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**COMPARING REAL EAR INSERTION GAIN MEASURES OF
MANUFACTURER'S FIRST FIT, MEASURED SENSOGRAM, AND
SIMULATED SENSOGRAM TO PRESCRIPTIVE TARGET VALUES**

By

Rachel Katherine Warman

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

Doctor of Audiology

**Washington University School of Medicine
Program in Audiology and Communication Sciences**

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Approved by:

**Alison Brockmeyer, Au.D., and Diane Duddy, Au.D., Capstone Project
Advisors**

***Abstract: An investigation of real ear insertion gain target values to the Widex®
Sensogram™.***

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Human Subjects Approval: Research reported in this Capstone Research Project was approved by Washington University's Institutional Review Board #201310031 on 10/30/2013.

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Key Words: real ear measures (REMs); Sensogram™; real ear insertion gain (REIG); real ear aided gain (REAG); real ear unaided gain (REUG); hearing aid; channel summation; sound pressure level (SPL)

Abbreviations: ANOVA=analysis of variance; ANSI=American National Standards Institute; APHAB=Abbreviated Profile of Hearing Aid Benefit; BTE=behind-the-ear; CID=Central Institute for the Deaf; dB SPL=decibel sound pressure level; DSP=digital signal processing; EAM=external auditory meatus; HIS=hearing instrument specialist; HRPO=Human Research Protection Office; Hz=Hertz; I/O=input/output; LDLs=loudness discomfort levels; NAL=National Acoustics Laboratories; NAL-NL1=National Acoustics Laboratories-non-linear1; NHS=National Health Service; REAG=real ear aided gain; REAR=real ear aided response; RECDs=real-ear-to-coupler; REDDs=real-ear-to-dial-difference; REIG=real ear insertion gain; REMs=real ear measures; REUG=real ear unaided gain; RIC=receiver-in-the-canal; SNHL=sensorineural hearing loss; SPL=sound pressure level ; TM=tympanic membrane; UK=United Kingdom; VA=Veteran’s Administration; WUSTL=Washington University in St. Louis

Introduction

Real ear measurements (REMs) using probe microphones for the purpose of fitting hearing aids to prescriptive target values have been well established as the gold standard in audiology. REMs were introduced to help overcome individual variability in ear canal volume and resonance. Ever since its introduction to the field, the validity and accuracy of REMs have been extensively researched (Swan & Gatehouse, 1995; Kuk & Ludvigsen, 1997; Aarts & Caffee, 2004; Valente et al, 2006; Aazh & Moore, 2007; Mueller & Picou, 2010; Abrams Chisolm, McManus, & McArdle, 2012). REMs obtained using probe microphone measurements are even included in the best practice recommendations by the American Academy of Audiology, outlined in “Guidelines for the Audiologic Management of Adult Hearing Impairment,” section 3.3 (Valente et al., 2006).

Despite the overwhelming research supporting the use of REMs, only an estimated 23% of fitting audiologists and hearing instrument specialists (HIS) use REMs to fit hearing aids on a routine basis- even though 57% of respondents had access to the appropriate real ear equipment (Kochkin, 2011; Mueller & Picou, 2010). Kochkin (2011) found a number of reasons for this lack of REM utilization, including but not limited to: the length of time needed to perform REMs, the cost of equipment, lack of space for equipment, uncertainty about its impact on patient satisfaction, and lack of proper training. Mueller and Picou (2010) found similar data, in that only 50% of audiologists and HIS that owned real ear equipment used it in the majority of their hearing aid fittings. These researchers also found that only 40% of dispensers (including audiologists) used probe microphone measurements as part of their real ear protocol (Mueller & Picou, 2010).

REMs are necessary, however, to evaluate if the hearing aid frequency-gain response is appropriate for a patient. Swan and Gatehouse (1995) assessed the importance of using REMs to fit hearing aids to prescriptive targets. Specifically, they were interested in two things: first, if real ear insertion gain (REIG) was an accurate measure to find inappropriately fit hearing aids, and second, if REIG can be used to make the fitting changes needed to match target. To investigate their questions, Swan and Gatehouse looked at the precision of fit obtained in a population of 319 new hearing aid users in the United Kingdom (UK). These subjects were fit initially using the UK's National Health Service (NHS) protocol, which did not include REMs or REIG measurements at the time of study. This protocol included audiogram-based adjustments to venting and tubing, subjective adjustments according to patient feedback, and then a follow-up visit for further subjective adjustments. After this protocol concluded, the researchers measured the REIG of every participant using a 65 decibel sound pressure level (dB SPL) composite speech signal on a portable real ear system. Target values were calculated based on threshold data and National Acoustics Laboratories (NAL) prescriptive target algorithms.

If the REIG of a subject was measured within 10 dB of the NAL target values at each frequency from 250 Hertz (Hz) through 4000 Hz, then the hearing aid fit was considered appropriate. Of the original 319 participants in this study, 241 (76%) of the subjects' hearing aids did not have appropriate gain for their hearing losses. Swan and Gatehouse determined that the inclusion of REIG measurements are necessary to ensure an accurate hearing aid fit according to NAL prescriptive target values (1995).

In a similar study by Aazh and Moore (2007), the need for measuring REIG in digital signal processing (DSP) hearing aids was analyzed. This study was more in depth, in that it had four specific research aims. First, the researchers looked at how many hearing aids came within

± 10 dB of National Acoustic Laboratories-non-linear 1 (NAL-NL1) target values. Secondly, Aazh and Moore wanted to find out how close to target values they could get by adjusting the frequency-gain response. Their tertiary goal was to determine how many subjects' hearing aids initially met/failed to meet target, categorizing them by hearing aid and earmold types. Finally, the last study aim was to determine the mismatch between target gain and measured REIG.

This study used the data of 42 ears from 24 participants. The subjects were fit with various levels of technology from three different manufacturers, determined by which hearing aids were most appropriate for their hearing losses. The researchers also investigated if varying types of earmolds (occluding versus non-occluding), earmold materials (acrylic, hypoallergenic, and soft shell), and types of earmold tubing had any effects on the fitting data. Aazh and Moore (2007) found that 64% of the hearing aids failed to meet NAL-NL1 REIG target values, with larger differences found in the high frequencies. After adjusting the gain, 83% of the hearing aids met REIG target values. The researchers also found that individuals with steeply sloping audiometric configurations were more likely to have an inadequately fit hearing aid. The slope of the hearing loss was also significantly correlated with earmold type. Though 17% of hearing aids were unable to reach target gain, the study found that this was due to variance in hearing aid output and was not an effect of REIG (Aazh & Moore, 2007). This data, combined with the Swan and Gatehouse (1995) study, demonstrates that a majority of hearing aid fittings were able to meet target insertion gain when REMs were used.

While hearing aids that are properly fit to prescriptive target values are the gold standard for the clinician, that measure alone has little value if a patient is unsatisfied with the hearing aids. To address this concern, Abrams et al. (2012) fit 22 experienced hearing aid users using both REMs and first fit techniques at the Bay Pines Veterans Administration (VA) Health

Center. There were a variety of manufacturers and hearing aid styles dispensed to the participants, and the Abbreviated Profile of Hearing Aid Benefit (APHAB) was administered prior to testing. Initially, 11 subjects were randomly assigned to be fit using prescriptive targets and REMs, while the other 11 were fit using manufacturer's first fit. After one month of use, participants were re-administered the APHAB, and they were refit with the alternate test condition. One month later, the subjects returned to the VA center and completed the APHAB for a third time and asked to choose which test condition they preferred. The results revealed that 15 (68%) out of the 22 participants preferred the verified prescriptive target fitting over the first fit protocol. Additionally, scores on the APHAB improved with the prescriptive fitting method on three out of four subsections. The only section that saw improved scores for manufacturer's first fit was the aversiveness to sound subtest, which is consistent with the reduced gain seen when using first fits (Abrams et al., 2012). This study's results are consistent with previously mentioned research. Furthermore, it adds the subjective benefit data that is essential to validating REMs as the most accurate protocol for hearing aid fittings.

