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Receiver position and acceptance of noise, speech understanding, and sound quality ratings

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RECEIVER POSITION AND ACCEPTANCE OF NOISE, SPEECH UNDERSTANDING, AND SOUND QUALITY RATINGS

by

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A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
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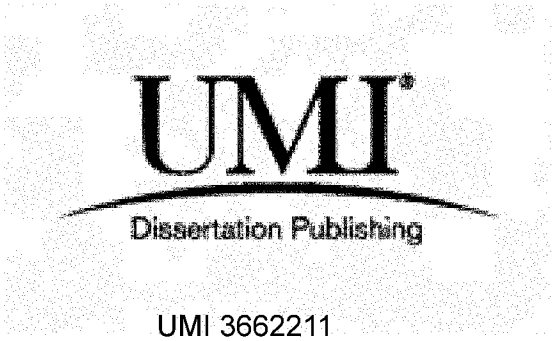

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Receiver Position and Acceptance of Noise, Speech Understanding, and Sound Quality Ratings

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Abstract

The effect of receiver position in a hearing aid on acceptance of background noise, speech intelligibility, sound quality judgments, and listener preference was measured in adults with normal to mild sloping to moderate to severe sensorineural hearing loss. Participants were fit with open-fit behind-the-ear (BTE) and receiver-in-the-ear (RITE) hearing aids. After a 3-week trial with each device, acceptance of noise levels, speech understanding in quiet and in noise, and sound quality ratings were conducted. At the conclusion of the study, listener preference between the devices was evaluated. Results revealed that receiver position did not significantly affect acceptance of background noise, speech understanding in quiet or in noise, sound quality ratings, or listener preference, indicating that no difference in objective or subjective benefit was observed based on the position of the receiver in a BTE hearing aid.

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Dedication

This dissertation is dedicated to several people. First, I am extremely grateful for my parents, Jerry and Pamela Ford, without whose support and love I would not be where I am today. I also want to thank my sister, Amy, who has always been a source of great encouragement. Additionally, I want to dedicate this dissertation to the Kelley family who has been my constant support system and inspires me to be a better person. Lastly, I dedicate this dissertation to my classmates, Sarah Babin, Kalyn Bradford, and Laura Wade. Together we have experienced the ups and downs of graduate school, and I am grateful to have undergone this process with their support, understanding, and encouragement.

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CHAPTER I

Introduction

Today, there are several styles of hearing aids available to the hearing impaired. One of the most popular styles is the behind-the-ear (BTE) hearing aid. A BTE hearing aid consists of two pieces: (1) a small casing that hooks behind the ear; and (2) a coupler that connects the device to the ear canal. Behind-the-ear hearing aids can be further differentiated according to the method of coupling the BTE casing to the ear canal. First, is the open-fit BTE that houses all electronic components in the same casing and is coupled to the ear canal via a thin, preformed tube and plastic domes. Open-fit BTEs are intended for listeners with a hearing loss configuration of normal to mild low frequency sensorineural hearing loss that slopes to moderate to severe high frequency sensorineural hearing loss (Kuk & Baekgaard, 2008). A second type of BTE is the receiver-in-the-ear (RITE), which is coupled to the ear canal via encased wiring and a plastic dome. In contrast to open-fit BTEs, RITE devices house the receiver separate from the aid by placing it in the ear canal. The fitting range of a RITE device is similar to that of an open-fit device and is primarily fit on listeners with sloping high frequency sensorineural hearing loss.

Since their introduction in 2003, the popularity of open-fit and RITE devices has increased steadily. Management of the occlusion effect (i.e., a build-up in sound pressure level in the ear canal due to occlusion of the canal by an occluding earmold or hearing aid) and a decrease in device size are two reasons for the rise in popularity of these

devices (Alworth, Plyler, Reber, & Johnstone, 2010). In 2007, the percentage of BTE instruments sold in the United States totaled 50% of hearing aid sales. Open-fit and RITE instruments accounted for 15% of those BTEs sold. By 2009 the percentage of BTE instruments sold in the United States increased to 63.4% of hearing aid sales with open-fit and RITE instruments accounting for about two-thirds of the BTEs sold (Kirkwood, 2009). Manufacturers have reacted to this increase in popularity and now offer numerous models in their product lines.

Research comparing subjective and objective data for open-fit and RITE devices is extremely limited. Research involving open-fit and RITE devices has typically focused on issues such as the occlusion effect or acoustic feedback or examined the devices in isolation. Studies conducted by Taylor (2006) and MacKenzie (2006) focus on open-fit hearing aids while Vasil and Cienkowski (2011) and Valente and Mispagel (2008) completed research that focused on the perceptual effects of RITEs hearing aids. Specifically, Taylor (2006) compared open-fit devices to traditional occluding hearing aids and found the devices are equal in real world benefit as measured by subjective sound quality ratings. MacKenzie (2006) aimed to objectively and subjectively measure the occlusion effect in open-fit devices and found that essentially no occlusion effect was observed. Furthermore, Vasil and Cienkowski (2011) investigated the occlusion effect with several different receiver sizes in a RITE device and found that differences in measured and perceived occlusion effect were negligible. Valente and Mispagel (2008) investigated RITE devices exclusively and sought to determine any differences between aided omnidirectional and aided directional performance. They concluded that

directionality enhanced performance over unaided and omnidirectional listening situations.

Research conducted by Hallenbeck and Groth (2008) looked at receiver placement, comparing the attainable gain before feedback between open-fit and RITE devices. Hallenbeck and Groth (2008) investigated the effect of receiver placement on the frequency response of the two devices. They found that each instrument had approximately the same amount of maximum available gain before feedback. A smoother, wider frequency response was noted for the RITE device; however, the two instruments were expected to perform comparably.

Furthermore, Alworth et al. (2010) sought to determine the effect of receiver location on measures of occlusion, gain before feedback, speech perception, subjective performance, and listener preference. Both the open-fit and RITE devices were found to reduce the occlusion effect while the RITE device had significantly greater gain before feedback at 4000 and 6000 Hz. Also, it was found that speech recognition in quiet was not significantly affected by hearing aids, but speech recognition in noise could be degraded significantly when omnidirectional open-canal devices were used. Furthermore, Alworth et al. (2010) found that both the open-fit and RITE devices significantly increased subjective benefit with participants rating greater success with the RITE devices. At the conclusion of the study, 76% of participants preferred the RITE devices. While this study offered valuable information comparing open-fit and RITE devices, the extendibility of the results are somewhat restricted due to the fact that the study only focused on one hearing aid manufacturer.

Research directly comparing speech perception and sound quality ratings for open-fit and RITE devices is incomplete. Hearing aid manufacturers claim that sound quality is superior with RITE devices over open-fit instruments. However, the extensive research necessary to support such a claim is unavailable. As RITE devices become more popular, the need for quality research on speech perception and sound quality of these devices as compared to open-fit hearing aids increases. Therefore, the purpose of this research is to determine the effect of the position of the receiver in a hearing aid on sound quality and speech perception.

CHAPTER II

Review of Literature

Speech Perception and Performance with Hearing Aids

Behavioral measures of speech understanding and subjective quality ratings. The hearing aid evaluation process has undergone many changes over the years as technology has advanced in the form of digital hearing aids. Currently, there are several hearing aid validation techniques and procedures available that assess whether or not hearing aids are beneficial. For example, a study by Mendel (2007) aimed to discover those speech recognition materials used for validation purposes that were sensitive enough to reveal objective hearing aid benefit. Another study conducted by Cox and Alexander (1992) sought to determine if hearing aid benefit, measured objectively or subjectively with different validation techniques, improved over the first 10 weeks of use.

First, Mendel (2007) sought to establish whether certain speech recognition measures were able to objectively demonstrate hearing aid benefit and whether the results would correlate positively with the participants' subjective evaluations of hearing aid benefit. Twenty-one experienced hearing aid wearers, 33 to 75 years old, with varying degrees of bilateral symmetrical sensorineural hearing loss were included in this study. All participants were fit with one or two hearing aids that utilized digital signal processing and were set according to the National Acoustics Laboratories (NAL-NL1) prescriptive formula (Byrne, Dillon, Ching, Katsch, & Keidser, 2001). Furthermore, the Revised Speech Perception in Noise test (R-SPIN, Bilger, Nuetzel, Rabinowitz, &

Rzeczkowski, 1984), the Quick Speech-in-Noise test (QuickSIN, Etymotic Research, 2001; Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004), and the Hearing in Noise Test battery (HINT, Nilsson, Soli, & Sullivan, 1994) were administered aided and unaided in the conventional manner to all participants. The HINT test battery included (1) speech in quiet (quiet), (2) speech in noise with the noise presented at 0° azimuth (noise front; NF), (3) speech in noise with the noise presented at 90° to the right (noise right; NR), and (4) speech-in-noise with the noise presented at 90° to the left (noise left; NL). Additionally, all participants completed the Hearing Aid Performance Inventory (HAPI, Walden, Demorest, & Helper, 1984) as a subjective measure of hearing aid benefit. The participants evaluated how they performed with and without hearing aids in different listening situations. Scoring reliability was performed through interjudge and intrajudge scoring reliability on 30% of the collected data (Mendel, 2007).

The study by Mendel (2007) showed that both aided (M = 70.57) and unaided (M = 60.86) R-SPIN scores were relatively poor. However, the aided mean score was significantly better than the unaided mean score. For the HINT Quiet, the aided mean score (M = 37.05) was significantly better than the unaided mean score (M = 43.55). For the three HINT noise conditions (NF, NR, and NL), aided and unaided scores were not significantly different. For the QuickSIN, percent correct was calculated for each signal-to-noise ratio (SNR) condition. These scores tended to increase as the SNR improved. Paired *t* tests revealed that aided QuickSIN scores were significantly better than unaided scores in every SNR condition except the 0 dB SNR condition. Signal-to-noise ratio loss was also significantly better in the aided condition compared to the unaided condition. The HAPI revealed that for all categories (i.e., conversation in quiet situations with

familiar talkers, conversation in quiet situations with unfamiliar talkers, conversation in noisy situations with familiar talkers, conversation in noisy situations with unfamiliar talkers) except environmental sounds in quiet and noise, the aided condition was significantly better than the unaided condition.

Based on this data, Mendel (2007) concluded that there were speech recognition tests that were more successful in assessing objective speech recognition ability in the aided condition. Specifically, the R-SPIN, the HINT Quiet, and the QuickSIN are the most sensitive tests because these tests supplied the most valuable information when evaluating speech perception in noise. Additionally, Mendel (2007) found that the HAPI was successful in documenting hearing aid benefit in all categories of the survey. Although significant correlations were not found between all the objective and subjective outcome measures, it should be noted that as R-SPIN, HINT Quiet, and QuickSIN scores improved, ratings on the HAPI also improved. This demonstrated that obtaining both objective and subjective outcome measures creates the most sensitive evaluation process of hearing aids.

Furthermore, Cox and Alexander (1992) sought to determine if hearing aid benefit measured objectively or subjectively changes or matures over the first 10 weeks of hearing aid usage. Seventeen hearing-impaired participants (52 to 81 years old, mean age 67 years) were included in different portions of the study, with 10 participants completing all portions. Nine participants were experienced hearing aid users wearing their devices about 8 hr/day while eight were new users wearing their devices about 4 hr/day. Objective and subjective measures of benefit were obtained in four different environments. Environment A involved communication at normal conversational levels

with available facial cues and low noise and reverberation. Environment B involved low noise and reduced speech cues due to reverberation, low speech levels, and limited facial cues. Environment C involved high noise, elevated speech levels, and available facial cues. Environment CL involved a typical clinical audiology setting with no facial cues. In this study, environments A, B, and C were simulated in an audiometric test booth.

New hearing aids were fit on four experienced hearing aid wearers who were replacing old devices and on eight new users. Half the participants were fit with BTE devices while the other half received custom in-the-ear (ITE) devices. Three fittings were binaural with the rest being monaural. All participants were counseled regarding care and use and given user instructions at the initial fitting. Most participants were seen for a two-week follow up appointment to modify minor problems. Data was collected in four separate sessions for the new users. The first session occurred prior to the hearing aid fittings and measured speech understanding in the unaided condition for all four environments. The Connected Speech Test (CST; Cox, Alexander, & Gilmore, 1987) was utilized as the means for gathering objective benefit measures. Aided CST scores for all environments were gathered in the second session, which occurred one to three days post-fitting. Participants then completed the Profile of Aided Benefit (PHAB; Cox, Gilmore, & Alexander, 1991), which was mailed to them two weeks after the second session. A second set of unaided CST scores was obtained in the third session, which occurred nine weeks after the initial fitting. Also, participants were given another copy of the PHAB to be completed and returned at the fourth session. The fourth session occurred one week after the third session, and a second set of aided CST scores were obtained. At the third and fourth sessions, participants rated the simulated test environments (environments A,

B, and C) compared to real life on a 10-point scale. Additionally, five experienced hearing aid users, not fit with new aids, participated in the third and fourth sessions.

Cox and Alexander (1992) demonstrated that benefit provided by hearing aids did improve over the first 10 weeks of use in some environments as shown by objective measures. Both experienced and inexperienced hearing aid users fit with new hearing aids noted this improvement. The most objective long-term improvement was noted for environment A (i.e., communication at normal conversational levels with available facial cues and low noise and reverberation) while no significant improvement was noted for environments B (i.e., low noise and reduced speech cues due to reverberation, low speech levels, and limited facial cues) and C (i.e., high noise, elevated speech levels, and available facial cues). Additionally, benefit provided by hearing aids for new and experienced wearers improved over the first 10 weeks of use in all environments as shown by subjective measures. It was also shown that subjective benefit was usually much greater than benefit measured objectively. Furthermore, subjective benefit predictions based on objective measures may be imprecise. It was also found that experienced users of hearing aids received more benefit, measured objectively and subjectively, than new users. Furthermore, the improved benefit over 10 weeks noted for both groups suggests that a patient's previous experience with hearing aids is not as important as the amount of hearing loss present. The authors concluded that the initial benefit noted could be an accurate estimate of long-term benefit in specific listening situations that are noisy and reverberant with available visual cues as well as situations that involve face-to-face communication or noisy situations without facial cues.

