) by 4 dB after the subject’s response to the second, third and fourth sentences. The step size was reduced and fixed at 2 dB after the fourth sentence, and a simple up-down stepping rule was continued for the remaining 15 sentences. The calculation of the SNR necessary for 50% sentence recognition is based on averaging the presentation level of sentences 5 through 20, plus the calculated intensity for the twenty-first presentation.

The Divino was placed in the directional microphone mode via the program switch and the volume control was adjusted to a position of “three” for the entire testing session. The subject was seated in the center of the R-Space™ facing the front (0°) loudspeaker. The head placement of the subject was always examined to make sure it was level with the loudspeakers. The Divino was then positioned into one of the five (-10°, 0°, +10°, +20°, and +30°) directional microphone alignment conditions using a protractor/level measurement tool (Figure 14). The protractor/level ensured that measurements were always made on a fixed, horizontal plane.
During the directional microphone alignment positioning, the subject was instructed to face the dot on the front loudspeaker and to keep his/her head level during each directional microphone alignment adjustment. The volume control and line running down the center of the Divino were utilized as reference points when changing to one of the five directional microphone alignment conditions. All of the directional microphone alignment conditions were randomly assigned for each trial and each subject (Table 4). The subject was instructed to face the dot on the front loudspeaker and to keep his/her head level at all times throughout the entire test session. Subjects were instructed that sentences would be arriving from the front loudspeaker and noise would be heard from all eight of the surrounding loudspeakers. Subjects were asked to repeat the sentence exactly as heard and if unsure, subjects were instructed to take a guess.
Table 4. Randomized presentation of treatment levels for each subject.

<table>
<thead>
<tr>
<th>Subject</th>
<th>-10°</th>
<th>OVP (0°)</th>
<th>+10°</th>
<th>+20°</th>
<th>+30°</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
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<td>2</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

*Note:* Numbers represent the order in which the treatment level was utilized; OVP = optimal vertical position.

A HINT RTS (dB) was obtained for each of the five directional microphone alignment conditions in diffuse, uncorrelated R-Space™ restaurant noise. The HINT lists were counterbalanced to control for learning effects (see Table 5). However, another study examining the effectiveness of the directional microphone in the Divino was conducted on the same day for Subjects 4 and 12 prior to this study that also utilized the HINT sentences. These subjects were provided a twenty-minute break between studies to minimize fatigue. There is a possibility that the same HINT sentence list may have been presented twice, causing a potential learning effect. Also, Subjects 1, 3, 5, and 6 were retested due to poor test-retest reliability when their OVP RTS (dB) was compared to a similar situation in the other study they completed. All subjects, with the exception of Subject 5, reported improved test-retest reliability with the other study’s data after the second test session. Upon completion of testing, the RTS (dB) was computed for each directional microphone alignment condition and was entered into an Excel® spreadsheet.
Table 5. Randomized presentation of HINT sentence lists for each subject.

<table>
<thead>
<tr>
<th>Subject</th>
<th>-10°</th>
<th>OVP (0°)</th>
<th>+10°</th>
<th>+20°</th>
<th>+30°</th>
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<td>15-16</td>
<td>1-2</td>
<td>9-10</td>
<td>17-18</td>
</tr>
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<td>11-12</td>
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<td>17-18</td>
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<td>7-8</td>
<td>9-10</td>
<td>11-12</td>
<td>15-16</td>
</tr>
<tr>
<td>10</td>
<td>17-18</td>
<td>1-2</td>
<td>9-10</td>
<td>3-4</td>
<td>13-14</td>
</tr>
<tr>
<td>11</td>
<td>11-12</td>
<td>1-2</td>
<td>15-16</td>
<td>19-20</td>
<td>13-14</td>
</tr>
<tr>
<td>12</td>
<td>1-2</td>
<td>7-8</td>
<td>9-10</td>
<td>17-18</td>
<td>11-12</td>
</tr>
</tbody>
</table>

Note: Numbers represent the HINT sentence lists that were presented for each treatment level; OVP = optimal vertical position.

RESULTS

HINT

A repeated measures ANOVA (Kirk, 1982) was performed to determine if the mean differences in the RTS (dB) across the five directional microphone alignment conditions reported in Tables 6 and 7 and Figure 15 were significantly different from each other. The repeated measures ANOVA revealed that the mean differences in RTS (dB) across the five directional microphone alignment conditions were not significantly different ($F = 0.438; df = 4,59; p = 0.780$). The observed power was 0.049 based upon a computed alpha of .05 indicating a reduced likelihood to detect a difference when one actually exists.
Figure 15. Mean RTS (dB) for the five directional microphone alignment conditions. Error bars representing +/- one standard deviation are also reported.

Table 6. Mean RTS (dB) and standard deviation (dB) for the five directional microphone alignment conditions reported in Figure 15.