As evidenced in the above articles, the research in support of REMs is strong as well as plentiful. Regardless of the data, there is still doubt that obtaining REIG is necessary with the advancements in digital hearing aids. Aarts and Caffee (2004) designed a study to compare how close one manufacturer's estimated real ear aided response (REAR) was to the measured REAR. The researchers programmed two identical digital hearing aids set with two different hearing loss configurations. Then, they coupled the hearing aids to 79 ears using temporary foam earmolds with size 13 tubing. They tested both 50 dB SPL and 90 dB SPL inputs to determine if the predicted REAR was or was not significantly different from the measured response. The results showed that only 0-12% (condition dependent) of REAR values were well predicted by the

manufacturer's software (Aarts & Caffee, 2004). This further supports the premise that REMs are necessary for accurate hearing aid fittings.

Since there is still contention regarding the use of REMs, there have been several studies attempting to reconcile verification procedures with actual clinical protocols. Kuk and Ludvigsen (1999) looked at alternative methods of verification with REMs in nonlinear hearing aids. They acknowledge the issue lies with the hearing aid output sound pressure level (SPL), which can vary significantly in most individuals (20-30 dB at some frequencies). Since the target values are based on audiometric thresholds obtained with a different transducer, it is likely that the actual SPL differs vastly from the gain values after matching to target; this problem is eliminated when using probe microphone measurements. The authors state that an alternative to using real-ear-to-dial-differences (REDDs) and real-ear-to-coupler-differences (RECDs) is to measure thresholds through the hearing aid itself; this is called in-situ audiometry. In-situ audiometry may also eliminate some of the variability present in REMs with probe microphone measurements, such as insertion depth, blocked or kinked probe tubes, speaker placement, et cetera. The authors do insist that in-situ audiometry is not a replacement for REMs, but a simpler means to evaluate real ear gain in digital hearing aids (Kuk & Ludvigsen, 1999).

In order to improve the fitting of hearing aids when using proprietary software, Widex® introduced an in-situ test measure called the Sensogram™. The Sensogram™ is essentially a hearing test administered through the hearing aids, and was introduced in 1996 as part of the Senso™ line of digital hearing aids (Ludvigsen & Topholm, 1997; Kuk, 2012). The Sensogram™ measurement was designed to improve digital hearing aid fittings through three specific methods. First, the original Sensogram™ measured thresholds through the hearing aids at low, mid, and high frequency ranges (Ludvigsen & Topholm, 1997). Additionally, target

input-output (I/O) curves were created for each frequency region utilizing estimated loudness discomfort levels (LDLs) from Pascoe (1988). Lastly, the Sensogram™ software was created with the option to manually fine tune specific points in the hearing aid fitting, including a feedback manager (Ludvigsen & Topholm, 1997).

Those three design elements are not the only aspects of the Sensogram™ that make it a viable fitting option, according to Widex®. Kuk (2012) argues that a Sensogram™ is more accurate than an audiogram for calculating prescriptive gain because the software is calibrated differently from an audiometer. Supra-aural headphones and insert earphones for audiometric evaluation are calibrated with standard 6cc and 2cc couplers, respectively. Alternatively, the Sensogram™ is calibrated with a 711, 2cc coupler which accounts for both the average volume and impedance of the middle ear system. Though this is more accurate than the standard 2cc coupler calibration, the Sensogram™ may differ significantly from the calibration due to acoustic variables presented by the earmold fit and type, tubing, and venting. Kuk (2012) further elaborates that these differences are acceptable as the Sensogram™ is used only to determine hearing aid gain amounts. This information creates questions about the reliability and validity of Sensogram™ measurements. For the purposes of the present study, reliability is defined as the ability to obtain the same or similar results on every subsequent test; validity means the test is measuring what it claims to test.

Since Widex® states that the Sensogram™ is a threshold measurement, DiGiovanni and Pratt (2010) investigated the direct relationship between Sensogram™ and audiometric thresholds. In a subject sample of twenty individuals (including ten normal hearing controls), the researchers found that there were statistically significant differences between audiometric thresholds and Sensogram™ thresholds. The largest differences were found in the mid-

frequency region, especially at 1000 and 2000 Hz, with the Sensogram™ thresholds measuring less than the audiometric thresholds. DiGiovanni and Pratt (2010) state this lower threshold may lead to under amplification at important frequencies, and therefore cannot be used as a replacement for REMs. The researchers do note that Sensogram™ measurements may estimate the acoustic changes based on venting and earmolds, and consequently might represent a shortcut in REMs (DiGiovanni & Pratt, 2010).

There have been other studies addressing the issue of test-retest reliability of in-situ measures. Smith-Olinde Nicholson, Chivers, Highley, and Williams (2006) specifically examined the reliability of Sensogram™ measures in a Widex® behind-the-ear (BTE) hearing aid (Diva™ SD-9). This study tested Sensogram™ thresholds of forty-three participants at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. Thresholds were measured twice using temporary foam earmolds, which were removed and re-inserted between trials. The researchers found the average change in threshold between trials was less than 1 dB at the tested frequencies. The lowest percentage found for test-retest reliability was 93% at 4000 Hz, but for 1000 to 2000 Hz there was 100% reliability and 98% at 500 Hz (Smith-Olinde et al, 2006). The results from DiGiovanni and Pratt (2010) and Smith-Olinde (2006) suggest that Sensogram™ thresholds may be a beneficial tool when fitting Widex® hearing aids, though they are not appropriate for documenting true audiometric thresholds.

The Sensogram™ may be a reliable test, but there is little research comparing the resulting hearing aid gain to prescriptive target values. If audiologists are to consider in-situ audiometry as an alternative or shortcut to REMs and/or probe microphone measurements, this evidentiary support is much needed. This led to the current study's research question: Do Sensogram™ measures adjust gain closer to target REIG values than using manufacturer's first

fit? To address this question, four test conditions were designed and measured on two different Widex® hearing aid models (Dream™ 220 Fusion and Dream™ 440 Fusion). All test conditions were compared to NAL-NL1 prescriptive target values. The first test condition measured was the four channel, basic Sensogram™. The second condition tested was the expanded, 14 channel Sensogram™. The third test condition was a simulated expanded Sensogram™, adjusted to match the participants' audiometric thresholds. Finally, the fourth test condition was first fit of the hearing aid. The test conditions were measured in a random order, and all conditions were compared to NAL-NL1 prescriptive target values. Test conditions two through four were also compared to the gain measures of first fit (condition one).

Methods

Participants

Twelve participants were recruited from Washington University School of Medicine's Division of Adult Audiology utilizing telephone, letter, and electronic mail (email) scripts. There were seven male and five female participants in this study. The mean age of participants was 67 years old. Prior to testing, participants signed an Informed Consent Document; all scripts and documents received approval from the Washington University in St. Louis Human Research Protection Office (WUSTL-HRPO). Eligibility was determined by reviewing the age of potential subjects and the most recent audiogram. Additionally, a clinical hearing aid database on the Washington University secure server- where individuals are entered whenever a hearing aid is dispensed- was accessed to find eligible participants. Inclusion criteria for potential participants in this study were as follows: (a) participant must be eighteen years or older, (b) participant must have sensorineural hearing loss (SNHL), (c) participant cannot have hearing thresholds greater than 70 dB HL, (d) participant must be a native English speaker, and (e)

participant must have clear external auditory meatuses (EAM) and intact tympanic membranes (TM).