Acceptance of Background Noise

Acceptable noise level (ANL) is a procedure that was developed in 1991 by Nabelek, Tucker, and Letowski. The ANL procedure is used to determine an acceptable level of noise while simultaneously listening to speech. Furthermore, this procedure is a way to quantify how willing a person is to listen to speech while background noise is present (Freyaldenhoven, 2007). The ANL procedure can be used clinically to predict hearing aid use. Specifically, listeners that are willing to accept background noise are typically willing to accept and successfully wear hearing aids. Other listeners may not accept or benefit from hearing aids if they are unable to accept background noise.

The ANL procedure can be administered quickly and easily in a clinical setting. Typically, sound is routed through loudspeakers located at 0° azimuth in a sound treated booth. First, under patient direction, a recording of running speech is adjusted to the most comfortable listening level (MCL) of the patient. Background noise is then added. The patient adjusts the background noise to a level that they are willing to put up with while concurrently listening to and following the running speech. The level of the noise is called the background noise level (BNL). By subtracting the BNL from the MCL, ANL is calculated in dB (Freyaldenhoven, 2007).

Predictive value of ANL. The primary purpose of the study by Nabelek, Freyaldenhoven, Tampas, Burchfield, and Muenchen (2006) was to determine if ANL predicted hearing aid use. Additional purposes of the study were to establish (1) how ANLs and SPIN scores were effected by hearing aids, (2) the relationship between predictive and outcome data and ANLs, (3) the reliability of an outcome assessment questionnaire, and (4) the differences between three listener groups in regards to

predictive data, ANLs, SPIN scores, and daily use of hearing aids in hours. In total, 191 participants with no known neurological or cognitive deficits were selected from the Audiology Clinic at the University of Tennessee, Knoxville. Each participant was fitted with binaural hearing aids independent of this study within the last three years. Participants were divided into three groups based on their use of hearing aids as determined by an outcome questionnaire. The three groups were full-time users, part-time users, and nonusers of hearing aids (Nabelek et al., 2006).

Running male speech and 12-talker speech babble was used to determine ANL. The revised SPIN test (Bilger et al., 1984) was used to assess speech perception in noise, and an outcome questionnaire was used to determine the number of hours the participants' hearing aids were worn each day. Each participant was tested in an audiometric test booth with the loudspeaker located 1.5 m from the participant at 0° azimuth. While listening to a recording of running male speech (Arizona Travelogue, Cosmos Inc.) the participants established their MCL by manipulating two handheld buttons that were connected to an indicator box that notified the examiner to manipulate the signal up or down. Next, while speech was held constant at MCL, multitalker speech babble was added. Maximum acceptable BNL was established in the same manner as MCL with the participants adjusting the noise. Calculated ANL in dB was determined by subtracting the BNL from the MCL. The SPIN test was conducted at each participant's MCL with speech babble at a +8 SNR. Both ANL and SPIN scores were obtained in the aided and unaided conditions. The nonusers of hearing aids who did not keep their devices were only tested in the unaided condition.

Nabelek et al. (2006) revealed that ANLs were linked to hearing aid use where full-time users of hearing aids had lower unaided ANLs than part-time and nonusers of hearing aids. No significant difference was found between unaided ANLs for part-time and nonusers. Consequently, the three groups were combined to form a successful users group (full-time) and unsuccessful users group (part-time and nonusers). The authors further completed a method for predicting hearing aid use. Those with high, unaided ANLs were most likely to become unsuccessful users while those with low, unaided ANLs were most likely to become successful users of hearing aids. Additionally, the ANL procedure was found to have an 85% accuracy rating when predicting hearing aid success as determined by regression analysis.

Nabelek et al. (2006) also determined that with the introduction of hearing aids, SPIN scores improved, and can therefore be used to measure hearing aid benefit. It was found that SPIN scores could not be used to predict hearing aid use since SPIN scores were not different between successful and unsuccessful users. The authors concluded that the ANL procedure, measuring a person's willingness to accept background noise, and the SPIN test, measuring speech perception in noise, reveal different information about hearing aids. Specifically, the ANL procedure may be used to predict hearing aid usage while speech perception in noise testing may be used to measure hearing aid benefit (Nabelek et al., 2006).

Furthermore, Nabelek, Tampas, and Burchfield (2004) sought to (1) to establish and compare the reliability of ANLs with the reliability of SPIN scores, (2) to compare SPIN scores and ANLs over a three-month period of time, and (3) to compare ANL and SPIN scores in the aided and unaided conditions. Fifty participants were recruited from

hearing aid dispensers in the Knoxville, TN area and from the University of Tennessee Hearing and Speech Clinic patient population. All participants were fitted with hearing aids by audiologists independent of this study. Data was collected during three test sessions in an audiometric test booth with participants seated 1.5 m from a loudspeaker located at 0° azimuth.

During the first test session, each participant was fitted with binaural hearing aids and tested in the aided and unaided conditions. ANL was determined with running male speech (Arizona Travelogue, Cosmos Inc.) as the initial signal and multitalker speech babble (revised SPIN test; Bilger et al., 1984) as the background noise. The revised SPIN test was administered with 25 high predictability and 25 low predictability sentences. The SPIN test was delivered at each participant's MCL and a +8 dB SNR for both the aided and unaided conditions. These procedures were repeated during two additional sessions which took place approximately one and three months post-fitting. Additionally, participants completed a hearing aid use questionnaire created by Nabelek et al. (1991) and were separated into three groups. Full-time users were defined as those that wore their hearing aids whenever necessary; part-time users wore theirs occasionally, and nonusers did not wear their hearing aids. The ANL and SPIN procedures were repeated during a third test session.

Nabelek et al. (2004) found that full-time hearing aid wearers had significantly smaller ANL scores than part-time and nonusers of hearing aids. Both ANLs and SPIN scores were highly reliable in the aided and unaided conditions. Also, neither ANLs nor SPIN scores changed during the three-month time period, indicating that acceptance of background noise and speech perception abilities do not vary during that amount of time.

The authors also found that ANLs are independent of amplification, indicating that acceptance of background noise is dependent on the individual and can be tested without amplification in order to predict success with hearing aids. Higher SPIN scores were recorded in the aided condition versus the unaided condition, indicating that hearing aids provide benefit in the form of speech perception abilities. However, SPIN scores cannot be used to predict success with hearing aids. In conclusion, the ANL procedure and SPIN test offer different information in regards to hearing aid use and benefit.

Taylor (2008) further investigated unaided ANL as a predictive measure of the benefit and satisfaction of hearing aids. Twenty-seven first-time binaural digital hearing aid wearers with a hearing loss that did not exceed the severe range in the high frequencies were selected at random to participate in this study. The original ANL procedure was administered bilaterally during pre-testing under headphones. Next, the participants were fitted with their binaural hearing aids based on the NAL-NL1 prescription formula. Approximately 30 days post-fitting, the participants returned for a routine appointment and completed the International Outcome Inventory for Hearing Aids (IOI-HA; Cox & Alexander, 2002). Based on unaided ANL score, each participant was assigned to one of three groups: (1) score between zero and six, (2) score between seven and 12, and (3) score of at least 13.

Taylor (2008) found that ANL scores tended to be higher or poorer as participants' total IOI-HA score became poorer. Also, it was found that Factor 1 IOI-HA scores (those that deal with introspection about a wearer's hearing aids) could be predicted from unaided ANLs, suggesting that unaided ANLs can predict inherent aspects of hearing aid outcome. In conclusion, Taylor (2008) found that the ANL procedure

could predict hearing aid benefit as well as use, and suggested that unaided ANL would be extremely beneficial in the pre-fitting, counseling stage of the hearing aid fitting process.

Directional benefit and digital noise reduction in hearing aids and ANL. The purpose of the study by Freyaldenhoven, Nabelek, Burchfield, and Thelin (2005) was to determine if the ANL procedure is an appropriate method for clinically assessing directional benefit in hearing aids. In total, 40 participants were selected from the University of Tennessee Hearing and Speech Clinic based on 2 criteria: (1) being fitted with binaural hearing aids with directional and omnidirectional modes and (2) having worn hearing aids for at least three months. Each participant was fitted with hearing aids at the University of Tennessee Hearing and Speech Clinic independent of the study and the aids were not adjusted for the purposes of the study.

In the study by Freyaldenhoven et al. (2005), the ANL procedure was compared to two alternative procedures for measuring hearing aid directional benefit: (1) masked speech recognition threshold (SRT) and (2) front-to-back ratio (FBR). First, participants were positioned in an audiometric test booth with two loudspeakers located 1.5 m from the participant at ear level at 0° and 180° azimuth. While listening to a recording of running male speech (Arizona Travelogue, Cosmos Inc.) the participants established their MCL and BNL by manipulating two handheld buttons that were connected to an indicator box that notified the examiner to manipulate the signal up or down by 2 dB. Most comfortable listening level was established for the omnidirectional microphone mode and BNLs were established for omnidirectional and directional modes. To obtain omnidirectional and directional ANLs, the two BNLs were subtracted from the MCL,

respectively. Then by subtracting the directional ANL from the omnidirectional ANL, directional benefit was established.

Freyaldenhoven et al. (2005) then obtained masked SRTs using a modified Tillman and Olsen (1973) procedure. Spondaic words were presented at the previously established MCL while the background noise was altered until intelligibility equaled 50% creating the masked SRT. A masked SRT was measured in the omnidirectional and directional modes. By subtracting directional SRT from omnidirectional SRT, directional SRT benefit was recorded. Lastly, probe microphone measures were used to determine sound pressure levels (SPLs) in the ear canal for both the omnidirectional and directional modes for both the speech and noise stimuli. Speech was presented from the loudspeaker located at 0° azimuth and background noise was presented from the loudspeaker located at 180° azimuth. Front-to-back ratio benefit was obtained by subtracting the omnidirectional value from the directional value.

Freyaldenhoven et al. (2005) found that each of the three measures, ANL, masked SRTs, and FBRs, improved by about 3 dB when utilizing directional microphones. They also found that ANL could be used for measuring directional benefit in hearing aids. Additionally, the ANL procedure was shown to be the quickest and easiest method utilized in this study for measuring directional benefit in hearing aids. The authors of this study concluded that ANL was a usable option for clinically assessing directional benefit in hearing aids.

Furthermore, Mueller, Weber, and Hornsby (2006) examined if digital noise reduction (DNR) activation in hearing aids would improve aided ANLs. Digital noise reduction in hearing aids aims to reduce gain for background noise while leaving the

speech signal unaffected. Additional purposes of this study were to determine if variables such as degree of hearing loss, speech understanding in noise, hearing aid gain, and MCLs (aided and unaided) could predict or change ANL when DNR was activated. This study included 22 participants with symmetrical mild to moderate sensorineural hearing loss that were experienced, full-time hearing aid wearers. The hearing aids used in this study were Siemens Acuris Model S BTEs with 16-channel input compression, output compression, and low-level expansion. Adaptive feedback cancellation was activated while directional technology was disabled. Continuous electromagnetic transmission was active between the hearing aids, which controlled DNR activation and strength and resulted in identical DNR processing for both aids. The hearing aids were set with two programs: (1) program 1 with DNR deactivated, and (2) program 2 with DNR activated and strength set to maximum. A modulation based DNR algorithm and an adaptive fast acting DNR algorithm operated independently and simultaneously in the DNR program.

Mueller et al. (2006) conducted testing in an audiometric test booth with the participants' seated 1 m from a loudspeaker at 0° azimuth. First, the HINT was administered in the aided-DNR off and aided-DNR on conditions with speech and noise presented from the same loudspeaker. Next, the ANL procedure was administered utilizing the same HINT speech and noise materials in the unaided, aided-DNR off, and aided-DNR on conditions. For both the speech intelligibility in noise and ANL procedures, the HINT material was modified so that the background noise was on continuously between sentences.

Mueller et al. (2006) revealed that ANLs recorded in the aided DNR-on condition were significantly smaller than the unaided and aided DNR-off conditions. Specifically, a

mean ANL improvement of 4.2 dB was recorded with DNR-on. This suggested that the DNR algorithms utilized in this study helped improve the acceptance of background noise significantly and verified that the algorithm did not affect speech intelligibility negatively. Also, the DNR algorithms did not have an effect on recorded HINT scores, and HINT thresholds were not significantly correlated to ANLs calculated in the DNR-on or off conditions. Additionally, there was not a significant relationship between ANLs and auditory threshold. Overall, Mueller et al. (2006) concluded that DNR provided significant improvements in ANLs, at least for the algorithms and procedures implemented in this study. Mueller et al. (2006) also concluded that the adaptive fastacting noise reduction DNR algorithm contributed the most to the overall perception of a lower background noise level by reducing interword, intersyllable, and intersentence noise.

Open-Fit Hearing Aids

Speech perception in noise. A study by Klemp and Dhar (2008) strove to determine if directional microphones provided benefit in open-fit hearing aids. The participants included 16 adults, ages 50 to 85 years, with bilateral sloping sensorineural hearing loss in the high frequencies. Participants were recruited from the Northwestern University Evanston Hearing Clinic and had no previous experience with hearing aids.

Klemp and Dhar (2008) selected the Phonak miniValeo 101 AZ and the Widex Diva elan SD-9Me open-fit BTE hearing aids as the test instruments for this study. Flexible ear tips and manufacturer supplied thin tubes were used to couple the devices to each participant's ears. The NOAH platform was used to program the aids using the NAL-NL1 prescriptive formula. The omnidirectional program did not include noise

reduction or feedback cancellation features. If feedback occurred when the devices were fit on a participant, the manufacturer's feedback management algorithm was activated. If an option, the level of hearing aid experience was set to the highest level. If directionality (DIR) and/or DNR were activated, the level was set the maximum.