<table>
<thead>
<tr>
<th>Directional Microphone Alignment Condition</th>
<th>-10°</th>
<th>0°</th>
<th>+10°</th>
<th>+20°</th>
<th>+30°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.71</td>
<td>2.52</td>
<td>2.54</td>
<td>1.82</td>
<td>2.72</td>
</tr>
<tr>
<td>SD</td>
<td>2.95</td>
<td>2.41</td>
<td>2.35</td>
<td>3.16</td>
<td>3.36</td>
</tr>
</tbody>
</table>
Table 7. Comparison matrix of RTS (dB) for the five directional microphone alignment conditions.

<table>
<thead>
<tr>
<th>Reference Condition</th>
<th>Directional Microphone Alignment Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-10°</td>
</tr>
<tr>
<td>-10°</td>
<td>0</td>
</tr>
<tr>
<td>0°</td>
<td>+0.19</td>
</tr>
<tr>
<td>+10°</td>
<td>+0.17</td>
</tr>
<tr>
<td>+20°</td>
<td>+0.88</td>
</tr>
<tr>
<td>+30°</td>
<td>-0.02</td>
</tr>
</tbody>
</table>

**Note:** (+) indicates the RTS (dB) of the directional microphone alignment condition performance is higher (poorer) than the reference condition. (–) indicates the RTS (dB) of the directional microphone alignment condition performance is lower (better) than the reference condition.

Figure 15 and Table 6 report the mean RTS (dB) and standard deviation for the five directional microphone alignment conditions. An RTS (dB) of 0 dB means the subject required the intensity level of the sentences to be equal to the level of the noise (65 dBA) in order to correctly repeat the HINT sentences 50% of the time. Thus, a higher RTS (dB) reflects poorer performance and a lower RTS (dB) reflects better performance. All five directional microphone alignment conditions had a mean RTS (dB) that was greater than 0. Table 7 displays the mean differences between each directional microphone alignment condition. A positive RTS (dB) indicates that directional microphone alignment performance was higher (poorer) than the reference condition and a negative RTS (dB) indicates that directional microphone alignment performance was lower (better) than the reference condition. This table reports that OVP performed, on average, better than the non-OVP directional microphone alignment conditions, except for +20°. The +20° directional microphone alignment condition performed, on average, better (-0.70 to -0.90 dB) than all other directional microphone alignment conditions. This table also reports that the +30° directional microphone alignment condition performed poorer (+0.02 dB) than the reference condition.
to +0.90) than all other directional microphone alignment conditions. These differences, however, were not statistically significant.

Figure 16. The mean (●) RTS (dB) and 95% confidence interval of the difference between the mean RTS (dB) for the non-OVP directional microphone alignment conditions re: OVP condition. (–) indicates better performance for the non-OVP directional microphone alignment condition and (+) indicates better performance for OVP.

Figure 16 reports the 95% confidence interval of the difference between the mean RTS (dB) for the non-OVP directional microphone alignment conditions relative to the OVP condition. A negative value indicates better performance for the respective non-OVP directional microphone alignment condition and a positive value indicates better performance for the OVP directional microphone alignment condition. It can be seen that only the +20° directional microphone alignment condition performed better, on average, than OVP compared to the other
Directional Microphone Alignment  Oeding

three non-OVP directional microphone alignment conditions in which the OVP directional microphone alignment condition performed, on average, better. However, neither of these conditions was significant as each 95% confidence interval crosses “0”.

Better or poorer performance of the OVP directional microphone alignment condition re: the -10°, +10°, +20°, and +30° directional microphone alignment conditions is reported for each subject along with the overall mean in Table 8 and in Figures 17 through 20, respectively. A higher RTS (dB) represents better performance of the OVP directional microphone alignment condition and a lower RTS (dB) represents better performance of the respective non-OVP directional microphone alignment condition. The dashed lines in each graph represent statistical significance as determined by Nilsson et al’s (1994) confidence interval for two 10-sentence HINT lists in noise of +/- 1.5 dB. It should be noted, however, that these confidence intervals are based on HINT sentences utilizing uncorrelated HINT noise (spectrally matched white noise) and this study utilized uncorrelated, R-Space™ restaurant noise. A study completed by Valente et al (2006) revealed that RTS (dB) thresholds in a diffuse listening situation when tested in HINT noise resulted in better thresholds (1.8 dB) than RTS (dB) thresholds in R-Space™ restaurant noise. This demonstrates that the uncorrelated, R-Space™ restaurant noise presents a more difficult listening situation.
Figure 17. Better or poorer performance of OVP re: -10° directional microphone alignment condition for each subject. Note: Dashed lines represent statistical significance as determined by Nilsson et al’s (1994) confidence interval for two 10-sentence lists in noise of +/- 1.5 dB. * denotes significantly better performance for the OVP directional microphone alignment condition and ** denotes significantly better performance for the -10° directional microphone alignment condition.
Figure 18. Better or poorer performance of OVP re: +10° directional microphone alignment condition for each subject. **Note:** Dashed lines represent statistical significance as determined by Nilsson et al’s (1994) confidence interval for two 10-sentence lists in noise of +/- 1.5 dB. * denotes significantly better performance for the OVP directional microphone alignment condition and ** denotes significantly better performance for the +10° directional microphone alignment condition.
Figure 19. Better or poorer performance of OVP re: +20° directional microphone alignment condition for each subject. Note: Dashed lines represent statistical significance as determined by Nilsson et al.’s (1994) confidence interval for two 10-sentence lists in noise of +/- 1.5 dB. * denotes significantly better performance for the OVP directional microphone alignment condition and ** denotes significantly better performance for the +20° directional microphone alignment condition.
Figure 20. Better or poorer performance of OVP re: +30° directional microphone alignment condition for each subject. Note: Dashed lines represent statistical significance as determined by Nilsson et al’s (1994) confidence interval for two 10-sentence lists in noise of +/- 1.5 dB. * denotes significantly better performance for the OVP directional microphone alignment condition and ** denotes significantly better performance for the +30° directional microphone alignment condition.