Equipment

One pair of Widex® Dream™ 220 Fusion receiver-in-the-canal (RIC) and Widex® Dream™ 440 Fusion RIC hearing aids with M receivers and size two earwires were used for each test session. Participants were fit with the appropriate size instant double ear-tip for their EAM (small, medium, or large) with a vent size of 0.7mm.

The Frye Fonix® 8000 Hearing Aid Test System (software version 2.41) was used for real ear probe measures in this study. The Frye Fonix® 8000 sound field speaker and probe microphone were calibrated (per Frye recommendations) prior to the start of this study to ensure accurate measures (Frye Electronics Inc., 2013).

Procedures

All subjects were assigned to every test condition. To control for bias, the order in which test conditions were completed, the ear to be tested first, and the hearing aid model to be tested first were randomly assigned. Randomization was performed prior to testing and using Randomizer.org (Urbaniak and Plous, 2013). All study procedures were performed in a sound booth at Central Institute for the Deaf (CID), which meets American National Standards Institute (ANSI) qualifications.

Prior to testing on each day, electroacoustic analysis using ANSI S3.22 2003 standards was performed with hearing aids at full-on gain (see figure 1). No significant changes in hearing aid output were found prior to any test session. Additionally, each day new power one® size 312 batteries were inserted into all hearing aids to ensure the most accurate test results.

After obtaining consent, otoscopy and pure tone air conduction audiometry was performed to confirm that the EAM was clear and that hearing thresholds did not exceed 70 dB HL (see figure 2). Pure-tone air conduction thresholds were tested using a GSI-61 Clinical Audiometer (calibrated to ANSI S3.6 1996 standards) and TDH 50 supra-aural headphones. Since all participants had established SNHL and no significant threshold shifts were found, bone conduction testing was not performed on any subject.

Once pure tone thresholds were obtained, the data were entered into the Frye Fonix® 8000 system. Channel-corrected target values (five channels for the Dream™ 220 Fusion and fifteen channels for the Dream™ 440 Fusion) were printed and documented for data analysis (see figure 3). Target values were not corrected for binaural summation, as this study was only analyzing monaural data. The pure tone thresholds were also entered into the NOAH hearing aid software database and saved. Before testing began, the hearing aids were coupled to each participant's ear using Widex® instant double ear-tips. Initially, appropriate fit was judged by visual occlusion of the EAM by the double ear-tip when the first bend of the earwire was even with the tragus (as seen in figure 4).

All subjects were placed 12 inches from the Frye speaker, according to the Frye Fonix® 8000 manual recommendations (Frye Electronics Inc., 2013). To ensure the consistency of all measures, a length of string (measuring 12" from edge of speaker) was attached to the loudspeaker and the participants were placed in a non-adjustable chair in the calibrated center of the sound booth (see figure 5). The string was then aligned with the top of the pinna. The probe microphone and reference microphone were then coupled to the subject's ear. The probe microphone tube was inserted and the real ear unaided gain (REUG) was measured (see figure 6). This study used an REUG measurement of 0 dB SPL at 6000 Hz (± 3 dB), as shown in figure

7, to guarantee that the probe tube was 5-6mm from the TM (Baum and Valente, 2009). There was one exception in subject 11 (right ear), whose anatomy created a large resonance at 6000 Hz, so the standard practice of inserting the probe microphone tube 30mm was used instead.

Once an appropriate REUG measurement was obtained, the probe tube was taped to the lobule with medical grade paper tape to prevent movement upon hearing aid insertion, as shown in figure 8. After the probe tube was taped in place, the REUG was measured again to ensure no displacement had occurred. The probe tube was removed prior to each test condition to preclude any unaccounted sources of leakage (see figure 9). The hearing aid was then inserted into the ear until the EAM was occluded by the double ear-tip.

Once the probe tube was removed, the fit of the ear-tip was confirmed. Next, the hearing aid was turned on and connected to Widex® Compass™ GPS version 1.2 via NOAH version 3 software using the USB Link. Next, the receiver strength and type of ear-tip were confirmed in the software, which automatically calculates the vent size and effect. The parameters were as follows: instant double ear-tip, unilateral fit, M receiver, average RECDs, and a 0.7mm vent size. Acclimatization was turned off. Once the participant's pure tone thresholds were loaded into Compass™ GPS, a feedback test was immediately performed in all test conditions to ensure the receiver and ear-tip were coupled properly. Preceding the feedback test, subjects were instructed to sit as still and silently as possible.

After REUG was measured and the probe tube removed, the hearing aid parameters were entered into Compass™ GPS. The first condition tested the basic Sensogram™ following the feedback test, which measures the in-situ thresholds of four frequencies: 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. The Sensogram™ was measured using the Modified Hughson-Westlake procedure, per manufacturer recommendations (Carhart and Jerger, 1959). This also guaranteed

consistency of test measures between subjects. Participants were instructed to say “yes” when the Sensogram™ tone was heard. After the threshold levels were confirmed for each frequency, the fitting was saved into the hearing aid and Compass™ GPS software was exited. Next, the hearing aid was removed and the probe tube was inserted into the EAM. The sound field speaker was leveled and REUG was measured to confirm probe tip placement. The hearing aid was placed back into the ear (figure 4), and real ear aided gain (REAG) was then measured at 65 dB SPL with a digital speech signal, which prevents the hearing aid from going into compression mode (Frye Electronics, Inc.). The REIG, which is automatically calculated by the Frye Fonix® 8000 software, numerical data were printed in order to compare to the target REIG data, and the hearing aid was removed (figures 10-11).

After each test condition, the hearing aids were connected to the Compass™ GPS software and the devices were reset. After resetting the hearing aids, the software was reconnected for the next test condition.

For test condition two, the first measure collected was the REUG after the speaker was leveled. The probe tube was removed, and the hearing aid was inserted into the ear canal. The hearing aid was connected to Compass™ GPS through NOAH version 3, and set for an instant double ear-tip with an M receiver. The feedback test was performed and appropriate maximum available gain was confirmed. Next, the 14 channel Sensogram™ was measured. The subjects were instructed to say “yes” when they heard a tone, and thresholds were measured using the Modified Hughson-Westlake procedure (Carhart and Jerger, 1959). The Sensogram™ measurements were saved into Compass™ GPS, and the hearing aid was disconnected from the software. The hearing aid was removed and the probe tube was inserted. The speaker was

leveled and REUG was measured (figure 7). The hearing aid was reinserted and REAG was measured, then the calculated REIG was printed (figures 4 & 10).

The third test condition comprised of a simulated expanded Sensogram™. This condition was designed to evaluate how close to target the Sensogram™ can get simply based on the subjects' audiometric thresholds. Once the hearing aid was connected to Compass™ GPS, the device was reset and the appropriate pre-fitting conditions were selected. After the feedback test was performed, the expanded Sensogram™ was opened. The levels at each of the 14 frequency handles (250 Hz, 350 Hz, 500 Hz, 630 Hz, 800 Hz, 1000 Hz, 1250 Hz, 1600 Hz, 2000 Hz, 2500 Hz, 3200 Hz, 4000 Hz, 6000 Hz, and 8000 Hz) were adjusted to match each subject's audiometric thresholds as closely as possible.