Furthermore, a modified HINT was administered to each participant in the unaided condition first, followed by the four aided conditions: (1) omnidirectional, (2) DIR, (3) DNR, and (4) both DIR and DNR, presented in a random order. The modified HINT given utilized four total channels that included the original channels of sentences and noise plus two additional noise channels. Also, a 12 s lead-in of noise was added before each sentence presentation in the three noise channels while a 12 s lead-in of silence was added before each sentence presentation in the speech channel. Testing was conducted in an audiometric test booth, and sentences were presented from a loudspeaker located 1 m from the participant's seat at 0° azimuth; noise was presented from loudspeakers located 1 m from the participant's seat at 90, 180, and 270 degrees azimuth. Throughout testing, hearing aid selection, hearing aid conditions, and HINT sentence lists were counterbalanced among the participants.

Klemp and Dhar (2008) found that speech understanding in noise was significantly better in the aided DIR condition than in the aided omnidirectional condition for the Phonak and Widex devices. For the Widex device, the DIR and DIR + DNR conditions were significantly better than the DNR condition. This was not found for the Phonak device. Also, for both hearing aids, the DIR and DIR + DNR conditions were not found to be significantly different from the unaided condition. An average improvement of 2.26 dB was observed across devices in the DIR condition compared to the unaided

condition. Average performance in the omnidirectional condition was worse than performance in the unaided condition. Based on these results, Klemp and Dhar (2008) concluded that in open-fit devices, directional benefit is smaller compared to directional benefit with occluding devices. It was also concluded that while performance in noise worsened when aided with omnidirectional open-fit devices compared to the unaided condition, directional signal processing in open-fit devices could aid in speech understanding in noise over the unaided condition.

Subjective quality ratings. As previously stated, many validation techniques have been introduced over the years as ways to assess hearing aid performance. Studies utilizing different techniques to measure speech perception in quiet and in noise with open-fit hearing aids have been previously addressed. There are also numerous studies that focus on subjective quality ratings as a method of assessing open-fit hearing aids. First, Taylor (2006) conducted a study to determine the answer to two questions. First, are experienced hearing aid users with new open-canal (OC) aids more satisfied than experienced hearing aid users with new non-OC aids? Second, are new hearing aid users with OC aids more satisfied than new hearing aid users with non-OC aids?

Taylor (2006) conducted two different survey studies within this study. Participants were randomly selected by clinicians at multiple dispensing sites around the United States. Study A compared two groups of experienced hearing aid users, 41 to 80 years of age. Group 1 was made up of 27 participants fit with new OC devices and group 2 was made up of 27 participants recently fit with new non-OC devices. Classification as an experienced user included those who had worn hearing aids for over a year. Technology was similar between the OC and non-OC devices. Study B compared two

groups of first time hearing aid users, 47 to 75 years of age. Group 1 was made up of 22 participants fit with OC devices and group 2 was made up of 13 participants fit with non-OC devices. All participants included in both studies underwent a complete audiologic battery and bilateral hearing aids were fit to match targets prescribed by the National Acoustics Laboratories (NAL-R) prescriptive formula (Bryne & Dillon, 1986). Also, all participants completed the Client Oriented Scale of Improvement (COSI, Dillon, James, & Ginis, 1997) before being fit with their new hearing aids. If more hearing loss than 45 dB at 500 Hz and/or 85 dB at 4000 Hz was found, participants were not included in either study.

In Study A, Taylor (2006) administered Question 36 from the MarkeTrak survey as well as the Amplifon Satisfaction Survey. Both groups completed the surveys one to three months post-fitting. In Study B, participants completed the Abbreviated Profile of Hearing Aid Benefit (APHAB, Cox & Alexander, 1995) as well as the IOI-HA. Again, both groups completed the outcome measures one to three months post-fitting.

The Amplifon Satisfaction Survey given by Taylor (2006) in Study A (which involved experienced users) revealed that participants in both group 1 and 2 favored their new hearing aids over their old ones. Additionally, on four of the 12 sub-questions, the OC group reported significantly greater satisfaction compared to the non-OC group. The four sub-questions were sound quality of own voice, sound localization, phone comfort, and appearance/cosmetics. Feedback on the phone and battery life were the only dimensions of satisfaction that non-OC device users ranked higher, but the differences were not significant. Question 36 of the MarkeTrak Satisfaction Survey also showed that participants preferred their new aids. Sound of own voice, sound of chewing/swallowing,

wind noise, localization, and visibility to others were the five features rated significantly higher by the OC group. No appreciable difference was measured between the two groups for the remaining features.

Taylor (2006) found that the results of the APHAB in Study B (which involved first-time hearing aid users) showed no difference between the OC and non-OC groups in three of the four subscales. The subscales were ease of communication, reverberant environments, and background noise. Results of the IOI-HA indicated that both groups received significant satisfaction, benefit, and life quality improvement from their devices when compared to IOI-HA published norms for people with mild to moderate hearing loss. For three dimensions, scores were distinctly higher for the OC group. These dimensions were hearing aid usage, residual activity limitation, and residual participation restriction. In conclusion, Taylor (2006) found that experienced hearing aid users found OC and non-OC devices to be equally satisfying in terms of overall satisfaction. However, experienced users of OC devices seemed to be more satisfied with how the devices looked, with sound localization ability, and with own voice sound quality. Additionally, new users of hearing aids reported that OC devices did not offer more benefit than non-OC devices. Taylor (2006) also revealed that OC and non-OC devices are equal in terms of real world benefit. However, it was determined that users of OC devices have fewer constraints on activity and participation than users of non-OC devices.

Secondly, MacKenzie (2006) aimed to objectively and subjectively measure the occlusion effect for OC mini-BTE, tube-fit hearing aids produced by Siemens, Phonak, and GN ReSound manufacturers. This study included 20 first time hearing aid users aged

20 to 59 years. All participants showed normal otoscopic and immittance results. The OC tube-fit devices chosen for this study were the Siemens Life, Phonak Fit'nGo, and GN ReSound Air. Each participant attended a 30-min session that was conducted in a sound treated test booth and began with the otoscopic evaluation. To objectively measure the occlusion effect, an Audioscan RM500CP probe-microphone system was used. First a real-ear unoccluded response (REUR) was recorded followed by successive measures for each of the three OC devices. Participants vocalized the vowel /i/ at 80 dB SPL, which was monitored by the examiner with a Bruel & Kjaer Type 2245 precision sound level meter. During this vocalization, sound pressure level was recorded in the ear canal without activation of the hearing aid. A real-time spectral analysis within the participant's ear during vocalization was recorded. The magnitude of the occlusion effect as a function of frequency was measured as the difference between the REUR and the occluded response of each of the three OC conditions. Additionally, participants rated the naturalness of their own voice for each OC condition to obtain subjective information. Each participant read the Rainbow Passage aloud and then rated their voice on a 10-point scale. The scale ranged from extremely natural (10) to extremely hollow (1). To establish a baseline, each participant first read the passage aloud with his or her ears unoccluded and then again with his or her ears fully occluded with E-A-R earplugs.

MacKensie (2006) found that for frequencies below 1000 Hz, there was a minimal difference between the unoccluded response and the occluded response conditions and average occlusion effect values never surpassed 2.1 dB for 250, 500, and 750 Hz. The greatest occlusion effect measurement recorded between 200 and 1000 Hz was 6 dB. Subjective ratings revealed that most participants did not discern significant

degradation in the quality of their own voice while vocalizing with any of the three devices in place. Average ratings were 9.45 for the Siemens device, 9.45 for the GN ReSound device, and 9.35 for the Phonak device. In conclusion, this study revealed that essentially no occlusion effect was observed with OC devices. However, these findings cannot be generalized to include RITE devices. Also, this study revealed that own-voice sound quality was rated as highly natural, suggesting that OC devices are an effective means to overcoming the occlusion effect caused by hearing aids.

Thirdly, Vasil and Cienkowski (2006) investigated (1) the degree of occlusion effect in open-fit hearing aids; (2) the amount of perceived occlusion in the studied devices; and (3) the correlation between the subjective and objective occlusion effect measurements. The participants consisted of 30 adults with a mean age of 23 years with normal hearing sensitivity bilaterally. Participants were recruited from the University of Connecticut student body. Inclusion criteria also required participants to have ear canals larger than 0.275 in. vertically and 0.230 in. horizontally at the aperture of the ear canal. A sizing mold with these measurements was used to determine ear canal size.

Vasil and Cienkowski (2006) selected three different open-fit hearing aids for this study including the Oticon Open Ear Acoustics Adapto, the General Hearing Instruments (GHI) Completely Open Ear (COE), and the Vivatone M44. Both the Adapto and the COE were custom, in-the-ear (ITE) devices while the M44 was a RITE device. For the purposes of this study, the custom devices were comprised of the outer shell, receiver, and battery door with a dead battery in place. A dead battery was also placed in the M44 in order for the weight of a functional hearing aid to be estimated. Each participant attended three sessions for data collection. At the first session, two sets of ear impressions

were made for each participant and sent to the manufacturer to have the custom devices (i.e., Oticon Adapto and GHI COE) constructed according the device guidelines. At the second session, occlusion effect was measured objectively and subjectively. Participants were first given information that explained the occlusion effect and were instructed to simulate the phenomenon by vocalizing /i/ and occluding their ears with their fingers. Objective measures of occlusion were obtained with the Fonix 7000 Quick Probe Real Ear Measurement System in a sound treated booth. First, a baseline REUR was measured using an 80 dB SPL signal. Next, in each hearing aid condition, REURs and real-ear occluded responses (REORs) were measured while the participants vocalized /i/ (REURvoc and REORvoc) for 5 s at a 70 dBC SPL. By subtracting REURvoc values from REORvoc values, real-ear occlusion effect (REOE) was determined (i.e., REORvoc-REURvoc=REOE). Occlusion effect was measured subjectively by having each participant rate all three devices separately based on an occlusion effect scale ranging from 0 (no occlusion), to 4 (complete occlusion) after vocalizing /i/ for 5 s at 70 dBC SPL unaided and aided. At the third test session, the subjective procedures were repeated. Each participant completed the objective and subjective procedures a total of five times (in random order), with each experimental device and two repeated devices, and were blinded to each condition.

Vasil and Cienkowski (2006) demonstrated that the amount of measured occlusion effect differed between the open-fit devices used in this study. Significantly less occlusion effect was measured objectively in the COE and M44 devices compared to the Adapto device. Overall, the smallest measured occlusion effect was recorded with the M44 RITE device. The largest measured occlusion effect was recorded with the Adapto,

which was also the largest ITE device. Subjectively, the M44 was rated as creating the least amount of occlusion effect (none to mild). The COE was rated as creating mild to moderate occlusion effect while the Adapto created moderate to severe occlusion effect. While the objective and subjective measurements were in agreement, the results were found to be weakly to moderately correlated. Vasil and Cienkowski (2006) concluded that certain devices successfully reduce the occlusion effect either measured or perceived. Specifically, the less space occupied in the ear canal resulted in the best occlusion effect ratings. It was also concluded that subjective opinions of occlusion effect should be considered when fitting hearing aids in order to secure a patient's success with hearing aids.

Furthermore, Byrne, Sinclair, and Noble (1998) tested the hypothesis that hearing aids coupled to nonoccluding earmolds increase vertical localization. Their participants included 22 adults (mean age 53 years) with sensorineural hearing loss. Participants were recruited from Australian Hearing Services centers and were required to have hearing equal to or worse than 30 dB from 250 to 2000 Hz and hearing better than or equal to 30 dB at 6000 and 8000 Hz. Bilateral, symmetrical hearing losses were found in 21 of the 22 participants. Also, hearing aid experience varied across participants ranging from no experience to full-time hearing aid wearers.

Byrne et al. (1998) selected three different earmold types for this study including: (1) a closed, completely occluding, unvented skeleton earmold; (2) an open, partially occluding, modified "G-mold;" and (3) a completely open, custom, "sleeve" earmold. The earmolds were coupled to Bernafon/NAL SB13 programmable BTE hearing aids manipulated to operate omnidirectionally and linearly and set with a high compression

threshold. The hearing aids were initially programmed based on the group's average audiogram and then adjusted according to each participant's preference. Localization testing was conducted in an anechoic chamber with a total of 20 loudspeakers arranged in a 180° horizontal arc and an intersecting 162° vertical arc with the loudspeakers located 18° apart. Participants were allowed to move around but were instructed to face a specific direction when waiting for the test signal. The test signal consisted of four pulses of pink noise approximately 0.83 s in length presented randomly at 50 or 65 dB SPL. After each signal presentation, the participant selected a loudspeaker, which they judged to be the sound source. Horizontal and vertical error scores were calculated by adding the number of loudspeakers between the perceived source and the actual source. Localization testing was conducted in the unaided condition as well as in the aided condition with all three earmold styles. Additionally, testing occurred over a period of three days and each condition was tested three times per participant. Final horizontal and vertical error scores were calculated by averaging the scores for the three trials.

Byrne et al. (1998) confirmed through this study that for people with moderate low frequency hearing loss and normal high frequency hearing, vertical localization is characterized as reasonable to very good. It was also found that bilateral hearing aids with closed earmolds seriously impair vertical localization while open earmolds may improve aided vertical localization. Also, Byrne et al. (1998) found the "sleeve" earmold to provide more localization benefit than traditional, open earmolds. Participants with the best unaided localization abilities received the most benefit from open and "sleeve" earmolds and performed the worst with the closed earmolds. Byrne et al. (1998)

concluded that the sleeve earmold could be useful clinically, especially for patients with normal high frequency hearing.

RITE Hearing Aids

Speech perception in quiet and noise. The following studies investigated the influence of open-fit RITE hearing devices on speech perception in quiet and in noise. First, Boeheim, Pok, Schloegel, and Filzmoser (2010) compared an active middle ear implant (AMEI) to an open-fit RITE hearing aid. The participants included 10 adults, 44 to 73 years of age, with symmetrical, sloping sensorineural hearing loss and normal middle ear function. All participants were selected from a group of 39 patients at an ear-nose-throat (ENT) center in a tertiary hospital who had a Vibrant Soundbridge (VSB) AMEI implanted between the years 2000 and 2006. Participants were recruited based on their pure-tone audiometric thresholds, and if they met the fitting criteria of both the open-fit hearing aid and the VSB. Also, all participants wore their AMEI daily and all but one participant (due to external ear psoriasis) had a trial with conventional hearing aids prior to implantation of the AMEI.