These figures demonstrate that although there were no significant performance differences between the mean of each directional microphone alignment condition, there was a considerable amount of inter- and intra-subject variability. Results revealed that four subjects reported significantly better performance for OVP relative to -10°, four reported significantly better performance for -10°, and four subjects along with the overall mean reported no significant performance differences between OVP and -10° directional microphone alignment conditions. Results for OVP relative to +10° revealed that five subjects reported significantly better performance for OVP, three reported significantly better performance for +10°, and four subjects along with the overall mean reported no significant performance differences between
OVP and +10° directional microphone alignment conditions. Results for OVP relative to +20° revealed that two subjects reported significantly better performance for OVP, four reported significantly better performance for +20°, and six subjects along with the overall mean reported no significant performance differences between OVP and +20° directional microphone alignment conditions. Finally, results for OVP relative to +30° revealed that three subjects reported significantly better performance for OVP, three reported significantly better performance for +30°, and six subjects along with the overall mean reported no significant performance differences between OVP and +30° directional microphone alignment conditions.

Table 8 reports better or poorer performance differences for the non-OVP directional microphone alignment conditions relative to OVP for each subject. A plus sign indicates that OVP performed better than the respective non-OVP directional microphone alignment condition and a negative sign indicates that OVP performed poorer than the respective non-OVP directional microphone alignment condition. Also shown is significance (*) for each condition using Nilsson et al’s (1994) criteria. Only one subject, Subject 7, demonstrated significantly better performance for OVP in all four non-OVP directional microphone alignment conditions. Subject 2, however, demonstrated significantly better performance for all four of the non-OVP directional microphone alignment conditions with three conditions performing significantly better than OVP (+10°, +20°, and +30°) relative to OVP. Subject 12 also demonstrated better performance for the non-OVP directional microphone alignment conditions relative to OVP in all four directional microphone alignment conditions, with two conditions (-10° and +30°) performing significantly better than OVP. Also, every subject reported at least two directional microphone alignment conditions that had significant performance for either OVP or for a non-OVP directional microphone alignment condition.
Table 8. Performance of the four non-OVP directional microphone alignment conditions re: OVP for each subject.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Directional Microphone Alignment Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-10°</td>
</tr>
<tr>
<td>1</td>
<td>+*</td>
</tr>
<tr>
<td>2</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
<td>_</td>
</tr>
<tr>
<td>4</td>
<td>+*</td>
</tr>
<tr>
<td>5</td>
<td>–</td>
</tr>
<tr>
<td>6</td>
<td>_</td>
</tr>
<tr>
<td>7</td>
<td>+*</td>
</tr>
<tr>
<td>8</td>
<td>+</td>
</tr>
<tr>
<td>9</td>
<td>_</td>
</tr>
<tr>
<td>10</td>
<td>+</td>
</tr>
<tr>
<td>11</td>
<td>–</td>
</tr>
<tr>
<td>12</td>
<td>_</td>
</tr>
</tbody>
</table>

**Note:** * indicates significant performance differences between the non-OVP and OVP directional microphone alignment conditions according to Nilsson et al’s (1994) confidence interval for two 10-sentence lists in noise of +/- 1.5 dB. (+) indicates better performance for OVP re: the non-OVP directional microphone alignment condition. (–) indicates better performance for the non-OVP directional microphone alignment condition re: to OVP. 0 indicates no difference in performance between the non-OVP and OVP directional microphone alignment condition.

**Directional Microphone Front-to-Back Ratio**

Front-to-back ratio measurements on the Audioscan Verifit system utilizing the TU-1000 skull simulator were performed on each Divino prior to HINT testing. Table 9 reports the front-to-back ratio differences for each subject at 250–8000 Hz in octave and mid-octave intervals at 3000 and 6000 Hz. A negative number indicates that the signal is being attenuated more from the back measurement compared to the front measurement. As can be seen, there is some variability across the Divino aids, particularly at 250 Hz, however, a general trend can be seen at most frequencies, such as 4000 and 8000 Hz reporting the least amount of attenuation and 1000–2000 Hz reporting the greatest amount of attenuation. Subject 9’s Divino had the poorest overall front-to-back ratio attenuation while Subjects 2 and 6 had the best front-to-back ratio attenuation.
Table 9. Front-to-back ratio differences (dB) for the Divino measured on the Audioscan Verifit system.