Once the fitting based on the simulated, expanded Sensogram™ was completed, the fitting was saved and the software was exited; the hearing aid was removed from the ear. The probe microphone tube was inserted into the EAM and the speaker was leveled. Once REUG was performed, the hearing aid was placed back into the canal (figures 4, 7, & 8). REAG was measured, and then the REIG data were printed and stored for analysis (figure 11). The probe tube was removed from the ear canal (figure 9).

For the fourth and final test condition, manufacturer's first fit was measured. The hearing aid was reconnected to the Compass™ GPS software, and it was reset to erase the previous condition's data. Once the pre-fitting conditions were saved, the software automatically estimates the fitting data based on the audiogram. After that step was completed, a feedback test was performed to ensure maximum available gain. The fit was then saved, the software was closed, and the hearing aid was removed. The probe tube was then placed into the EAM, the speaker leveled, and REUG measured. The hearing aid was inserted into the canal, and REAG

measured (figures 4 & 11). After the test finished, the REIG numerical data were printed and stored.

Each aforementioned test condition was performed on each individual hearing aid and on each ear. There was one exception in subject three, who did not complete any of the test conditions for the Dream™ 440 Fusion in the left ear; these measures were not completed due to a device failure. That hearing aid was sent back to Widex®, and an alternate Dream™ 440 Fusion hearing aid was used for the other nine participants. The conditions were measured identically for each subject, ear, and device. The order of conditions, ears, and hearing aids was predetermined and randomized as described previously. To ensure the data from each condition was documented accurately, each target and REIG printout were labeled immediately and stored in the order of printing to be cross-checked; no labelling errors were identified during or after each test session.

Results

A five-way repeated measures analysis of variance (ANOVA) was performed examining differences between gain (measured and target), device (220 Fusion and 440 Fusion), condition (basic Sensogram™, expanded Sensogram™, simulated Sensogram™, and first fit), ear (right and left), and frequency (500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz). Results revealed mean differences for the main effect of condition ($F(1,3)=13.1$; $p<0.001$) and frequency ($F(1,6)=54.8$; $p<0.001$), the two-factor interaction of gain \times condition ($F(1,3)=13.1$; $p<0.001$), gain \times device ($F(1,1)=7.7$; $p<0.02$), condition \times device ($F(1,3)=3.0$; $p<0.05$), and the three-factor interaction of gain \times condition \times device ($F(1,3)=3.0$; $p<0.05$) were statistically significant.

It is important to note that only eleven of the twelve subjects were included in the primary data analysis. One subject did not complete all test conditions and was therefore excluded from the ANOVA, which requires complete data for each variable.

Condition One

In the basic Sensogram™ with the Dream™ 220 Fusion, pairwise comparisons revealed mean differences between target REIG and measured data at 1000 Hz ($p < 0.05$), 3000 Hz ($p < 0.05$), 4000 Hz ($p < 0.001$), 6000 Hz ($p < 0.05$), and 8000 Hz ($p < 0.001$) were statistically significant. In the basic Sensogram™ with the Dream™ 440 Fusion, pairwise comparisons revealed mean differences at 4000 Hz ($p < 0.05$), 6000 Hz ($p < 0.05$), and 8000 Hz ($p < 0.001$) were statistically significant.

Condition Two

In the expanded Sensogram™ with the Dream™ 220 Fusion, pairwise comparisons revealed mean differences at 500 Hz ($p < 0.05$), 3000 Hz ($p < 0.05$), 4000 Hz ($p < 0.001$), 6000 Hz ($p < 0.05$), and 8000 Hz ($p < 0.001$) were statistically significant. In the expanded Sensogram™ with the Dream™ 440 Fusion, pairwise comparisons revealed mean differences at 4000 Hz ($p < 0.05$), 6000 Hz ($p < 0.05$), and 8000 Hz ($p < 0.001$) were statistically significant.

Condition Three

In the simulated expanded Sensogram™ in the Dream™ 220 Fusion, pairwise comparisons revealed mean differences at 500 Hz ($p < 0.05$), 1000 Hz ($p < 0.05$), 2000 Hz ($p < 0.05$), 3000 Hz ($p < 0.001$), 4000 Hz ($p < 0.001$), 6000 Hz ($p < 0.05$), and 8000 Hz ($p < 0.001$) were statistically significant. In the simulated expanded Sensogram™ in the Dream™ 440 Fusion, pairwise comparisons revealed mean differences at 500 Hz ($p < 0.05$), 4000 Hz ($p < 0.05$), 6000 Hz ($p < 0.05$), and 8000 Hz ($p < 0.001$) were statistically significant.

Condition Four

In the manufacturer's first fit in the Dream™ 220 Fusion, pairwise comparisons revealed mean differences at 500 Hz ($p<0.001$), 1000 Hz ($p<0.05$), 3000 Hz ($p<0.05$), 4000 Hz ($p<0.001$), 6000 Hz ($p<0.05$), and 8000 Hz ($p<0.001$) were statistically significant. In the manufacturer's first fit in the Dream™ 440 Fusion, pairwise comparisons revealed mean differences at 500 Hz ($p<0.001$), 4000 Hz ($p<0.05$), 6000 Hz ($p<0.05$), and 8000 Hz ($p<0.001$) were statistically significant.

Discussion

Results revealed statistically significant differences between the NAL-NL1 target data and measured REIG data at multiple frequencies in each test condition for both the Dream™ 220 Fusion and Dream™ 440 Fusion hearing aids (see figures 12-13). When comparing the statistical analysis of the basic Sensogram™ (condition one) and the expanded Sensogram™ (condition two), there were no significant differences between the conditions in either the Dream™ 220 Fusion or Dream™ 440 Fusion (see figures 14-15). However, there were differences in REIG at the low frequencies for the Dream™ 220 Fusion based on test condition (see figure 16). In condition one, there was a significant difference at 1000 Hz that was not seen in the second condition. Additionally, there was a significant difference at 500 Hz for condition two that was absent in the first condition. In total, the REIG for the Dream™ 220 Fusion hearing aids differed significantly from the target data at five of the seven test frequencies for condition one (1000 Hz, 3000 Hz, 4000hz, 6000 Hz, and 8000 Hz) and condition two (500 Hz, 3000 Hz, 4000hz, 6000 Hz, and 8000 Hz). In comparison, the Dream™ 440 Fusion only had statistically significant differences between the NAL-NL1 target data and the measured REIG at three (4000 Hz, 6000 Hz, and 8000 Hz) of the seven test frequencies in conditions one and two. It is

important to note that, comparable to the Aazh and Moore (2007) results, the measured REIG at 4000 Hz, 6000 Hz, and 8000 Hz were significantly different from NAL-NL1 target values in all four conditions with the both the Dream™ 220 Fusion and the Dream™ 440 Fusion hearing aids. This data differs from previous research which found that the Sensogram™ is most variable in the mid-frequency region (DiGiovanni & Pratt, 2010).