Boeheim et al. (2010) selected the Oticon Delta 8000 as the open-fit RITE hearing aid used in this study. For each participant, the hearing aid was initially fit using the Clarity fitting strategy designed for the Delta series. Subsequent adjustments were made to the device according to participant feedback. The VSB (Model 404), composed of internally implanted elements as well as external elements, was the AMEI analyzed in this study. For each participant, the VSB was initially fit using the DSL (i/o) fitting strategy and adjustments were made according to participant feedback. Testing took place during two separate sessions. In the first session, the following unaided measurements

were completed: warble-tone thresholds, word recognition scores using the Freiburger Monosyllabic Word Test (Hahlbrock, 1970) at 65 and 80 dB SPL, SRT in quiet using Freiburger numbers (Hahlbrock, 1970), and SRT in quiet and in noise using the Oldenburg Sentence (OLSA) Test (Wagener, Brand, & Kollmeier, 1999). In the second session, the devices were programmed and worn for 30 minutes before all testing from the first session was repeated in the aided condition. All sound-field testing was conducted in an audiometric test booth.

Boeheim et al. (2010) found that for frequencies 2000 to 8000 Hz, aided thresholds with both the Delta 8000 open-fit RITE hearing aid and the VSB AMEI were significantly better than unaided thresholds. At 1000 Hz, only the AMEI significantly improved thresholds. Excluding 3000 and 4000 Hz, open-fit RITE hearing aid thresholds were significantly worse than AMEI thresholds. Word recognition in quiet scores at 65 and 80 dB SPL were better in both aided conditions than the unaided condition. At both levels, performance with the AMEI was significantly better than performance with the open-fit RITE aid. Speech recognition thresholds in quiet for Freiburger numbers were significantly improved in the AMEI condition compared to the unaided condition. Speech recognition thresholds in quiet and in noise for OLSA were significantly improved for both aided conditions as well as for AMEI compared to open-fit RITE performance.

Based on these results, Boeheim et al. (2010) concluded that open-ear solutions such as AMEIs and open-fit RITE hearing aids supply people with sloping high frequency sensorineural hearing loss with benefit without occluding the ear canal while limiting acoustic feedback. Additionally, on all tests administered, AMEIs performed significantly better than the open-fit RITE hearing aids. This suggested that AMEIs are

an effective alternative to open-fit RITE hearing aids in patients who experience dissatisfaction with such devices.

Secondly, Valente and Mispagel (2008) sought to determine if there were any differences in performance between unaided, aided omnidirectional, and aided directional listening conditions with an open-fit RITE hearing aid. The participants consisted of 26 adults with symmetrical hearing loss and no previous experience with amplification. All participants had normal hearing in the low frequencies, 250 to 500 Hz, sloping to slight to moderately severe sensorineural hearing loss from 1000 to 8000 Hz. Participants were offered compensation for their involvement in the form of $200 or a 50% discount for the experimental hearing aids if they decided to purchase the devices at the conclusion of the study.

Valente and Mispagel (2008) selected the Vivatone Dual D44 as the experimental RITE hearing aid. The VivaSet 1.1 software was used to "First-Fit" the hearing aids and to set the two programs. The first program was an omnidirectional program and the second was a directional program with a hypercardioid polar plot. Participants returned to the clinic one-week post-fitting to address any problems. Four weeks after the one-week follow-up, participants returned to the clinic for speech in noise testing. The HINT was administered and reception thresholds for sentences (RTS) were measured in each listening condition (unaided, aided omnidirectional, and aided directional) utilizing a multi-loudspeaker setup. Specifically, eight loudspeakers positioned 45° apart presented R-Space restaurant noise at 65 dBA to the participant while HINT sentences were presented at 0° azimuth. Also, each participant completed the APHAB at the conclusion of the study.

Valente and Mispagel (2008) showed that a significant difference in RTS existed between performance on the HINT in the aided directional and aided omnidirectional conditions (directional better than omnidirectional). Also, a significant difference was found between aided directional and unaided performance (directional better than unaided). A significant difference did not exist between aided omnidirectional and unaided performance. Significantly better scores were noted on the APHAB for the aided condition versus the unaided condition on the ease of communication, reverberation, and background noise subscales. Valente and Mispagel (2008) concluded that the results of this study indicated that patients would perform better with directional microphones than when they are unaided or when using omnidirectional microphones. They also concluded that participants did observe benefit from the experimental devices. However, only 31% of the participants opted to purchase the devices at the conclusion of the study indicating that a significant number of participants did not receive enough benefit to purchase the hearing aids.

Subjective quality ratings. As previously stated, there are numerous studies that focus on subjective quality ratings as a method of assessing open-fit hearing aids. Additionally, there are multiple studies that focus on RITE hearing instruments and subjective quality ratings. Otto (2005) compared new open-canal devices to experienced hearing aid wearers' current hearing aids. In total, 23 participants were selected based on their audiometric configuration and previous hearing aid use. Each participant had normal low frequency hearing that sloped to a sensorineural hearing loss in the mid to high frequencies. Additionally, each participant was an experienced user of hearing aids. Initially, participants were instructed to rate their current hearing aids on an 8-item

questionnaire that included issues such as occlusion effect and appearance; a 10-point scale was utilized on each test item. Styles of the participants' hearing aids included five completely in the canal (CIC), three mini-canal (MC), nine in-the-canal (ITC), five ITE, and one BTE. Next, a Vivatone Totally Open Canal (TOC) RITE device was fit on each participant. With the device in place, participants then judged whether or not soft sounds were audible, moderate sounds were clear and comfortable, and loud sounds were tolerable. Also with the RITE device in place, all participants chewed a cracker, listened on the phone while the time-and-temperature recording played, and engaged in conversation both inside the office and outside the building with typical traffic noise in the background. Finally, each participant used the same 8-item questionnaire to rate the RITE devices.

Otto (2005) found that for all participants, the RITE device was favored on at least one of the 8-items. Additionally, the RITE device was preferable on four or more test items in 22 of the participants. Preference for the RITE device was found to be statistically significant on seven test items (i.e., hollow quality of voice, pressure feeling, feedback problems, comfortable level without feedback, loudness of chewing sounds, feedback on the telephone, and clarity of speech on the telephone). The eighth test item, involving appearance, revealed no preference for either the new RITE device or the participants' current devices. The author concluded that a statistically significant preference for RITE hearing aids did exist, suggesting that fitting a patient with an open-canal RITE device would result in less feedback and occlusion problems.

Secondly, Vasil and Cienkowski (2011) investigated (1) the acoustic occlusion effect with several different receiver sizes for a RITE hearing aid; (2) changes in the

perceived occlusion effect with different receiver sizes for a RITE hearing aid measured with an occlusion effect self-rating scale; (3) whether or not acoustic and perceived measures of occlusion effect are directly related; and (4) if ear canal volume and measures of occlusion effect are related. Participants were recruited from the University of Connecticut student body. Thirty participants with a mean age of 22.37 years and normal hearing were selected. An otoscopic evaluation revealed that all participants had normal external auditory canals and tympanometry screenings ruled out any middle ear pathology. Also, prior to testing, the participants read information that described and defined the occlusion effect. Participants also simulated total occlusion by vocalizing /i/ loudly while occluding both ears with their fingers.

Vasil and Cienkowski (2011) divided testing into two sessions. All screening procedures were conducted and ear impressions were taken during the first session. At the second session, Vivatone M44 RITE devices were fit binaurally on all participants. Sleeves made of plastic (produced for research purposes only) were used to adjust the size of the receiver. Testing occurred in a sound-treated booth with participants seated in the middle with their heads placed on a chin rest to ensure the ears remained at a stable level. The Fonix 7000 Quick Probe Real Ear Measurement System was used to obtain acoustic measures. A baseline REUR was recorded with an 80 dB SPL signal. Next, REURs and REORs for each receiver size were measured with the signal source turned off. Participants vocalized /i/ at 70 dBC SPL for 5s while monitoring vocalization intensity with a Radio Shack Model 33-4050 7-Range Analog Display Sound Level Meter. Real-ear unaided responses with /i/ vocalizations were measured first and REORvoc were then measured with the hearing aid in the left ear. Real-ear occlusion

effect was calculated by subtracting REURvoc from REORvoc (REORvoc-REURvoc = REOE). Subjective measures of occlusion were then obtained for each test condition. Furthermore, subjective and acoustic measures of occlusion were completed for each of the six receiver size conditions. Two of six conditions were repeated randomly across participants for test-retest data and the order of presentation of the different receiver sizes was randomized.

Vasil and Cienkowski (2011) found that perceived occlusion measures were highly reliable. Also, it was concluded that measured occlusion effect across the frequency range did not differ significantly. No receiver and receiver only conditions had significantly less perceived occlusion compared to the 0.190-in. and 0.230-in. receiver conditions. The smallest receiver condition had significantly more perceived occlusion that the no receiver condition while having a significantly better mean rating that the largest receiver condition. Compared to no receiver, receiver only, and the smallest receiver, the largest receiver condition had higher ratings of perceived occlusion. No significant relationship was found between either ear canal volume measure and acoustic or perceived occlusion. Additionally, no relationship was found between the two ear canal volume measures.

Vasil and Cienkowski (2011) also measured negligible amounts of occlusion effect at all frequencies through acoustic real-ear measures. Results from this study were consistent with previous studies that demonstrated no significant difference between REOE in the open and unaided conditions. Overall, differences in perception of the occlusion effect were negligible. None or mild occlusion were the median perceived ratings. This demonstrated that RITE devices resulted in minimal perceived occlusion

effect, regardless of receiver size. The authors also noted that patient perception of occlusion effect may not match acoustic measures. Additionally, this study showed that no direct relationship existed between ear canal size and occlusion effect, measured or perceived. The RITE hearing aids typically resulted in little occlusion effect, measured or perceived, regardless of ear canal size.

Thirdly, Hoen and Fabry (2007) sought to (1) describe devices with external receivers and the purposes of such a device; and (2) compare the performance of two different RITE devices with a traditional BTE device. The participants included 18 adults with a mean age of 65 years with moderate to severe sensorineural hearing loss in the high frequencies. All the participants were experienced hearing aid wearers.

Hoen and Fabry (2007) selected the Phonak microPower RITE device that is fit on patients with moderate to severe hearing losses as one of the RITE devices. The second RITE device was chosen due to its comparative performance with the microPower, labeled the x-Receiver Device. The traditional BTE selected for this study was the Phonak Eleva 311. Each participant attended three test sessions for data collection with a different device tested objectively and subjectively at each session. In order to obtain subjective sound quality ratings, participants listened to soft classical music and then rated the sound as echoic, dull, hollow, sharp, or natural. Objective measures of performance were obtained by administering the OLSA in omnidirectional and directional aided conditions. Test administration order and experimental device order were randomized across participants.

Hoen and Fabry (2007) found that most participants rated the classical music as natural in sound. The device that received the highest ratings was the microPower with

88% rating the device as natural sounding. The traditional BTE received the second highest rating with 72% natural followed by the x-Receiver Device with a 60% natural rating. Also, participants performed better on the OLSA with each instrument in both omnidirectional and directional conditions than in the unaided condition. While all three devices enhanced performance globally, the traditional BTE had the best results, followed by the microPower and then the x-Receiver Device. Hoen and Fabry (2007) concluded that RITE devices could provide excellent sound quality and directionality as well as high fidelity amplification while maintaining comfort and offering cosmetic advantages.

Fourthly, Hallenbeck and Groth (2008) investigated the effect of receiver placement in two matched open-fit devices on the frequency response and amount of gain before feedback. Twelve participants familiar with feedback from hearing aid use, were fit binaurally with ReSound Pulse BTE hearing aids and ReSound Pulse canal receiver technology (CRT) hearing aids. The Audiogram+first-fit rationale was applied to program the devices based on mild sloping to moderately severe high-frequency sensorineural hearing loss. Noise reduction and feedback cancellation were disabled in all devices. Gain before feedback was determined by slowly increasing the gain for 50 dB inputs from 1000 Hz to 6000 Hz in one-unit increments in the Aventa fitting software until the participant heard feedback. The procedure was repeated to ensure that a reliable measure was documented. Also, the procedure was repeated for each device on both ears. The simulated insertion gain level at which the participant heard feedback was recorded as maximum gain before feedback in the fitting software. Next, gain was reduced in each

device to a feedback free level and a real-ear aided response (REAR) was measured using the GN Otometrics Aurical Plus real-ear system with a warble-tone sweep at 65 dB SPL.

Hallenbeck and Groth (2008) found that according to the Aventa gain display, average maximum gain before feedback for the Pulse BTE was 23 dB while the Pulse CRT was 22 dB. The two were not significantly different. This result was expected since the primary feedback pathway was not altered between the two devices. Significant differences of about 5 dB were found at 2000 Hz and 6000 Hz with the Pulse CRT response surpassing the Pulse BTE. The additional gain at 2000 Hz for the Pulse CRT was a result of a system limitation at that frequency that prevented full compensation for the tube response. The additional gain at 6000 Hz for the Pulse CRT was a result of a wider bandwidth of the receiver that may have aided in the perception of advanced sound quality. In conclusion, open-fit and CRT devices offered approximately the same amount of maximum available real-ear gain. Canal receiver technology devices offered a smoother, wider frequency response, but both devices were expected to perform comparably.

Comparison of Open-Fit and RITE Hearing Aids

The purposes of the study by Alworth et al. (2010) were to determine if the location of the receiver in a hearing aid affects measures of (1) occlusion; (2) maximum gain before feedback; (3) speech perception in quiet; (4) speech perception in noise; (5) subjective performance; (6) and/or listener preference. The authors also sought to determine if previous experience with open-canal hearing devices related to effects of receiver location. The participants in this study included 25 adults with sensorineural hearing loss that fell within the fitting range of the test instruments. Additionally, each

participant had to be a native English speaker with no known learning disabilities, neurological issues, or cognitive deficits. In total, 10 participants were experienced users of open-canal devices while 15 had no experience with hearing devices.