<table>
<thead>
<tr>
<th>Subject</th>
<th>250 Hz</th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>3000 Hz</th>
<th>4000 Hz</th>
<th>6000 Hz</th>
<th>8000 Hz</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-6</td>
<td>-5</td>
<td>-11</td>
<td>-12</td>
<td>-3</td>
<td>2</td>
<td>-8</td>
<td>-2</td>
<td>-6</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>-11</td>
<td>-6</td>
<td>-16</td>
<td>-18</td>
<td>0</td>
<td>4</td>
<td>-8</td>
<td>-3</td>
<td>-7</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>-5</td>
<td>-6</td>
<td>-12</td>
<td>-4</td>
<td>0</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>-2</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>-14</td>
<td>-3</td>
<td>-6</td>
<td>-10</td>
<td>-7</td>
<td>-3</td>
<td>-7</td>
<td>0</td>
<td>-6</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>-2</td>
<td>-10</td>
<td>-8</td>
<td>-11</td>
<td>-6</td>
<td>-6</td>
<td>-8</td>
<td>0</td>
<td>-6</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>-16</td>
<td>-1</td>
<td>-7</td>
<td>-12</td>
<td>-8</td>
<td>-3</td>
<td>-8</td>
<td>0</td>
<td>-7</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>-7</td>
<td>-3</td>
<td>-8</td>
<td>-10</td>
<td>-6</td>
<td>-2</td>
<td>-5</td>
<td>0</td>
<td>-5</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>-6</td>
<td>-8</td>
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<td>4</td>
<td>1</td>
<td>-6</td>
<td>0</td>
<td>-1</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>14</td>
<td>-5</td>
<td>-13</td>
<td>-4</td>
<td>0</td>
<td>6</td>
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<tr>
<td>10</td>
<td>5</td>
<td>-7</td>
<td>-9</td>
<td>-4</td>
<td>1</td>
<td>0</td>
<td>-7</td>
<td>7</td>
<td>-2</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>-15</td>
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<td>-7</td>
<td>-2</td>
<td>-6</td>
<td>-2</td>
<td>-6</td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td>-10</td>
<td>3</td>
<td>-2</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

Note: (–) indicates that the signal is being attenuated more from the back measurement compared to the front measurement.

**Real-World Directional Microphone Alignment Placement**

Each subject had two photographs taken of his/her Baha (one close-up and one further away) prior to HINT testing to examine how each subject wore the Baha when arriving to be evaluated for the project. These photographs were analyzed to determine the directional microphone alignment of each subject’s Baha using a technique created by Jones et al (2008) described in Appendix B. The results from analyzing the photographs are reported in Table 10. Nine of the 12 subjects wore the Baha within the -10° to +30° range utilized in this study while three subjects, Subjects 3, 8, and 9, wore the Baha outside of this alignment range (-25°, -51°, and -17°, respectively). Whether Subjects 3, 8, and 9 would receive significantly poorer or better directional microphone performance from these non-OVP directional microphone alignments relative to OVP is unknown as these angles were not examined in the current study. Also, five of
the subjects (Subjects 3, 5, 8, and 10) wore the Baha outside of the critical ±20° range discussed by Ricketts (2000) and Mueller and Wesselkamp (1999) that causes a significant decrease in the DI.

### Table 10. Directional microphone alignment of Baha as worn in daily life.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Directional Microphone Alignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+7°</td>
</tr>
<tr>
<td>2</td>
<td>-8.5°</td>
</tr>
<tr>
<td>3</td>
<td>-25°</td>
</tr>
<tr>
<td>4</td>
<td>+3°</td>
</tr>
<tr>
<td>5</td>
<td>+23.5°</td>
</tr>
<tr>
<td>6</td>
<td>-2°</td>
</tr>
<tr>
<td>7</td>
<td>+3°</td>
</tr>
<tr>
<td>8</td>
<td>-51°</td>
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<td>12</td>
<td>-3.5°</td>
</tr>
<tr>
<td>Mean</td>
<td>-4°</td>
</tr>
<tr>
<td>SD</td>
<td>20°</td>
</tr>
</tbody>
</table>

*Note:* (-) indicates directional microphone alignment towards the pinna.