There were greater differences seen between NAL-NL1 target data and measured REIG in conditions three and four (see figures 17-18). For the Dream™ 220 Fusion hearing aids in condition three (simulated Sensogram™), statistically significant differences were found at every test frequency (figure 17). Additionally, the Dream™ 220 Fusion hearing aids in the fourth test condition (first fit) were found to be significantly different between target data and measured REIG data at every test frequency except 2000 Hz (see figure 18). Similar results were noted in the Dream™ 440 Fusion hearing aids, in that condition three REIG data differed significantly from target data at more frequencies than in condition four. In condition three, the differences were statistically significant at 500 Hz, 1000 Hz, 4000 Hz, 6000 Hz, and 8000 Hz (figure 17). In condition four, REIG data for the Dream™ 440 Fusion hearing aids were significantly different from target at 500 Hz, 4000 Hz, 6000 Hz, and 8000 Hz. Furthermore, a comparison of conditions three and four to conditions one and two in the Dream™ 440 Fusion revealed an improvement in accuracy by only one to two frequencies for either hearing aid level (see figures 13 & 19).

When comparing the statistical analysis overall, the Dream™ 440 Fusion hearing aids met NAL-NL1 target values at more frequencies than the Dream™ 220 Fusion hearing aids in all four test conditions as shown in figures 14-18. Additionally, measured REIG data at 4000 Hz, 6000 Hz, and 8000 Hz were significantly different from NAL-NL1 target data in every test

condition with both the Dream™ 220 Fusion and Dream™ 440 Fusion hearing aids (figures 12-13). It is important to note that REIG data at 2000 Hz was not significantly different from target data in all conditions except for the Dream™ 220 Fusion in condition three (figure 17). The measured REIG at 500 Hz was also significantly different from target values for the Dream™ 220 Fusion and Dream™ 440 Fusion in both the simulated Sensogram™ and manufacturer's first fit (conditions three and four). However in the first two conditions, a significant difference was only noted at 500 Hz in the Dream™ 220 Fusion hearing aids in condition two.

Even though there were statistically significant differences documented at multiple frequencies in each condition and with both levels of technology, the mean measured REIG values were still within 10 dB of the target values, which would be considered an accurate fit according to previous research (Swan and Gatehouse, 1995; Aazh and Moore, 2007). However, it is important to state that there were significant standard deviations within the measured REIG at multiple frequencies in all test conditions with both hearing aids.

A possible limitation of the present study is the use of only one manufacturer's hearing aids, even though other manufacturers have similar in-situ technology. Because this research was completed as a Capstone Project, it was not feasible to test multiple hearing aid manufacturers in this study design. Another possible shortcoming is the use of only RIC-style hearing aids; it is possible that the receiver placement (in-the-ear versus behind-the-ear) may alter in-situ thresholds. Further limitations may be due to the small number of subjects and the inclusion of only SNHL in the current study. Additionally, the use of instant double ear-tips rather than custom molds may be a limitation. Due to the time constraints mentioned above, it was not possible to make custom earmolds for each participant. Also, instant double ear-tips were chosen for use with the research hearing aids to ensure the same acoustic properties were

present for every test subject, in every ear. Based on the feedback test results from the current study, it is the author's opinion that the ear-tips did not significantly impact the results of this study.

Further research on the Widex® Sensogram™ using various ear-tips (open dome, closed dome, and custom earmold) and bilateral hearing aid fittings may provide valuable clinical information. Also, research utilizing subjects with various magnitudes and types (conductive, mixed, and sensorineural) of hearing loss could provide relevant data. Additionally, research comparing multiple manufacturers and styles of hearing aids is necessary to properly assess the overall validity and accuracy of in-situ thresholds.

Conclusions

The current study found that the expanded Sensogram™ does not create a fitting that is closer to target than the basic Sensogram™, regardless of the level of technology. The analysis did reveal that a measured Sensogram™ is more precise than first fit or simulated measures, though the improvement was only seen at one to two frequencies. Moreover, the data also shows that simulating a Sensogram™ by matching thresholds to the audiogram is less accurate than using manufacturer's first fit. Although measuring the Sensogram™ did result in mean REIG data within 10 dB SPL of target data, the REIG was still significantly different from the NAL-NL1 target values. Therefore, the Sensogram™ cannot be used alone for fitting hearing aids. Since the measured Sensogram™ only improves proximity to NAL-NL1 target values at a few frequencies, it may represent a viable, but not crucial, shortcut for fine tuning with REMs. The results from the current study reiterate the importance of using REMs with probe tube measures for an accurate hearing aid fitting, even when utilizing in-situ measurements.

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Figure 1. Frye Fonix® 8000 setup for electroacoustic analysis of Widex Dream™ 220/440 Fusion hearing aids.

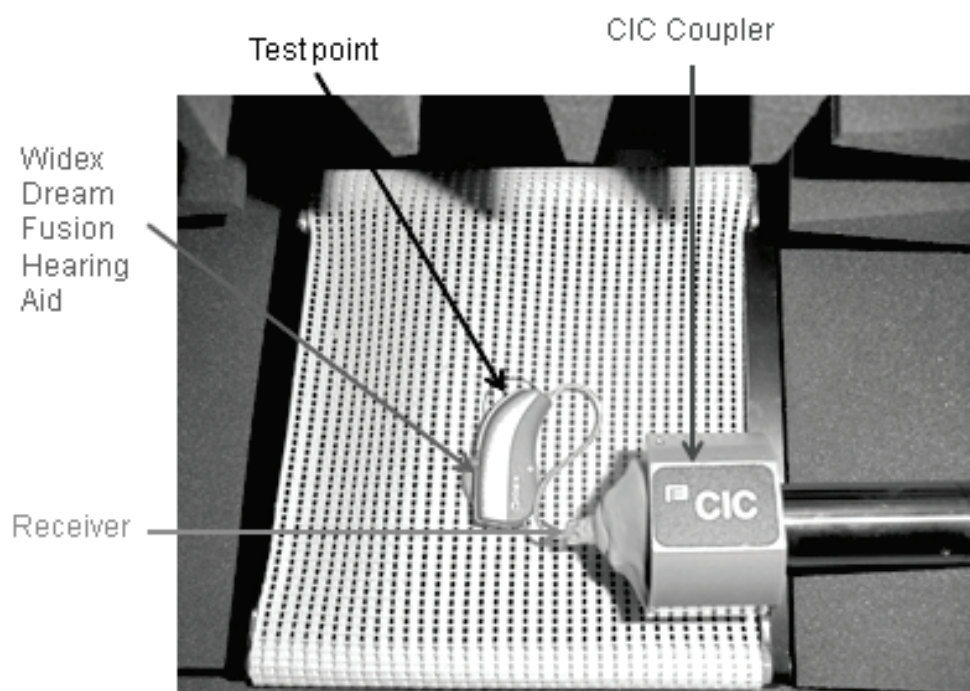


Figure 2. Audiogram reporting the mean and ± 1 SD for hearing thresholds in the right ear (o) and left ear (x).