The Bernafon ICOS 106 BTE DM was the receiver-in-the-aid (RITA) hearing instrument used in the study by Alworth et al. (2010). The ICOS RITA device was an open canal hearing instrument that utilized preformed tubing and an open dome to couple the device with the ear canal. The Bernafon BRITE 503 RITE DM was the RITE hearing instrument used in this study. Encased wiring and an open dome coupled the RITE device to the ear canal. The audiometric data of each participant was used to program each digital hearing instrument using the NAL-NL1 fitting strategy and the Bernafon fitting software. Specifically, the gain and compression parameters were determined by the Bernafon software and varied from participant to participant based on their audiometric data. Furthermore, signal processing was the same for both devices and each had wide dynamic range compression with seven channels. Also, both devices utilized adaptive feedback cancellation. The participants were fit binaurally and trialed both devices for six-week periods. At the beginning and end of both trial periods, probe microphone measures were taken to ensure that the hearing devices were functioning properly.

Alworth et al. (2010) also measured occlusion objectively at the end of both six-week trial periods for each ear on all participants using probe microphone measurements. The participants were instructed to vocalize /i/ at 60 dBA. An occluded measure was recorded with the hearing aid in place as well as an unoccluded measure with no hearing aid in place. By subtracting the unoccluded response from the occluded response, occlusion effect was established. Maximum gain before feedback was also measured

objectively at the end of both six-week trial periods for each ear on all participants using probe microphone measurements. A baseline probe microphone measurement recorded with pink noise at 65 dB SPL was subtracted from the maximum attainable output before feedback measurement to get a measure of maximum gain before feedback.

Alworth et al. (2010) also administered several performance measures including the CST, the HINT, Pascoe's High Frequency Word List (Pascoe's HFWL), and ANLs. These performance measures were administered in the unaided condition at the beginning of both six-week trials and again at the end of each trial period. The CST was given at 65 dB SPL with no background noise to assess speech recognition in quiet. Pascoe's HFWL was also given at 65 dB SPL to assess speech recognition in quiet. Each measure was administered twice and the average of the two scores was recorded as the score for that session. The adaptive HINT and Pascoe's HFWL (5 dB signal to noise ratio) were used to assess speech recognition in noise. The speech signal was presented at 65 dB SPL. Again, two trials were administered for both tests and the average of the two scores was recorded as the score for that session. Acceptable noise levels were also measured twice, and an average of two test trials was computed. The authors also utilized several subjective measures in their study. The APHAB was completed by all participants in the unaided condition at the beginning of both six-week trials and again at the end of each trial period. Additionally, twice a week during each trial period, participants filled out a five-point satisfaction rating based on sound quality, retention and comfort, ease of use and care, appearance, and speech clarity. Finally, all participants were asked to pick which device they preferred for listening in noise, for listening in quiet, and overall. Participants

were also instructed to rank, in order of importance, the five qualities listed above on how they contributed to deciding overall preference for one device.

Alworth et al. (2010) indicated that when comparing RITA and RITE devices, the occlusion effect was not significantly different at any frequency tested. It was also shown that at 4000 and 6000 Hz, gain before feedback in the RITE devices was significantly larger when compared to the RITA devices. For speech recognition in quiet, CST scores recorded with RITE devices on experienced hearing aid users were significantly better than unaided scores; however, no other comparisons for speech recognition in quiet were significant. For speech recognition in noise, both RITA and RITE scores were significantly worse than unaided scores and no significant difference was found between the two devices. Also, the ANL results were not significantly different between the RITA and RITE devices. On the APHAB, experienced hearing aid users stated significantly more problems than new hearing aid users. Also, both the RITA and RITE devices offered significant improvement for experienced and new users on subjective performance. However, APHAB scores were not significantly different between the RITA and RITE devices for any subtest. Subjective performance as measured by a satisfaction rating questionnaire showed more satisfaction with RITE devices than RITA devices. Specifically, experienced hearing aid wearers were significantly more satisfied with appearance, speech clarity, sound quality, and overall performance of the RITE devices. New hearing aid wearers were significantly more satisfied with RITE appearance alone. The authors also found that RITE devices were preferred by the participants in quiet and overall but no difference was found for performance in noise. Also, experience with hearing aids was not related to preference in quiet, noise, or

overall. Finally, it was found that factors such as sound clarity, sound quality, and retention and comfort were significantly more critical than factors such as use and care or appearance in establishing overall preference.

In conclusion, Alworth et al. (2010) found that both RITA and RITE devices reduced the occlusion effect. Gain before feedback was significantly greater at 4000 and 6000 Hz in the RITE device allowing more high frequency gain, which may affect subjective measures significantly. Speech recognition in quiet results indicated no difference between performance with the RITA and RITE devices. Speech recognition in noise results indicated that HINT scores were significantly better in the unaided condition compared to both the RITE and RITA conditions, but again the RITA and RITE performance was similar. Acceptance of noise results were not significantly different between the RITE and RITA devices, indicating that acceptance of background noise may be similar for RITA and RITE devices. Results of the APHAB showed that both RITA and RITE devices significantly increase subjective benefit for experienced and new hearing aid users, but results were not significantly different between the two devices for any APHAB subtest. Satisfaction ratings showed that participants were more satisfied with the appearance, sound quality, speech clarity, and overall experience for the RITE devices. At the end of the study, 76% of the participants preferred the RITE device and 24% preferred the RITA. Finally, it was found that the effects of location of the receiver were not related to prior experience with hearing aids. Lastly, this study determined that the location of the receiver did affect subjective overall device preference, and preference was influenced by speech clarity, sound quality, and retention and comfort; however,

speech in quiet and noise and acceptance of background noise was unchanged by the location of the receiver.

CHAPTER III

Methods

Participants

Fifteen adults participated in various portions of this study, with 13 participants completing all phases. Two participants were fitted with a set of hearing aids but failed to complete follow-up testing. Specifically, one participant returned the devices one-week post fitting while the other did not return to the facility for further testing. Of those completing all phases of the study, nine participants were experienced hearing aid wearers while four were first-time hearing aid wearers. The inclusion criteria included (1) participants with symmetrical normal to mild low frequency sensorineural hearing loss sloping to moderate to severe high frequency sensorineural hearing loss (i.e., no more than 40 dB HL at 250 - 1000 Hz, at least 40 dB HL at 2000 - 8000 Hz, and no worse than 85 dB HL at 2000 - 8000 Hz, or SNHL consistent with the available fitting range of the test hearing instruments that were tested) and (2) native English speakers with no known neurological, cognitive, or learning impairments. Symmetry was defined as no greater than a 15 dB difference between the right and left ears for octave frequencies between 250 – 8000 Hz. Right and left thresholds, measured under insert earphones, were averaged across listeners to obtain mean audiometric thresholds (see Figure 1). All participants were recruited from the greater Glenview, Illinois and surrounding areas.

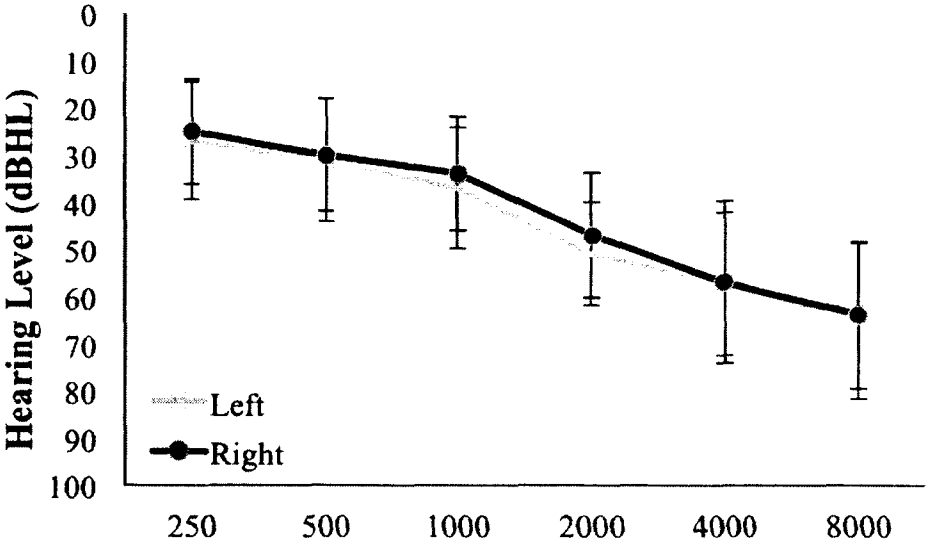


Figure 1: Mean and standard deviation audiometric data for 13 participants.

Materials and Procedures

Hearing instruments. Thirty sets of wide dynamic range compression (WDRC) hearing aids (i.e., 15 sets of BTEs and 15 sets of RITEs) were used to conduct this study. Each participant was fitted with two digital mini BTE hearing instruments (ReSound Alera 9 AL967-DW Open Transitional BTE). The BTE hearing instruments were coupled to the ear using preformed tubing and open domes (i.e., plastic domes with holes on the sides; not a custom earmold or plus dome). A thin support tube that locks into the concha assisted with retention of the tube and dome in the ear canal. Each participant was also fitted with two digital RITE hearing instruments (ReSound Alera 9 AL962-DRW NP Open RITE). The RITE hearing instruments were coupled to the ear using an interchangeable receiver unit placed in the ear canal. The hearing instrument was connected to the receiver via encased wiring and an open dome attached at the end. For each participant, open dome size used was consistent between trials.

The audiometric data of each participant was used to program each hearing instrument (i.e., both open-fit BTE and RITE) using GN ReSound's proprietary fitting formula, Audiogram+. Audiogram+ was used in this study due to the fact that most of the participants were accustomed to GN ReSound's proprietary fitting strategy. The digital hearing instruments were programmed for each participant using the ReSound Aventa 3.2.5 fitting software. The compression parameters were determined by the ReSound Initial Fit software and varied from participant to participant based on their audiometric data and their resulting in situ targets (see Appendix B for specific programming protocol). All other fitting parameters were identical between the two sets of hearing instruments. Hearing thresholds were reestablished before the second set of hearing aids was programmed and fitted on each participant. Furthermore, each participant utilized each hearing instrument style for a three-week trial period. Initial amplification condition was counterbalanced between participants.

Binaural probe microphone measures were obtained before each trial period to verify hearing aid function for each amplification condition (i.e., BTE and RITE). Probe microphone measures were obtained on each ear to verify that hearing aid responses fell within each participant's dynamic range using the Audioscan Verifit Open fittings with Speechmap function at 50 and 75 dB SPL. As recommended by Audioscan (Verifit), probe microphone insertion depth was 30 mm. Output levels in the ear canal were measured over the frequency range from 250 to 6000 Hz. Levels were stored on a personal computer for consequent data analysis.

Experimental procedures. All qualification and experimental testing was conducted in a sound-treated examination room (Acoustic Systems single-walled custom

booth) with ambient noise levels suitable for testing uncovered ears (ANSI S3.1-1991; American National Standards Institute, 1991). Prior to testing, all participants were given a verbal description of the study and completed an informed consent form (see Appendix A). An otoscopic evaluation was conducted to determine if each participant had normal external auditory canals with no visible evidence of significant cerumen. Additionally, a pure-tone audiogram (air and bone conduction) was obtained prior to fitting both sets of hearing aids using the modified Hughson-Westlake technique (Carhart & Jerger, 1959) to ensure that participants met the qualification criteria for the study (i.e., symmetrical normal to mild low frequency sensorineural hearing loss sloping to moderate to severe high frequency sensorineural hearing loss at octave frequencies between 250 and 8000 Hz). Hearing thresholds were reestablished before the second set of hearing aids was programmed and fitted on each participant.

Acceptable noise level testing. At the conclusion of each three week trial period, participants were seated in the center of the sound-treated room at the calibration point with the loudspeaker positioned at 0° azimuth. Acceptance of background noise was obtained using the conventional ANL procedure with each pair of hearing instruments. Running male speech (Arizona Travelogue, Cosmos Inc.) and 12-talker speech babble were produced by a compact-disc player, routed through a calibrated Madsen Astera PC-based audiometer, and presented through soundfield loudspeakers located at 0° azimuth. While listening to the recording of running male speech, the participants established their MCL by manipulating the intensity of the speech signal up or down. Participants were instructed to increase the stimulus intensity until it was judged to be too loud, decrease the stimulus intensity until it was judged to be too soft to follow the story, and then

increase the stimulus intensity to their MCL. Next, while speech was held constant at MCL, the 12-talker speech babble was added. Maximum acceptable BNL was established in the same manner as MCL with the participants increasing the noise until they could not hear the story, decreasing intensity until the story level was very clear, and then adjusting the noise to an intensity level where they were willing to "put up with" and still follow the story. Participants utilized push buttons to increase or decrease stimulus intensity level and verbally notified the instructor when MCL and BNL were reached. Calculated ANL in dB was determined by subtracting the BNL from the MCL (MCL - BNL = ANL). Two ANL trials were conducted during each test session. An average of the two trials served as the ANL score for that given test session.

Speech understanding in quiet. The Hearing in Noise Test (HINT) was used as test stimuli for speech perception testing. The HINT is made up of 250 sentences (25 lists of 10 sentences). Each sentence is read by a male speaker and all are around the same length and difficulty (six to eight syllables; first-grade reading level). The HINT noise conditions measure the reception thresholds for sentences (RTS) in signal-to-noise ratio (SNR). Reception thresholds for sentences are the SNR at which sentences can be correctly repeated 50% of the time in the presence of competing noise. The HINT Quiet measures RTS and was used to evaluate speech recognition in quiet at the end of each three-week trial.

Speech recognition in quiet was evaluated using the HINT Quiet for each experimental condition (BTE and RITE) at the end of each three-week trial. Hearing in Noise Test sentences were produced by a compact-disc player, routed through a calibrated Madsen Astera PC-based audiometer, and presented through a soundfield

loudspeaker located at 0° azimuth. For each participant, two sequential sentence lists of 10 sentences (20 sentences total) were presented in both hearing aid conditions. The first sentence was presented at a level below threshold (15 dBA below threshold). The first sentence was then repeated until a correct response was elicited from the participant, increasing presentation level by 4 dB with each repeated presentation. Next, intensity was decreased by 4 dB for the presentation of the second sentence. According to the participant's response on the second, third, and fourth sentences, stimulus level was either raised (incorrect response) or reduced (correct response) by 4 dB. After the fourth sentence, step size was reduced to 2 dB, and the up-down stepping rule was continued for the remaining 16 sentences. By averaging the presentation level of sentences five through 20, as well as the calculated intensity level for the twenty-first presentation, RTS was calculated.