### Placement of Baha Abutment

Four measurements were obtained to examine inter-subject variability of the Baha abutment placement compared to the standard template of a distance of 50–55 mm at a 45° angle from the external auditory meatus suggested by Cochlear Corporation in their surgical manual (Brenner et al, 2007). The angle of the abutment to the tragus, distance (mm) from the abutment to the tragus, distance (mm) from the abutment to the shoulder, and distance (mm) from the
Directional Microphone Alignment  Oeding

abutment to the tip of the nose were measured for each subject and are reported in Table 11. The angle of the abutment to the tragus is displayed graphically in Figure 21. Some inter-subject variability can be seen with each measurement, particularly for the angle of the abutment to the tragus measure, which ranges from 5° to 54° with a mean of 39° (SD = 13°). The distance measurements demonstrate moderate consistency between subjects, however, the abutments of these subjects are implanted considerably beyond the recommended distance of 50–55 mm with a mean of 73 mm (SD = 6 mm).

Table 11. Subject variability in the placement of the Baha abutment.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Angle of abutment to tragus</th>
<th>Distance from abutment to tragus (mm)</th>
<th>Distance from abutment to shoulder (mm)</th>
<th>Distance from abutment to tip of nose (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>47°</td>
<td>72</td>
<td>144</td>
<td>202</td>
</tr>
<tr>
<td>2</td>
<td>42°</td>
<td>73</td>
<td>150</td>
<td>192</td>
</tr>
<tr>
<td>3</td>
<td>44°</td>
<td>72</td>
<td>146</td>
<td>216</td>
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<td>4</td>
<td>42°</td>
<td>75</td>
<td>168</td>
<td>214</td>
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<td>5</td>
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<td>6</td>
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<td>67</td>
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<td>193</td>
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<td>7</td>
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<td>77</td>
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<td>8</td>
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<td>76</td>
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<td>9</td>
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<td>73</td>
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<td>203</td>
</tr>
<tr>
<td>SD</td>
<td>13°</td>
<td>6</td>
<td>15</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure 21 was created using the technique described by Jones et al (2008) (see Appendix B) that was utilized in measuring directional microphone alignment in the Baha photographs. The green dot on the tragus was utilized as a reference point for determining the angle and distance from the tragus to the abutment for each subject. Also note that the distance from the abutment to tragus was kept to scale in this figure. As can be seen, the abutment placement of
the subjects in this study differs from the suggested abutment placement, shown with the gray dot. Subject 8 in particular varied significantly from the guideline (5° versus 45°, respectively). Overall, the abutment placement of the subjects in this study cluster around approximately 39° and are at a distance that is farther than the suggested abutment placement (73 mm versus 50–55 mm, respectively).

Figure 21. Baha abutment placement of subjects compared to the suggested abutment placement (gray circle). The green dot on the tragus was utilized as a reference point for measuring the different abutment angles and distances for each subject. Please note that the distance from the tragus to the abutment in this diagram was drawn to scale. Diagram of ear from: http://content.answers.com/main/content/img/oxford/Oxford_Sports/0199210896.Frankfort-plane.1.jpg.
DISCUSSION

The results revealed that non-OVP directional microphone alignments in the Baha Divino between -10° to +30° did not result in statistically significant differences in the mean RTS (dB) in a diffuse listening situation compared to OVP. These results suggest that the Divino’s directional microphone can be aligned anywhere between -10° to +30° and subjects, on average, will receive similar directional benefit from the directional microphone. Clinically, this is significant as many of the 12 subjects wore the Baha at directional microphone alignments other than OVP (Table 10). As mentioned previously, nine subjects wore their current Baha within the investigated range of -10° to +30° and three subjects, Subjects 3, 8, and 9, wore their current Baha outside of this range (-25°, -51°, and -17°, respectively). This study did not examine directional microphone alignments outside this range, and therefore, the impact of these directional microphone alignments on speech recognition in noise is unknown. Also, since the Baha can freely rotate 360°, it is unknown as to how consistently subjects wear their Baha at the observed directional microphone alignments, although some subjects mentioned they always wore the Baha at OVP. Clinically, it is still important to counsel patients to wear the Divino at OVP because the consequences of wearing the Divino outside of this range are unknown. It would also be difficult for patients to determine if the Divino is within this range while worn without having a measurement tool, such as the one utilized in this study.

When examining the overall mean RTS (dB) performance for the non-OVP directional microphone alignment conditions relative to OVP, results revealed a difference of –0.19 dB for -10°, -0.02 dB for +10°, +0.70 dB for +20°, and –0.20 dB +30°. A positive RTS (dB) indicated better performance for the respective non-OVP directional microphone alignment condition relative to OVP, while a negative RTS (dB) indicated better performance for OVP relative to the
respective non-OVP directional microphone alignment condition. These findings are similar to previous studies examining directional microphone alignment in BTEs and ITEs. Ricketts (2000) and Mueller and Wesselkamp (1999) reported that a deviation of ±20° resulted in a 0.5 dB decrease in the DI. A theoretical model (Figure 22) created by Kuk et al (2007) reported that angular deviation of ±10° could result in a DI decrease of approximately 0.2 dB and angular deviation of ±30° could result in a DI decrease of approximately 1.2 dB.