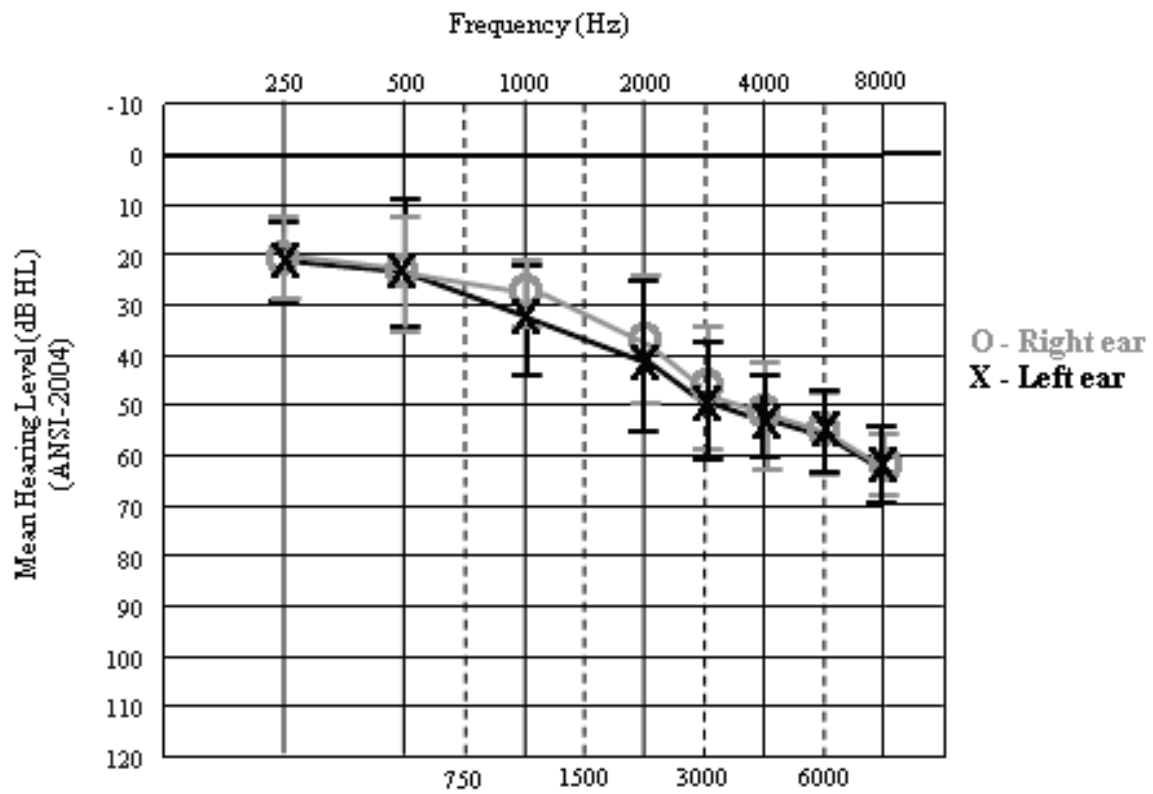


Figure 3. Insertion gain target data for left and right ears, corrected for channel summation.

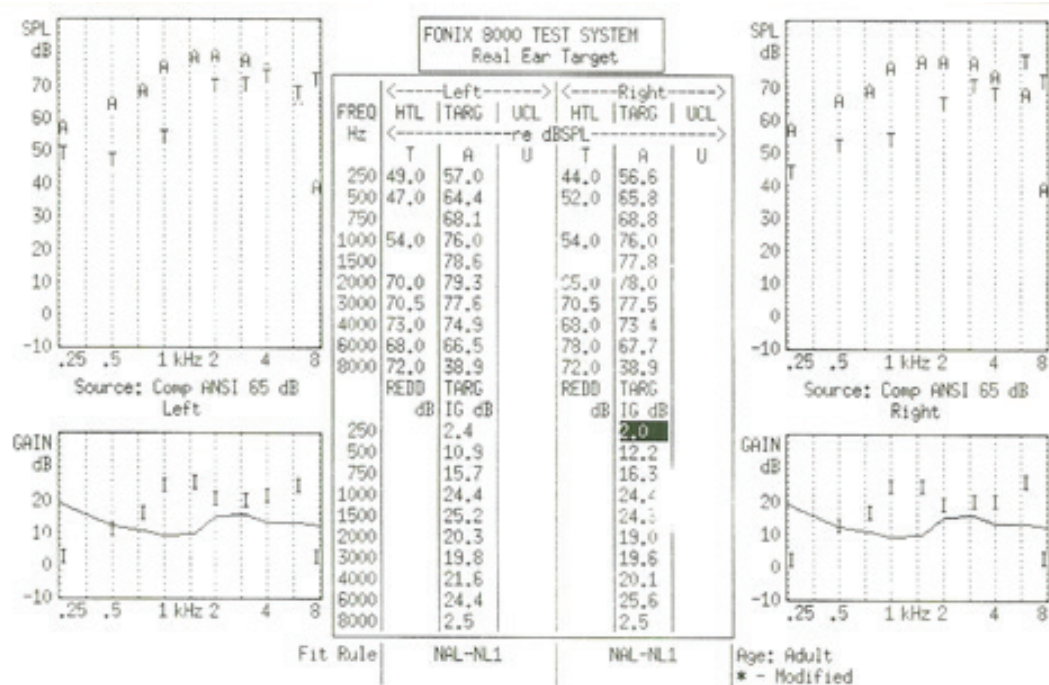


Figure 4. Shown is the fit of the hearing aid, as well as the setup for REAG with both the hearing aid receiver and probe tube inserted into the EAM.

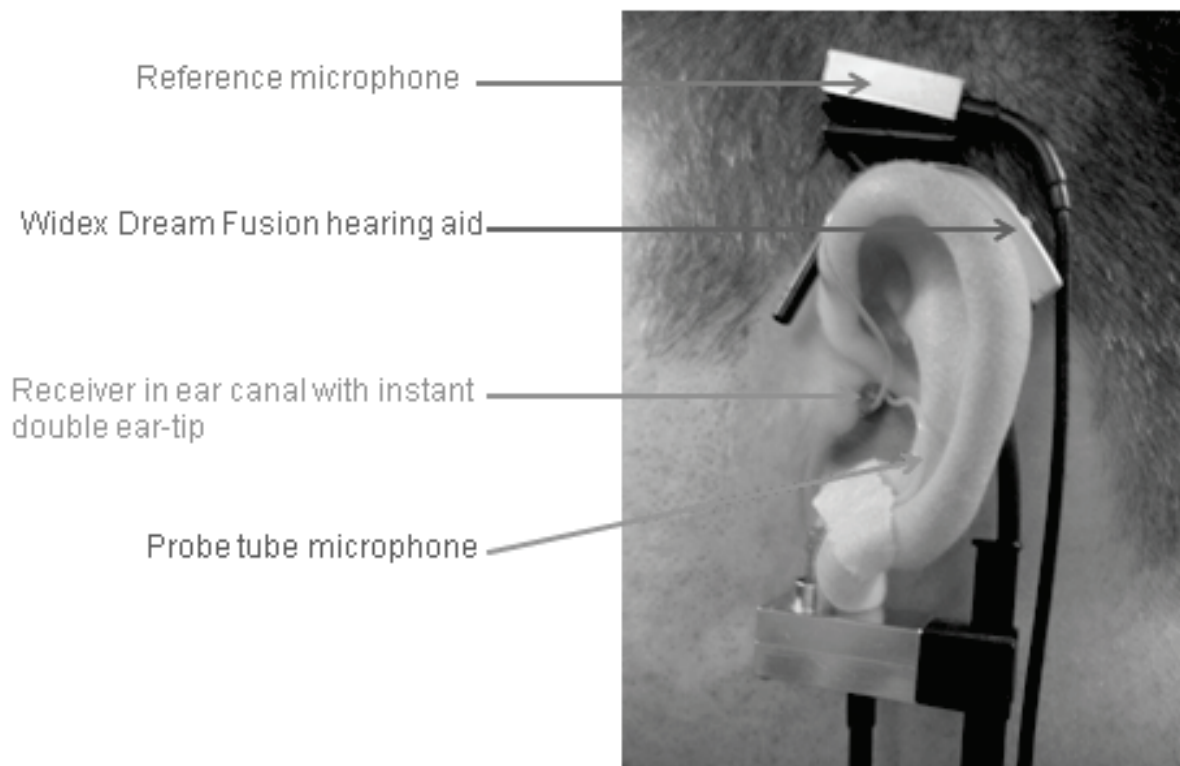


Figure 5. Booth setup with speaker and subject placement.