Speech understanding in noise. The HINT Noise Front (NF) was used to evaluate speech recognition in noise at the end of each three-week trial. The HINT (NF) was administered for the BTE and RITE conditions. Hearing in Noise Test sentences and masking noise were produced by a compact-disc player, routed through a calibrated Madsen Astera PC-based audiometer, and presented through a soundfield loudspeaker located at 0° azimuth. For each experimental condition (BTE and RITE), two sequential sentence lists (20 sentences total) were presented. The first sentence was presented 4 dB below the noise presentation level of 65 dBA, which remained constant and continuous throughout the entire test to maintain activation of automatic hearing aid features. The first sentence was then repeated until a correct response was elicited from the participant, increasing presentation level by 4 dB with each repeated presentation. Next, intensity was

decreased by 4 dB for the presentation of the second sentence. According to the participant's response on the second, third, and fourth sentences, stimulus level was either raised (incorrect response) or reduced (correct response) by 4 dB. After the fourth sentence, step size was reduced to 2 dB, and the up-down stepping rule was continued for the remaining 16 sentences. By averaging the presentation level of sentences five through 20, as well as the calculated intensity level for the twenty-first presentation, and subtracting out 65 (for the noise) from the average, RTS was calculated.

Prior to the administration of any HINT tests (i.e., HINT Quiet and HINT NF), a practice list was administered to each participant in the HINT (NF) condition. Furthermore, random selection of HINT sentence lists was utilized, and no list was repeated for any participant during the test session to reduce learning effects. Also, prior to data collection, an experimental schedule was created for each participant listing a completely randomized assignment for hearing aid style order and HINT sentence list.

Sound quality ratings and listener preference. A sound quality questionnaire was administered to assess the quality of sound produced by both sets of hearing aids. The questionnaire was comprised of eight categories to be rated on a 10-point scale. The categories were (1) softness, (2) brightness, (3) clarity, (4) fullness, (5) nearness, (6) loudness, (7) spaciousness, and (8) total impression. For each category, participants rated the sound quality from 1 to 10 (e.g. for softness: 1 being very sharp and 10 being very soft, see Appendix C). The Sound Quality Questionnaire was administered once a week for each three-week trial period to obtain subjective measures of sound quality for the BTE and RITE devices; therefore, each participant rated each instrument a total of 24 times for each trial period (1 questionnaire × 8 items × 3 weeks). At the conclusion of

the study, each participant was also asked to designate which set of hearing aids they preferred on all categories of the Sound Quality Questionnaire, when listening in quiet, when listening in noise, and overall (see Appendix D).

CHAPTER IV

Results

Performance Measures

Acceptable noise levels. One purpose of this study was to determine the effect of receiver location on acceptance of background noise. Thirteen participants were tested using BTE hearing aids with two receiver locations (i.e., open-fit BTE and RITE). Acceptance of background noise was assessed with the ANL test. Data was averaged across participants for each receiver location. Mean data for the ANL is displayed in Figure 2.

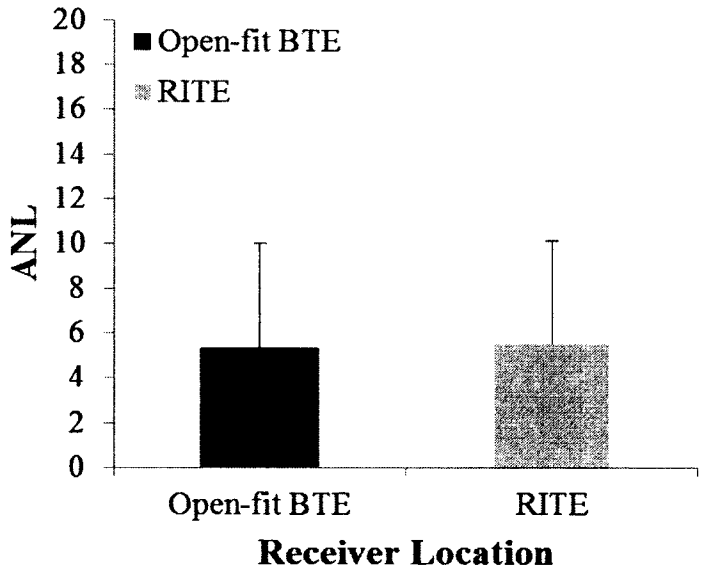


Figure 2. Mean ANLs for open-fit BTE and RITE devices.

A one-way repeated measure analysis of variance (ANOVA) was conducted to determine the effect of receiver location on acceptance of background noise (i.e., ANLs).

The within subject variable was receiver location with two levels (open-fit BTE and RITE). The results showed no significant difference for receiver location [$F(1,12) = 0.053, p = 0.822$]. These results indicated that receiver location did not significantly affect acceptance of background noise.

Speech understanding in quiet. Another purpose of this study was to determine the effect of receiver location on speech perception in quiet. Again, thirteen participants were tested using BTE hearing aids with two receiver locations (i.e., open-fit BTE and RITE). Speech in quiet was assessed with the HINT Quiet, which is scored using the RTS. Data was averaged across participants for each receiver location. Mean data for the HINT Quiet is displayed in Figure 3.

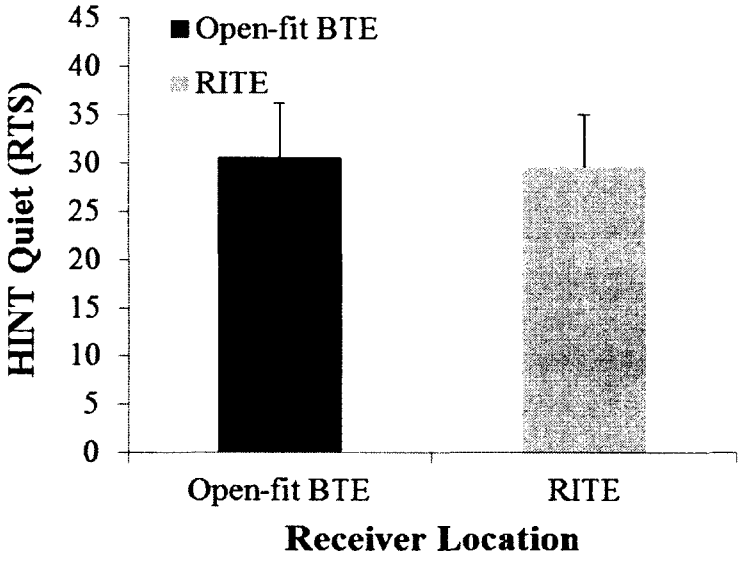


Figure 3. Mean HINT Quiet values (in RTS) for open-fit BTE and RITE devices.

A one-way repeated measure ANOVA was conducted to determine the effect of receiver location on listening in quiet. The within subject variable was receiver location with two levels (open-fit BTE and RITE). The results showed no significant difference

for receiver location [$F(1.12) = 1.490$, $p = 0.246$], indicating that receiver location did not significantly affect speech perception ability in quiet.

Speech understanding in noise. An additional purpose of this study was to determine the effect of receiver location on speech perception in noise. Again, thirteen participants were tested using a BTE with two receiver locations (i.e., open-fit BTE and RITE). Speech perception in noise was assessed with the HINT NF which is scored by finding a sentence reception threshold in terms of signal to noise ratio. Data was averaged across participants for each receiver location, and mean data for the HINT NF is displayed in Figure 4.

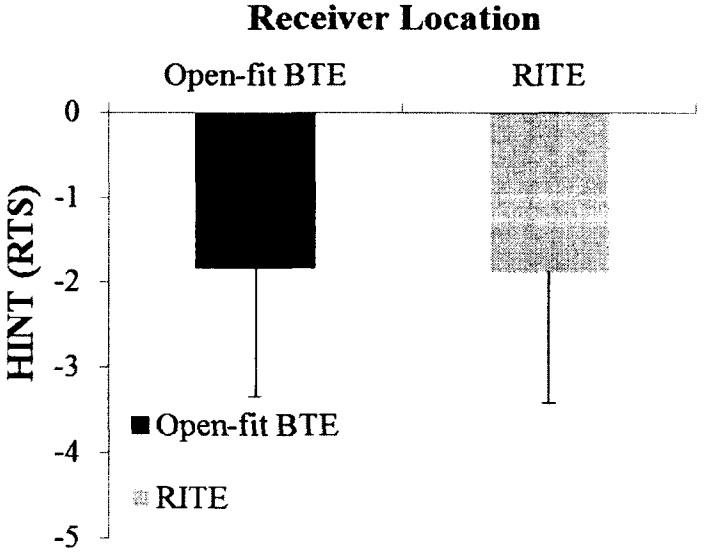


Figure 4. Mean HINT with noise generated from the front loudspeakers (in SNR) for the open-fit BTE and RITE devices.

A one-way repeated measure ANOVA was conducted using the HINT NF values to determine if speech understanding in noise scores differed when using open-fit BTE versus RITE instruments. The within subject variable was receiver location with two levels (open-fit BTE and RITE). The results showed no significant difference for receiver

location [$F(1,12) = 0.017, p = 0.899$)]. These results indicated that receiver location did not significantly affect speech perception ability in noise.

Sound quality ratings and listener preference. Another purpose of this study was to determine the effect of receiver location in a hearing aid on subjective sound quality ratings. The same thirteen participants using two receiver locations (open-fit BTE and RITE) were asked to judge sound quality in the following eight areas: (1) softness, (2) brightness, (3) clarity, (4) fullness, (5) nearness, (6) loudness, (7) spaciousness, and (8) total impression. All categories were rated based on a 10-point scale (e.g. for softness: 1 being very sharp and 10 being very soft, see Appendix C). The Sound Quality Questionnaire was administered once a week for each three-week trial period; therefore, each participant rated each instrument a total of 24 times for each hearing aid style (1 questionnaire × 8 items × 3 weeks). For week three with both receiver locations (i.e., open-fit BTE and RITE), the questionnaire was completed in a sound-treated room while listening to continuous running speech at MCL through a soundfield loudspeaker located at 0° azimuth. For week three, data was averaged across participants for each receiver location. Mean data is displayed in Figure 5.

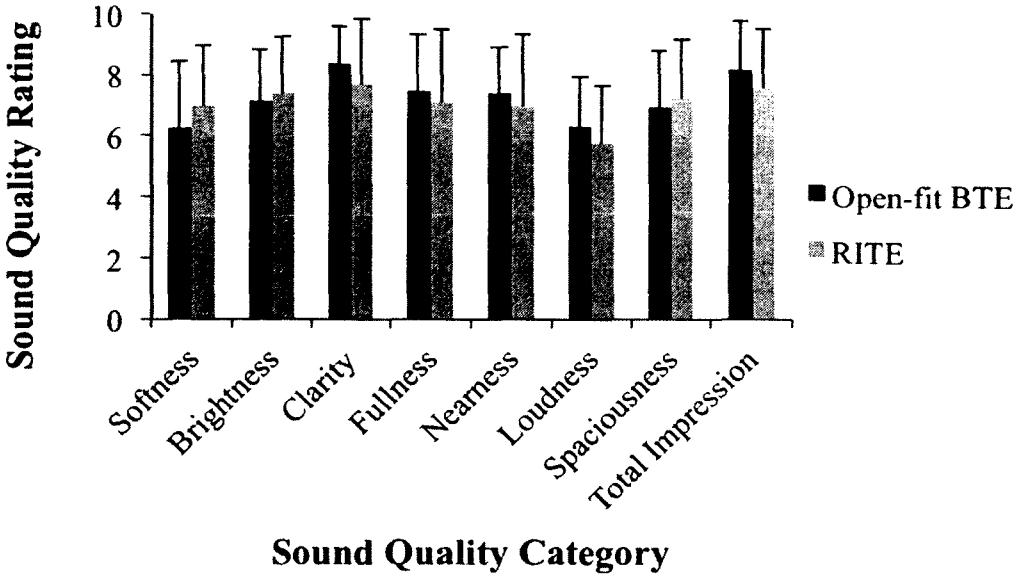


Figure 5. Mean sound quality ratings for open-fit BTE and RITE devices in the sound treated booth.

Eight paired Wilcoxon signed ranks tests were conducted using week three subjective sound quality values to determine if judgments of sound quality differed when using open-fit BTE versus RITE instruments. The results showed no significant difference for receiver location in any category. These results indicated that sound quality in a sound-treated room was not affected by receiver location. Statistical data is displayed in Table 1.

Table 1

Sound Quality Judgments in Sound-Treated Room

	Z	significance
Softness	-0.810	0.418
Brightness	-0.205	0.837
Clarity	-1.028	0.304
Fullness	-0.205	0.837
Nearness	-0.667	0.505
Loudness	-1.244	0.214
Spaciousness	-0.535	0.592
Total Impression	-0.671	0.502

For weeks one and two with both hearing aid fittings (i.e, open-fit BTE and RITE), participants were asked to judge sound quality in their daily listening environments in same eight areas (i.e., (1) softness, (2) brightness, (3) clarity, (4) fullness, (5) nearness, (6) loudness, (7) spaciousness, and (8) total impression). All categories were again rated based on a 10-point scale (see Appendix C). Data was averaged across participants for each receiver location. Mean data is displayed in Figure 6.