Figure 22. Theoretical decrease in the Directivity Index (DI in dB) as the angle of the directional microphone deviates from the optimal horizontal position (Kuk et al, 2007).

The current study reported a negligible mean RTS (dB) decrease in performance, on average, for the ±10° directional microphone alignment conditions relative to OVP (-0.19 dB at -10° and -0.02 dB at +10°). This finding is in close agreement to the Kuk et al (2007) theoretical decrease in DI of 0.2 dB. Results for the directional microphone alignment of +30° (-0.20 dB) is not in as close agreement with the Kuk et al (2007) theoretical prediction of a 1.2 dB decrease in DI. However the difference of 1 dB is not considered significant. What is interesting, however, is that at +20°, the RTS (dB) performance, on average, is better for non-OVP than OVP (+0.70
Directional Microphone Alignment Oeding

dB) and is slightly contrary to what Ricketts (2000) and Mueller and Wesselkamp (1999) reported (-0.5 dB). In fact, +20° performed, on average, better than all four directional microphone alignment conditions (-0.88 dB for -10°, -0.70 dB for OVP, -0.72 dB for +10°, and -0.90 dB for +30°), however, none of these differences were statistically significant.

Why the +20° directional microphone alignment condition outperformed all four directional microphone alignment conditions is unknown. The different polar patterns from the previous studies (not mentioned) compared to this study (hybrid bidirectional-hypercardioid) may perform differently at each directional microphone alignment condition. These differences may also be related to anatomical differences in the placement of the Baha directional microphones compared to BTES and ITEs. Ricketts (2000) noted that the pinna affected the DI at greater angular deviations, particularly at higher frequencies (3 dB decrease in DI from 2000 to 4000 Hz). As reported earlier, the placements of the Baha abutment in this study were further away than the suggested abutment placement and may therefore have avoided this “sound shadow” Ricketts (2000) noted in BTEs. It must also be noted that DI and RTS (dB) are different directional microphone measurements and comparison with each other must be interpreted with caution. Also, Ricketts (2000) and Mueller and Wesselkamp (1999) measured DI on KEMAR while this study measured RTS (dB) on subjects. Currently, no studies have measured the affect of directional microphone alignment on speech recognition on subjects. By performing these measurements on subjects, many uncontrollable variables can occur compared to measures using KEMAR.

First, subject head movement may have resulted in the inter-subject variability in RTS (dB) thresholds. In this study, subjects’ heads were not restricted during testing, however, each subject was instructed to focus at a dot on the 0° loudspeaker and to keep his/her head level
before and after each directional microphone alignment change and throughout the entire test session. This is a difficult task to complete for 45 minutes and it is likely that during the test session the angle of the Divino was not always at its intended position. Also, there is a tendency for patients to change the position of their head during difficult listening situations to obtain the best signal possible. This may have occurred during testing, as the subjects’ heads were not held stationary.

Second, the uncorrelated, R-Space™ restaurant noise may also have caused some variation in the RTS (dB). There are peaks and valleys within the restaurant noise, as is true in “real world” listening situations, and subjects may have had small windows of opportunity to hear the HINT sentence or possibly not hear the sentence. Third, subject attention is another factor as 45 minutes is a long time to sit and listen intently. Also, the restaurant recording contains actual conversations, clatter, and music, again making it more “real world” than stationary HINT noise, and subjects may have been distracted by the background noise and paid attention to the noise instead of the HINT sentences. Several subjects mentioned during testing that it was difficult to attend to the sentences because they were distracted by conversations and music around them. In a study completed by Valente et al (2006), an average decrease of 1.8 dB in RTS (dB) was reported when HINT thresholds were measured in a diffuse listening environment using the R-Space™ noise in comparison to the HINT noise. All or a combination of these factors could have contributed to the inter- and intra-subject variability reported in this study in RTS (dB) thresholds. It is also important to note that head movement, uncorrelated background noise, and attention are all factors that subjects face in a “real-world” listening environment and, therefore, this study reflects a more “real-world” environment versus an ideal laboratory environment.
Although the results from this study indicate that subjects, on average, can wear the Divino between -10° and +30° and still perform similar to OVP, there was significant subject variability between directional microphone alignment conditions. In order to quantify why these differences occurred, eight variables: angle of the abutment to the tragus, distance from the abutment to the tragus (mm), distance from the abutment to the shoulder (mm), distance from the abutment to the tip of the nose (mm), sensation level, PTA, average front-to-back ratio attenuation, and years of experience with the Baha were examined between each subject in Table 12. Sensation level is the average amount of gain (250–8000 Hz) from the directional microphone minus the average hearing thresholds in the better ear (250–8000 Hz). A higher value indicates a better sensation level. The PTA is the average air conduction threshold in the better ear at 500, 1000, 2000, and 3000 Hz. The front-to-back ratio represents the average amount (250–8000 Hz) of attenuation from the back measurement compared to the front measurement. A lower value indicates greater attenuation of the signal from the back. At the time of submission, a correlation analysis between these variables and RTS (dB) was not fully completed and therefore, only speculation of relationships between these variables and RTS (dB) could be made.