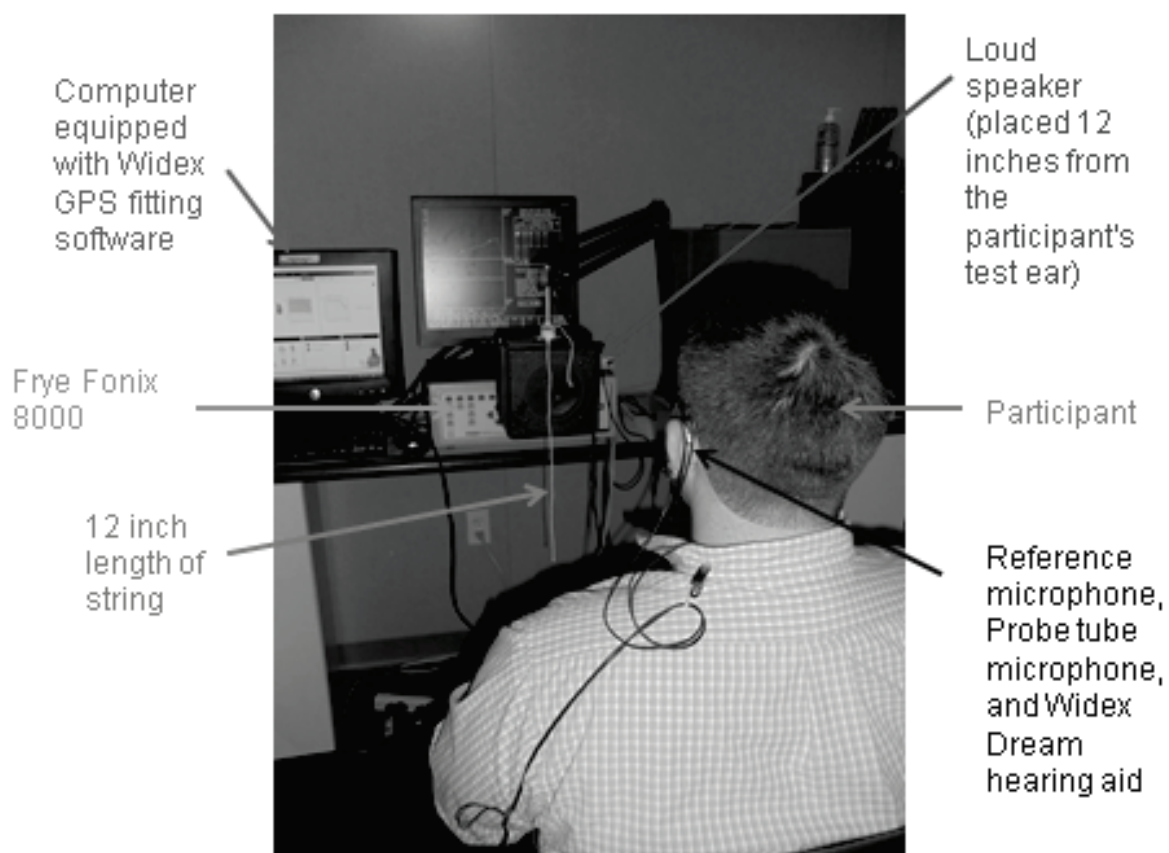


Figure 6. Setup for REUG with an on-ear reference microphone.

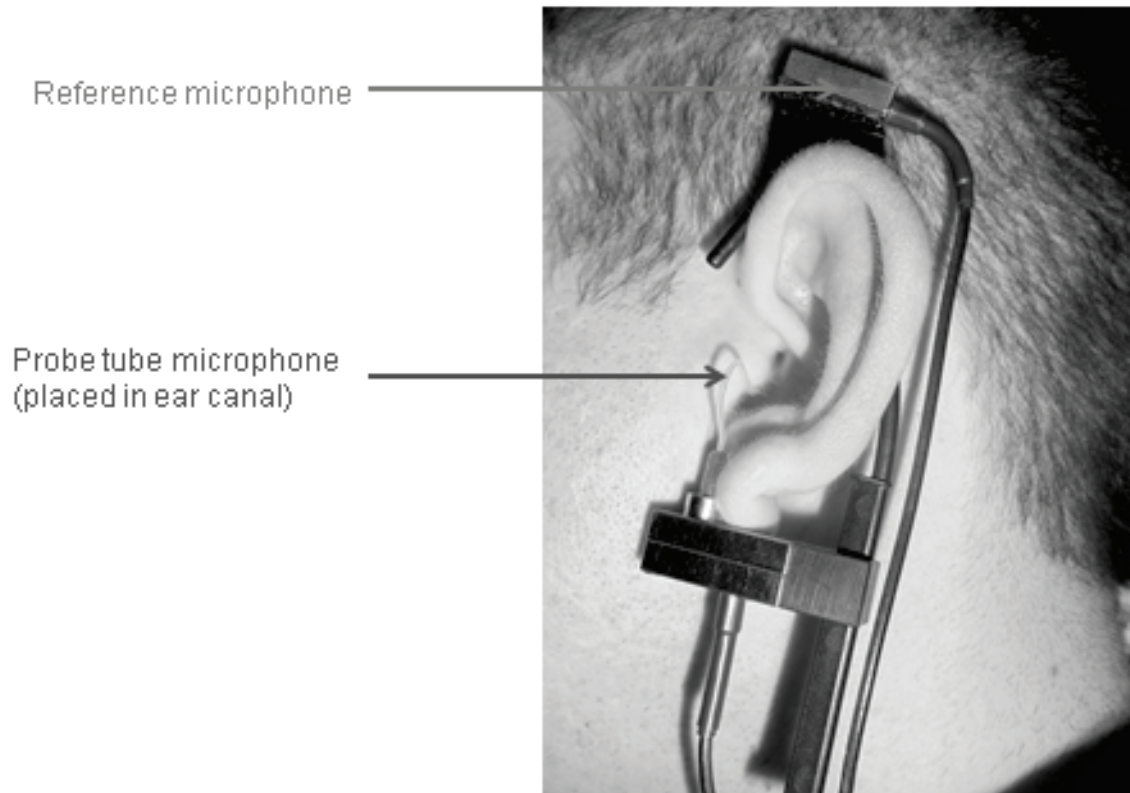


Figure 7. REUG curve with approximately 0 dB SPL of gain at 6000 Hz.