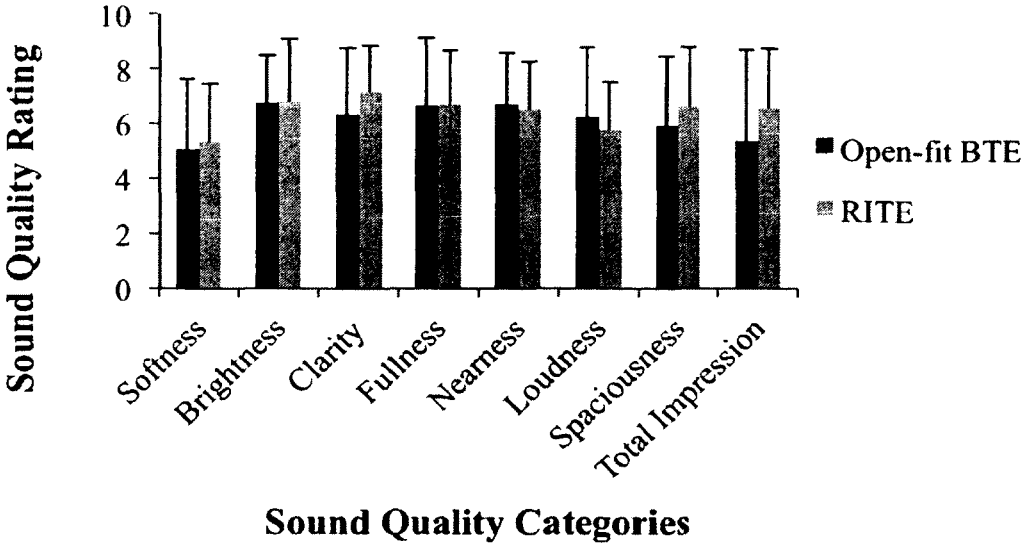


Figure 6. Mean sound quality ratings for open-fit BTE and RITE devices when measured in the subject's daily listening environments.

Eight paired Wilcoxon signed ranks tests were conducted using subjective sound quality values to determine if judgments of sound quality differed when using open-fit BTE versus RITE instruments in the subject's daily listening environment. The results showed no significant difference for receiver location in any category. These results indicated that sound quality in the real world was not affected by receiver location. Data is displayed in Table 2.

Table 2

Sound Quality Judgments in Real World

	Z	significance
Softness	-0.357	0.721
Brightness	-0.089	0.929
Clarity	-1.218	0.223
Fullness	-0.052	0.959
Nearness	-0.079	0.937
Loudness	-0.670	0.503
Spaciousness	-0.946	0.344
Total Impression	-1.425	0.154

At the conclusion of all experimental testing, each participant was asked to indicate which hearing instrument receiver location (i.e., open-fit BTE or RITE) they preferred for listening for each category of the Sound Quality Questionnaire (i.e., softness, brightness, clarity, fullness, nearness, loudness, spaciousness, and total impression), as well as when listening in quiet, in noise, and overall. Preference data is displayed in Figure 7.

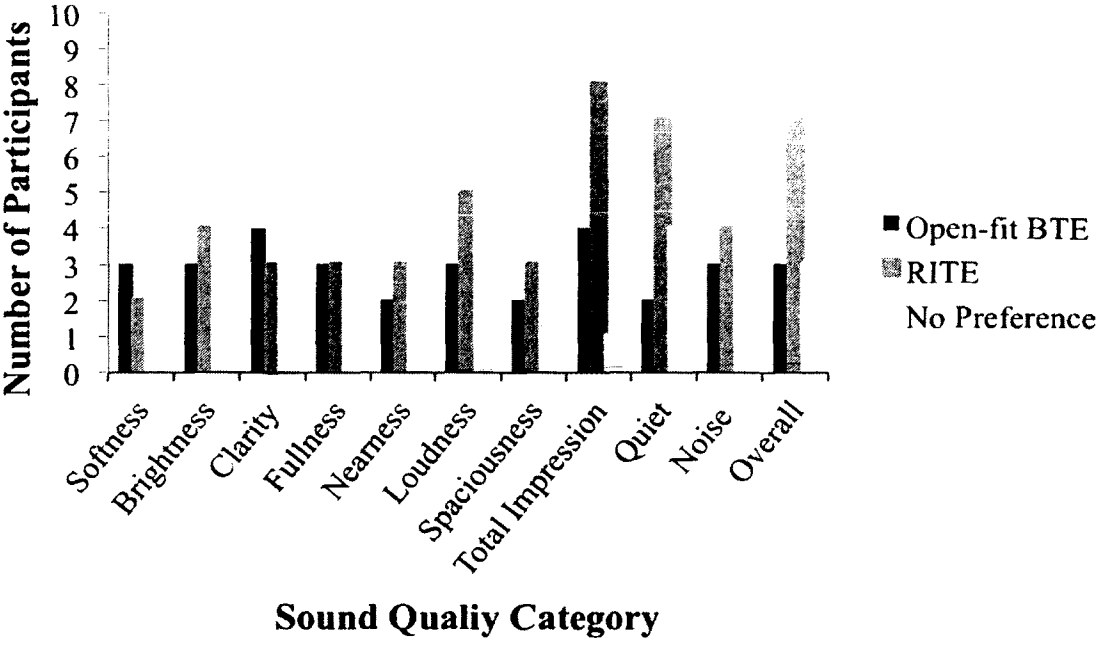


Figure 7. Listener preference results for each Sound Quality Questionnaire category and when listening in quiet, in noise, and overall for open-fit BTE and RITE devices.

Eleven one-sample chi-square tests were conducted to assess receiver location preference. The hypothesized proportion of listeners that preferred the open-fit BTE, RITE, or no preference for receiver location was 0.33. The results showed no significant preference for receiver location in any category. These results indicated that listener preference was not affected by receiver location. Data is displayed in Table 3.

Table 3

Listener Preference

	Chi-square	df	significance
Softness	4.769	2	0.092
Brightness	1.077	2	0.584
Clarity	1.077	2	0.584
Fullness	2.462	2	0.292
Nearness	4.769	2	0.092
Loudness	0.615	2	0.735
Spaciousness	4.769	2	0.092
Total Impression	5.692	2	0.058
Quiet	2.923	2	0.232
Noise	1.077	2	0.584
Overall	2.462	2	0.292

In summary, purposes of this study were to determine the effect of receiver location on (1) acceptance on background noise, (2) speech perception in quiet, (3) speech perception in noise, (4) subjective sound quality ratings in a sound-treated room and in the real world, and (5) listener preference. Results showed that receiver location did not significantly affect acceptance of background noise, speech perception ability in quiet or in noise, sound quality in a sound-treated room or in the real world, or listener preference. These results indicate that the position of the receiver in a BTE hearing aid does not affect the amount of noise listeners can accept, their speech understanding ability, or the sound quality of the device.

CHAPTER V

Discussion

Performance Measures

Acceptable noise levels. One purpose of this study was to determine the effect of receiver location in a hearing aid on acceptance of background noise. Thirteen adults with symmetrical, normal to mild low frequency sensorineural hearing loss sloping to moderate to severe high frequency sensorineural hearing loss participated in this study. The results revealed no significant difference on acceptance of background noise for receiver location. These results indicate that acceptance of background noise is not affected by the position of the receiver in a hearing aid.

The results of the present study were expected and agreed with previous acceptance of background noise research, which indicated that ANLs are not significantly affected by amplification. First, Alworth et al. (2010) found that acceptance of noise results were not significantly different between RITE and receiver in the aid (RITA, i.e., open fit BTE hearing aids) devices. Furthermore, Nabelek et al. (2004) compared acceptance of background noise in aided and unaided conditions over a three-month time period. The authors found that ANLs were not related to use of amplification and did not vary significantly between aided and unaided conditions. Results from the present study agreed with this research, showing that acceptance of background noise is not affected by the position of the receiver in a hearing aid.

Furthermore, past research has linked acceptance of background noise to hearing aid use. Specifically, Nabelek et al. (2006) determined that listeners who accept small amounts of background noise are unsuccessful hearing aid wearers while listeners who accept large amounts of noise are successful hearing aid users. Furthermore, Nabelek et al. (2006) determined that unaided ANLs could predict a person's success with hearing aids with 85% accuracy. Therefore, the results of this study suggest that success with hearing aids should not change based on the position of the receiver in a BTE device.

Speech understanding in quiet. Another purpose of this study was to determine the effect of receiver location in a hearing aid on speech perception in quiet. The results revealed no significant difference on speech perception in quiet for receiver location. These results were expected and agreed with previous receiver location research, which indicated that speech recognition in quiet was not significantly affected by location of the receiver in a hearing aid. Specifically, Alworth et al. (2010) found that speech perception in quiet results were not significantly different between RITE and open-fit BTE hearing devices. These results indicate that speech perception in quiet is not affected by the position of the receiver in a hearing aid.

Speech understanding in noise. An additional purpose of this study was to determine the effect of receiver location in a hearing aid on speech perception in noise. The results indicated that receiver location did not significantly affect speech perception ability in noise. In other words, speech perception in noise ability is not affected by the position of the receiver in a BTE hearing aid. These results were expected and agreed with previous receiver location research which found that speech recognition in noise was unchanged when using open-fit BTE versus RITE instruments. Alworth et al. (2010),

Valente and Mispagel (2008), and Klemp and Dhar (2008) further found that speech perception in noise was unchanged or degraded when using open-canal instruments with omnidirectional microphones compared to utilizing no hearing aids at all. Specifically, Alworth et al. (2010) found speech perception in noise results were not significantly different between RITE and open-fit BTE hearing devices. The authors also found that unaided speech perception in noise scores were significantly better than both the RITE and open-fit BTE speech perception in noise scores. Valente and Mispagel (2008) and Klemp and Dhar (2008) found that directional microphones are required for a person to perform significantly better than unaided or aided with omnidirectional microphones on speech perception in noise measures.

Sound quality ratings and listener preference. Another purpose of this study was to determine the effect of receiver location in a hearing aid on subjective sound quality ratings. The results indicated that sound quality was not affected by receiver location in a sound-treated room or in the real world. Improvements in sound quality with RITE devices over open-fit BTE devices were expected. Specifically, improved sound clarity, brightness, and total impression were expected for the RITE device compared to the open-fit BTE device. Furthermore, results from the present study disagreed with previous receiver location research that indicated that people were more satisfied with sound quality, appearance, speech clarity, and overall performance of RITE devices over open-fit devices. In a study conducted by Alworth et al. (2010), results on the APHAB were not significantly different between RITE and open-fit BTE hearing instruments. However, subjective performance as measured by a satisfaction rating questionnaire consisting of a five-point satisfaction rating on sound quality, retention and comfort, ease

of use and care, appearance, and speech clarity showed more satisfaction with RITE devices than open-fit BTE hearing devices. Specifically, Alworth et al. (2010) found that experienced hearing aid wearers were significantly more satisfied with the appearance, speech clarity, sound quality, and overall performance of the RITE devices, while new hearing aid wearers were significantly more satisfied with RITE appearance alone. Hoen and Fabry (2007), who compared a BTE device and two different RITE devices, found that the best sound quality ratings were obtained for one of the RITE devices. Lastly, Valente and Mispagel (2008) found that open-fit BTE aided APHAB scores were significantly better than unaided scores on all subtests except Aversiveness.

The present study evaluated satisfaction by measuring different aspects of sound quality. The sound quality questionnaire that was administered to assess both sets of hearing aids was comprised of eight categories to be rated on a 10-point scale. The categories were (1) softness, (2) brightness, (3) clarity, (4) fullness, (5) nearness, (6) loudness, (7) spaciousness, and (8) total impression. For each category, participants rated the sound quality from 1 to 10 (e.g. for softness: 1 being very sharp and 10 being very soft). The Sound Quality Questionnaire was administered once a week for each three-week trial period to obtain subjective measures of sound quality for the open-fit BTE and RITE devices. No significant difference was seen on any sound quality measure included in this study. These results may have differed from past research due to the number of specific sound quality categories included. As previous research has mainly evaluated overall sound quality or clarity, this study evaluated specific aspects of sound. Additionally, the inclusion of only 13 participants may have affected the outcome of this measure. Although more subjects are currently being tested, it should be noted that the

current data shows no trends for objective measures, real world sound quality judgments, or sound quality judgments obtained in the sound-treated room for experienced hearing aid users. Additionally, the data obtained from the four new hearing aid users shows slight trends for increased clarity, loudness, spaciousness, and total impression with the open-fit BTE devices compared to RITE devices in a sound-treated room.

Many hearing aid manufacturers claim that sound quality is superior with RITE devices over open-fit BTE instruments. Audiologists are, therefore, fitting these instruments with the perception that sound quality is improved and clearer. Reports claim that sound quality is improved in RITE devices due to a smoother frequency response from avoided tube resonances, more gain before feedback, and better high frequency amplification (Hallenbeck & Groth, 2008). For example, Hallenbeck and Groth (2008) compared attainable gain before feedback and the effect of receiver placement on the frequency response with open-fit BTE and RITE devices. The results of the study indicated that each instrument had approximately the same amount of maximum available gain before feedback. A smoother, wider frequency response was noted for the RITE device over the open-fit BTE device; however, the two instruments were expected to perform comparably in the patient's ear, with the exception of possible variations in the smoothness of the frequency response Furthermore, the present study noted no difference in sound quality between the two devices in any of the eight categories rated (i.e. softness, brightness, clarity, fullness, nearness, loudness, spaciousness, and total impression).

A final purpose of this study was to determine the effect of receiver location in a hearing aid on listener preference on each of the eight categories of the Sound Quality

Questionnaire (i.e. softness, brightness, clarity, fullness, nearness, loudness, spaciousness, and total impression), as well as when listening in quiet, in noise, and overall. At the conclusion of the study, each participant was also asked to designate which set of hearing aids they preferred on these categories. The results indicated that listener preference was not affected by receiver location. These results were not expected and disagreed with previous receiver location research, which indicated that people preferred RITE instruments when listening in quiet and overall. Specifically, Alworth et al. (2010) found that people preferred RITE instruments over open-fit BTEs when listening in quiet and overall but no difference was found for performance in noise. The authors found that 76% of their participants preferred the RITE device over the open-fit BTE device. In the present study, no preference was see for either the RITE or open-fit BTE device.