When all of the variables are examined across subjects, no specific trends are noticed. As an example, Subjects 2 and 7 are at extreme ends of the spectrum. Subject 2 performed significantly better, according to Nilsson et al (1994), for +10°, +20°, and +30° relative to OVP, whereas Subject 7 performed significantly better for OVP relative to all four non-OVP directional microphone alignment conditions. Sensation level for these two subjects does show some variability with Subject 2 having a sensation level of –21.50 and Subject 7 a sensation level of –10.50. This suggests that subjects with poorer sensation levels perform better with non-OVP
directional microphone alignment conditions and subjects with a better sensation level perform better with OVP. However, when other subjects are examined, such as Subject 4 who had the poorest sensation level of –31.50, the relationship of poorer sensation levels associated with better non-OVP RTS (dB) thresholds does not hold true. OVP performed significantly better than -10° and +30° and non significantly better at +20° for this subject. Also, Subject 6, who had the best sensation level (-1.63) performed better overall with non-OVP directional microphone alignment conditions, again not supporting the possible trend. Another variable that shows a possible trend between Subjects 2 and 7 is PTA. Subject 2 had the poorest overall PTA (20.00 dB) and subject 7 has a better PTA (11.25 dB) suggesting a trend that a poorer PTA favors non-OVP directional microphone alignment conditions. When the best PTA is examined (Subject 6 = 3.75 dB), however, this subject favors non-OVP directional microphone alignment conditions, which does not support this trend. Finally, years of experience with the Baha were also examined as a possible trend of greater years of experience with the Baha favoring non-OVP directional microphone alignment conditions was noted between Subjects 2 and 7. However, when other subjects, such as Subject 8 (3.5 years) and Subject 12 (0.08 years), are examined, the trend does not appear as strong as Subject 8 favored OVP and Subject 12 favored non-OVP directional microphone alignment conditions. However, whether there is or is not a trend cannot be determined at this time as correlation analysis has not been fully completed.

Although some subjects performed better using non-OVP directional microphone alignments, it would not be clinically practical to determine which patients perform better with OVP compared to non-OVP directional microphone alignment conditions. Many clinics would not have the time or the resources (many do not have an R-Space™ system) to perform RTS (dB) testing. Also, because the RTS (dB) differences between the five directional microphone
Table 12. Comparison of variables in all 12 subjects.

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of abutment to tragus (°)</td>
<td>47°</td>
<td>42°</td>
<td>44°</td>
<td>42°</td>
<td>40°</td>
<td>24°</td>
<td>34°</td>
<td>5°</td>
<td>50°</td>
<td>45°</td>
<td>37°</td>
<td>54°</td>
</tr>
<tr>
<td>Distance from abutment to tragus (mm)</td>
<td>72</td>
<td>73</td>
<td>72</td>
<td>75</td>
<td>77</td>
<td>67</td>
<td>77</td>
<td>76</td>
<td>86</td>
<td>69</td>
<td>60</td>
<td>72</td>
</tr>
<tr>
<td>Distance from abutment to shoulder (mm)</td>
<td>144</td>
<td>150</td>
<td>146</td>
<td>168</td>
<td>160</td>
<td>166</td>
<td>174</td>
<td>128</td>
<td>143</td>
<td>178</td>
<td>150</td>
<td>160</td>
</tr>
<tr>
<td>Distance from abutment to tip of nose (mm)</td>
<td>202</td>
<td>192</td>
<td>216</td>
<td>214</td>
<td>205</td>
<td>193</td>
<td>202</td>
<td>218</td>
<td>208</td>
<td>187</td>
<td>199</td>
<td>198</td>
</tr>
<tr>
<td>Pure-tone Average (dB)</td>
<td>17.50</td>
<td>20.00</td>
<td>15.00</td>
<td>12.50</td>
<td>6.25</td>
<td>3.75</td>
<td>11.25</td>
<td>13.75</td>
<td>13.75</td>
<td>8.75</td>
<td>8.75</td>
<td>10.00</td>
</tr>
<tr>
<td>Front-to-Back Ratio</td>
<td>-5.63</td>
<td>-7.25</td>
<td>-2.25</td>
<td>-6.25</td>
<td>-6.38</td>
<td>-6.88</td>
<td>-5.13</td>
<td>-0.88</td>
<td>1.00</td>
<td>-1.75</td>
<td>-5.63</td>
<td>-0.13</td>
</tr>
<tr>
<td>Experience with Baha (years)</td>
<td>0.6</td>
<td>2.5</td>
<td>1.5</td>
<td>0.5</td>
<td>0.5</td>
<td>4.3</td>
<td>0.6</td>
<td>3.5</td>
<td>3.0</td>
<td>0.8</td>
<td>1.0</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Note: Sensation level is the average amount of gain (250–8000 Hz) minus the average hearing thresholds in the better ear (250–8000 Hz). A higher value indicates a better sensation level. Pure-tone average is the average air conduction threshold in the better ear at 500, 1000, 2000, and 3000 Hz. Front-to-back ratio represents the average amount of attenuation from the back measurement compared to the front measurement. A lower value indicates greater attenuation of the signal from the back.
alignment conditions, on average, were less than 1 dB, these differences are not clinically significant. Therefore, it is recommended to continue counseling patients to wear the Baha at OVP as, on average, there were no statistically significant differences between the directional microphone alignment conditions and the consequences of wearing the Baha outside of this range are unknown.