In summary, these results indicated that acceptance of background noise, speech perception ability in quiet or in noise, sound quality in a sound-treated room or in the real world, and listener preference are not affected by the position of the receiver in a hearing aid. Collectively, these results indicated that audiologists can fit open-fit BTE or RITE hearing devices based on other factors such as degree of hearing loss, hearing loss configuration, patient performance, medical considerations, cost, and/or convenience. Future research should further explore open-fit BTE and RITE instruments manufactured by multiple companies and compare the two conditions (open-fit and RITE) in a larger sample size. Additionally, evaluation of directional technology and related features should be included in future comparison studies of open-fit BTE and RITE devices.

APPENDIX A

Human Subjects Permission Form

HUMAN SUBJECTS CONSENT FORM

The following is a brief summary of the project in which you have been asked to participate. Please read this information before signing below:

TITLE: Receiver Position and Acceptance of Noise, Speech Understanding, and Sound Quality Ratings
PURPOSE OF STUDY/PROJECT: The purpose of this study is to determine the effect of the position of the receiver in a hearing aid on sound quality and speech perception.

PROCEDURE: Prior to inclusion in this study, each participant will receive a hearing evaluation, which will include otoscopy and audiometric pure tone testing. Participants not meeting the qualification criteria will be dismissed from the study. Participants will be fit binaurally with two sets of hearing aids. After each set of hearing aids is set to match the needs of their hearing loss, the participant will wear the aids for a three-week trial period prior to experimental testing. Participants will then be seated in a sound treated booth 3 feet from a loudspeaker located in front of the participant. Acceptance of background noise will be assessed using the Acceptable Noise Level (ANL) procedure. Speech in quiet and speech in noise abilities will be assessed using the Hearing in Noise Test (HINT), both of which are standard clinical/research procedures. All procedures will be completed at 65 dBA. Each participant's performance will be assessed using two sets of hearing aids (BTE and RITE). Participants will also be asked to complete a questionnaire, judging softness, brightness, clarity, fullness, loudness, spaciousness, and total impression on a scale from one to 10 at the end of each week during both three-week trial periods. Additionally, at the conclusion of the study, each participant will be asked to indicate which hearing instrument they prefer on all categories of the Sound Quality Questionnaire and when listening in quiet, in noise, and overall. Due to the inclusion of two hearing aid trial periods, participants will be asked to complete the testing over three sessions. Session 1 will include the audiometric testing and the first hearing aid fitting (1 hour). Session 2 will include experimental testing for the first set of hearing aids, a hearing re-evaluation, and the hearing aid fitting for the second set of hearing aids (1 hour, 30 minutes). Session 3 will include the second set of experimental testing procedures (45 minutes).

INSTRUMENTS: The subject's identity will be confidential throughout the study and will not be utilized in any form in the analysis or representation of the data.

RISKS/ALTERNATIVE TREATMENTS: There are no known risks to the subject, however according to Louisiana Tech Office of Research the following statement must be made, *the participant understands that Louisiana Tech is not able to offer financial compensation nor to absorb the costs of medical treatment should you be injured as a result of participating in this research.* All testing procedures will be conducted at normal conversational speech levels and are similar to clinical audiometric measures. Participation is voluntary with informed consent. You are free to discontinue participation at any time. Participants are not expected to complete online surveys, however, the following disclosure applies to all participants using online survey tools: *This server may collect information and your IP address indirectly and automatically via "cookies".*

BENEFITS/COMPENSATION: Each participant will receive a free hearing evaluation in exchange for participation in this study. Furthermore, each participant will also be provided monetary compensation in the amount of $20 per visit (funding by GN ReSound). Moreover, the scientific and clinical communities will benefit from a better understanding of the effects of receiver location for hearing aid users.

I,_____, attest with my signature that I have read and understood the following description of the study, "Receiver Position and Acceptance of Noise, Speech Understanding, and Sound Quality Ratings", and its purposes and methods. I understand that my participation in this research is strictly voluntary and my participation or refusal to participate in this study will not affect my relationship with Louisiana Tech University or the Louisiana Tech University Speech and Hearing Center. I am aware that once the experimental treatment is completed, I will receive traditional clinical services for the remainder of the Quarter, if applicable. This procedure will not substitute for any hearing services currently being received. Further, I understand that I may withdraw at any time or refuse to answer any questions without penalty. Upon completion of the study, I understand that the results will be freely available to me upon request. I understand that the results will be confidential, accessible only to the project director, principal experimenters, myself, or a legally appointed representative. I have not been requested to waive nor do I waive any of my rights related to participating in this study.

_____ _____
Signature of Participant or Guardian Date

CONTACT INFORMATION: The principal experimenter listed below may be reached to answer questions about the research, subject's rights, or related matters.
Melinda F. Bryan, Ph.D., CCC-A; Anna Ford, B.S. Department of Speech, (318) 257-2146

Members of the Human Use Committee of Louisiana Tech University may also be contacted if a problem cannot be discussed with the experimenters: Dr. Les Guice (318) 257-4647; Dr. Mary Livingston (318) 257-2292; Nancy Fuller (318) 257-5075

APPENDIX B

Hearing Instrument Programming Protocol

Hearing Instrument Programming Protocol (BTE)

1. Complete Human Subjects Permission Form
2. Complete audiogram
3. Fit the first set of Hearing Aids
    a. Open GN ReSound Aventa 3.2.5
    b. Make sure audiogram is updated and save or update it and save.
    c. Determine preformed tubing length and open dome size.
    d. On Prefit tab,
        i. click "Reconfigure"
        ii. choose "DW Open RITE"
    e. Connect hearing instruments
        i. Software prompts this message: "Calculated Focus Ear. P1 will be changed to the Natural Directionality II environment."
            1. Click "No"
        ii. Software prompts this message: "Calibrate FB suppression for connected instrument."
            1. Click "No"
        iii. Start Tab
            1. Make sure Experience- Non Linear user is selected at left under Patient Information
        iv. Prefit Tab
            1. Make sure correct hearing instruments are selected (L/R)
        v. Fit Tab
            1. Click P2 Restaurant
                a. Click remove
            2. Click P3 Telecoil
                a. Click remove
            3. Under Tools on left click Advanced Features
                a. Make sure the following are selected:
                    i. Directionality: select Softswitching
                    ii. Expansion: select Mild
                    iii. DFS Ultra: select Off
                    iv. Directional Mix: select Very Low
                    v. NoiseTracker II: select Per Environment
            4. Under Tools on left click Physical Properties
                a. Select Tulip-Dome
                b. Select Tube Size depending on patient
        vi. Summary Tab
            1. Save session
4. Put hearing aids on patient
    a. Fit Tab
    b. Calibrate DFS at bottom

Hearing Instrument Programming Protocol (RITE)

1. Re-check audiogram
2. Fit the second set of Hearing Aids
    a. Open GN ReSound Aventa 3.2.5
    b. Make sure audiogram is updated and save or update it and save.
    c. Determine preformed tubing length and open dome size.
    d. On Prefit tab,
        i. click "Reconfigure"
        ii. choose "DW Open"
    e. Connect hearing instruments
        i. Software prompts this message: "Calculated Focus Ear. P1 will be changed to the Natural Directionality II environment."
            1. Click "No"
        ii. Software prompts this message: "Calibrate FB suppression for connected instrument."
            1. Click "No"
        iii. Start Tab
            1. Make sure Experience- Non Linear user is selected at left under Patient Information
        iv. Prefit Tab
            1. Make sure correct hearing instruments are selected (L/R)
        v. Fit Tab
            1. Click P2 Restaurant
                a. Click remove
            2. Click P3 Telecoil
                a. Click remove
            3. Under Tools on left click Advanced Features
                a. Make sure the following are selected:
                    i. Directionality: select Softswitching
                    ii. Expansion: select Mild
                    iii. DFS Ultra: select Off
                    iv. Directional Mix: select Very Low
                    v. NoiseTracker II: select Per Environment
            4. Under Tools on left click Physical Properties
                a. Vent Configuration: Select Air-Dome
                b. Tube Size: select depending on patient
                c. Dome Size: select depending on patient
        vi. Summary Tab
            1. Save session
3. Put hearing aids on patient
    a. Fit Tab
    b. Calibrate DFS at bottom

APPENDIX C

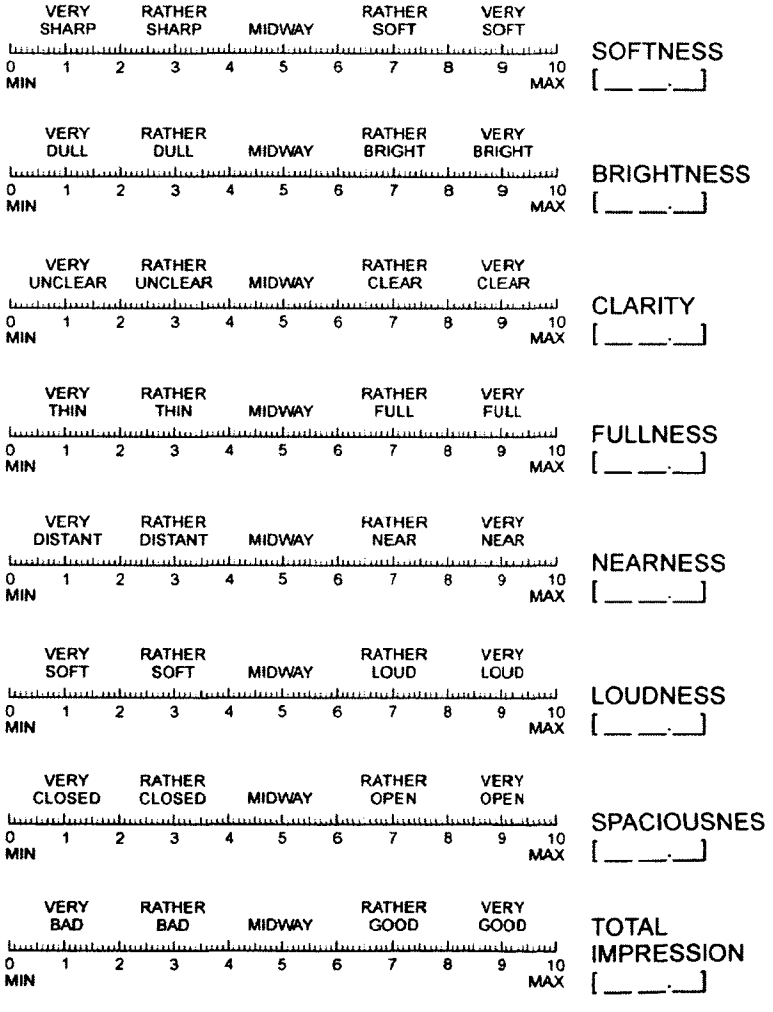
Sound Quality Questionnaire and Instructions

Sound Quality Questionnaire

Instructions: Please judge the sound quality of the information that you are about to listen to. Describe how the information sounds using the scale below. The scales refer to various properties of the sound reproduction. Please judge the sound on a scale from 10 (maximum) to 0 (minimum). The integers 9, 7, 5, 3, and 1 on the response form are defined. For instance, in the scale for clarity 10 means maximum (highest possible) clarity, 9 means very clear, and 0 minimum clarity.

The scales are described as follows:

- ***Softness***. How soft and gentle is the reproduction - in opposition to sharp, hard, keen, and shrill.
- ***Brightness***. How bright is the reproduction - in opposition to dull and dark.
- ***Clarity***. How clear, distinct, and pure is the reproduction – in opposition to sounding diffuse, blurred, thick, and the like.
- ***Fullness***. How full is the reproduction - in opposition to thin.
- ***Nearness***. How close to you does the reproduction sound – in opposition to at a distance.
- ***Loudness***. How loud is the reproduction - in opposition to soft or faint.
- ***Spaciousness***. How open and spacious does the reproduction sound – in opposition to closed and shut up.
- ***Total impression***. What is your overall judgment of how good you think the reproduction is?



APPENDIX D

Preference Form

Preference Form

Please circle one answer for each question.

1. Which trial period did you prefer for **softness**?

   Trial #1 Trial #2 No Preference

2. Which trial period did you prefer for **brightness**?

   Trial #1 Trial #2 No Preference

3. Which trial period did you prefer for **clarity**?

   Trial #1 Trial #2 No Preference

4. Which trial period did you prefer for **fullness**?

   Trial #1 Trial #2 No Preference

5. Which trial period did you prefer for **nearness**?

   Trial #1 Trial #2 No Preference

6. Which trial period did you prefer for **loudness**?

   Trial #1 Trial #2 No Preference

7. Which trial period did you prefer for **spaciousness**?

   Trial #1 Trial #2 No Preference

8. Which trial period did you prefer for **total impression**?

   Trial #1 Trial #2 No Preference

9. Which trial period did you prefer for listening **in quiet**?

   Trial #1 Trial #2 No Preference

10. Which trial period did you prefer for listening **in noise**?

    Trial #1 Trial #2 No Preference

11. Which trial period did you prefer **overall**?

    Trial #1 Trial #2 No Preference

Additional Comments:

APPENDIX E

BRIRB Memo

LOUISIANA TECH
UNIVERSITY

OFFICE OF VICE PRESIDENT
FOR RESEARCH AND DEVELOPMENT

MEMORANDUM

TO: Dr. Sheryl Shoemaker

FROM: Don Braswell, BRIRC Chair

SUBJECT: BRIRC 5 – Annual Renewal Review

DATE: January 31, 2012

RE: "Speech and Hearing Services"

This proposal has been reviewed by the BRIRC and is recommended for approval.

The BRIRC recommended approval of this project is for one (1) calendar year from the date of approval. ***This approval was finalized on January 31, 2012 and this project will need to receive a continuation review by the BRIRB if the project, including data analysis, continues beyond January 31, 2013.*** The project is to be terminated at that time unless the BRIRC receives a request for continuance.

Modification of an approved project is STRICTLY PROHIBITED without prior BRIRC review and the approval of the Vice President of Research & Development of these modifications. **Request for continuance or protocol modification must be received by the VP Research's Office 30 days prior to the renewal date or before initiation of the modified protocol.**

If you have any questions, please contact Dr. Ed Griswold at 257-2120.

cc: Dr. Edward C. Jacobs
Human Use Committee (HUC)

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