In the future, directional microphone alignment measurements on KEMAR that were completed in the previous studies would help verify the results of this study. It would be interesting to see whether different directional microphone alignment conditions and the resulting DIs of the Baha are similar to or different from BTEs and ITEs. Other future studies could decrease variability by developing a device in which subjects could rest their heads on or stabilize their heads to avoid the angle from deviating from its intended alignment. The results, however, would have to be interpreted with caution as in the real world subjects can freely move their heads and non-OVP alignments may be corrected to an OVP directional microphone alignment. In subsequent studies, it may also be helpful to give subjects breaks between each alignment condition so that they do not fatigue and their attention is alert throughout the whole test session. Also, a study that utilized a larger sample of subjects could provide more power to determine whether the variables in this study were truly non-significant. Finally, a study examining directional microphone alignments beyond the examined range in this study would help determine the point at which the performance of the directional microphone in the Divino significantly decreases.

CONCLUSIONS

In conclusion, results revealed no statistically significant differences in the mean RTS (dB) between OVP and the four non-OVP directional microphone alignment conditions. These
results were similar to previous studies and all RTS (dB) differences were within 1 dB of each other. Also, although statistical analysis has not been fully completed yet as to whether the anatomical position of the abutment affects the directional advantage of the Divino, no relationships are currently observed between better or poorer RTS (dB) and variables such as anatomical placement. Finally, it was shown that subjects wear the Baha at directional microphone alignments other than OVP as three out of 12 subjects wore their current Baha at directional microphone alignments greater than the -10° to +30° directional microphone alignment range examined in this study. Although, these results suggest that the Divino can be worn within the examined range without a statistically significant impact on RTS (dB), the consequences of wearing the Divino outside of this range are unknown. It is therefore, clinically important to counsel patients to wear the Divino at OVP as it was shown that subjects do wear the Divino outside of the -10° to +30° directional microphone alignment range.
REFERENCES


APPENDICES

Appendix A: Photographs of Each Subject’s Baha

Subject 1
Subject 2
Subject 3
Subject 4
Subject 5
Subject 6
Subject 8
Subject 9
Subject 10
Appendix B: Measuring Baha Alignment in Photographs Utilizing PowerPoint®

Jones et al (2008) describe a technique to measure angles on digitalized radiographic images using PowerPoint®. This technique was developed as the traditional software that is utilized to measure these images is expensive and not readily available to small clinics. Twenty-six images were examined twice by six examiners using the traditional Cobb method, which consists of manually drawing lines by hand and measuring the angle from these lines, which has a 3-5° test-retest reliability, and the PowerPoint® technique described below. Results revealed that the traditional Cobb method and PowerPoint® techniques had a mean difference 95% confidence interval of approximately +/ – 3°, making the PowerPoint® technique a viable option for smaller clinics that cannot afford the traditional software.

The following technique was utilized on the two photographs that were taken at the initial visit to measure the angle of how each subject wore his/her current Baha. Each angle on each picture was measured three times to ensure accuracy. If there was a discrepancy between the two photographs, the two measured angles were averaged. It must also be noted that the subject’s head may not have been horizontal during the photographs and therefore the angles that were measured must be interpreted with caution.

1. Insert picture into PowerPoint® by going to Insert...Picture...From File and click Insert once the picture you wish to insert is found and highlighted.

2. On the drawing toolbar at the bottom of the PowerPoint® screen, click on the line icon.
3. Then near the line running down the center of the Baha, click and hold down the left mouse button and draw a straight vertical line.

4. Click on Format...AutoShape, then click on the size tab. Under Size and rotate, Rotation should say 0°. If it does not, the line is not vertical and you must redraw the line.
5. Then, make sure the line is selected by clicking on it (you will see two white squares on either end of the line when it is selected (see picture for step 3)). Next, select the *Free Rotate* icon on the drawing toolbar at the bottom of the PowerPoint® screen.

6. The line should now have two green dots on either end. Click and hold on to one of the green dots and rotate the line by moving the mouse so that it lines up with the line on the Baha.
7. Then Click on *Format...AutoShape*, and click on the size tab. Under *Size and rotate*, *Rotation* will tell you the angle of the Baha. Please note that if you move the line counterclockwise, you must subtract the number from 360° in order to figure out the angle of the Baha.