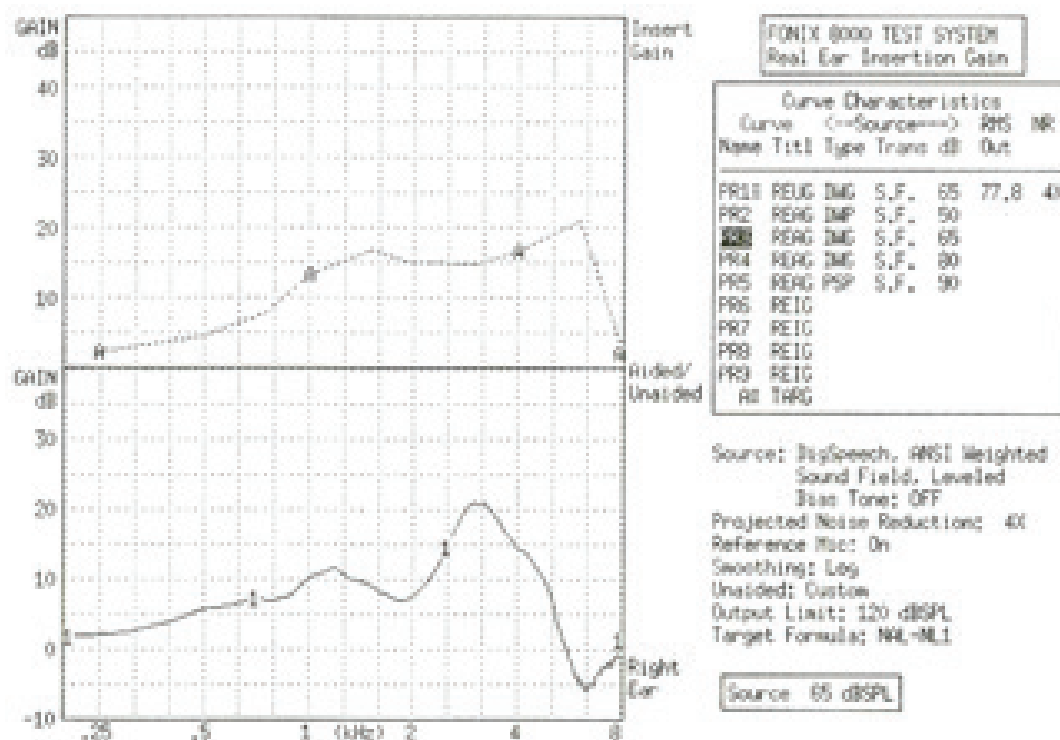


Figure 8. Setup for REUG shown after probe tube was taped to the lobule.

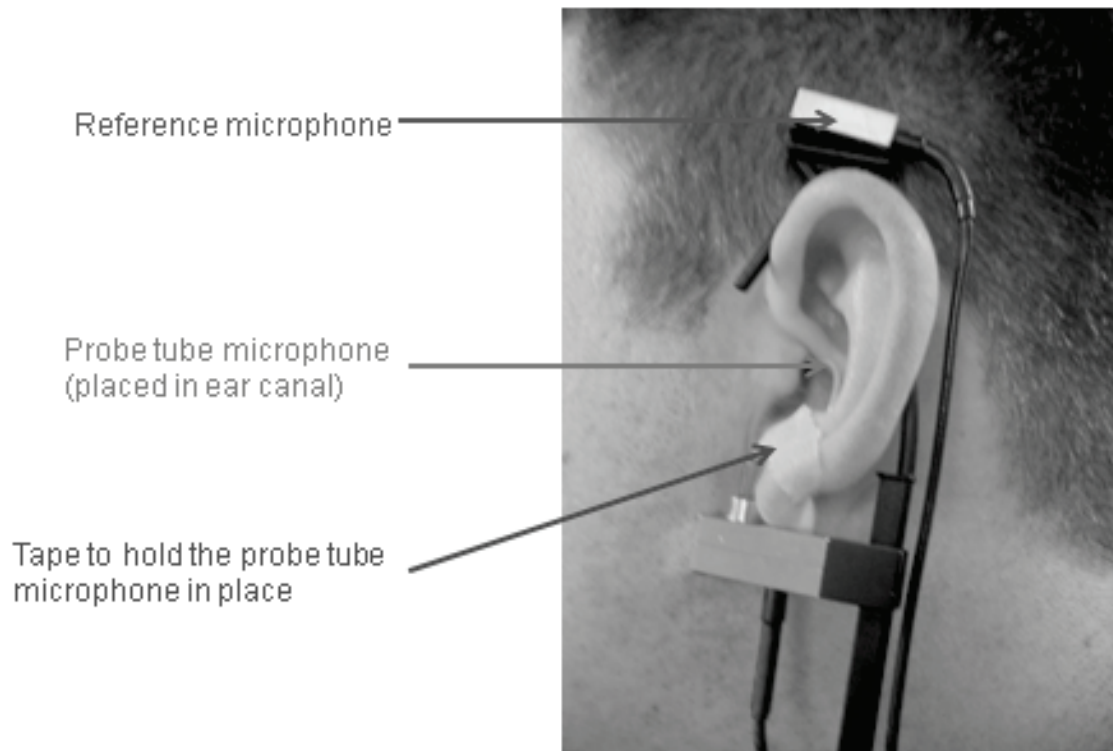


Figure 9. Probe tube remained taped to the lobule after removal from the EAM.



Figure 10. REAG curve after a 65 dB SPL input of ANSI weighted digital speech noise.

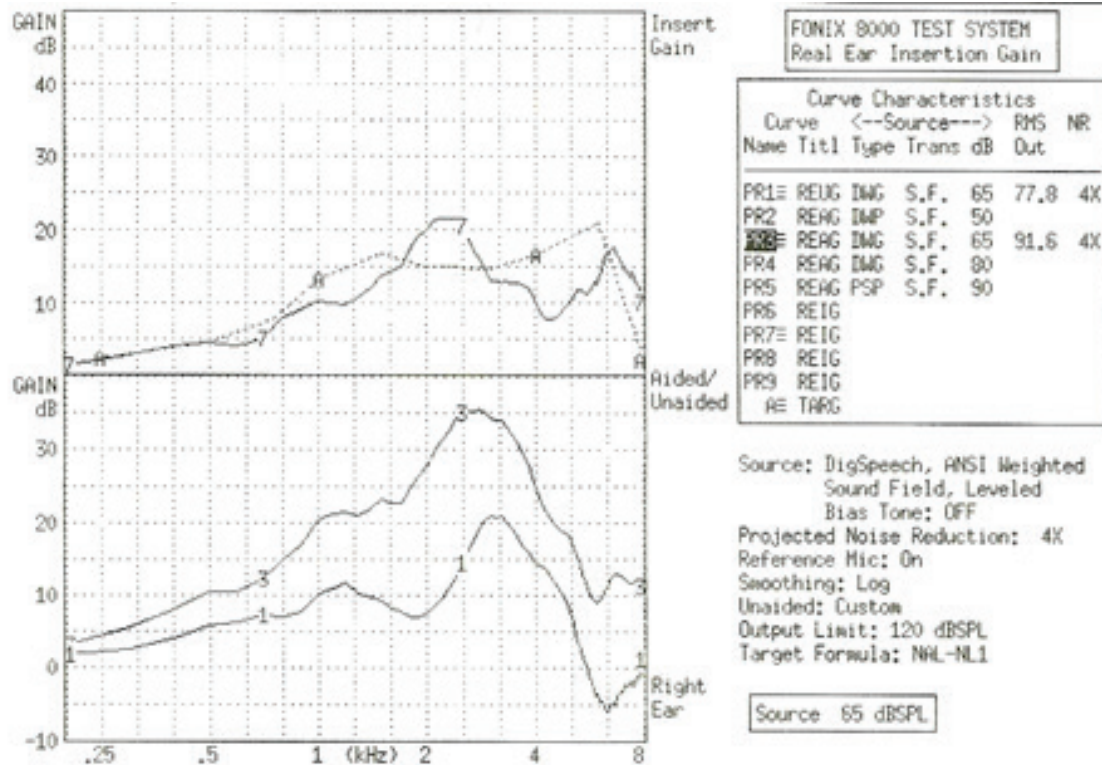


Figure 11. REIG numerical output data in dB SPL.

		Probe Right REIG3			
Freq Hz	Gain dB	Freq Hz	Gain dB	Freq Hz	Gain dB
200	5.9	2100	38.0	4100	33.0
300	9.1	2200	39.2	4200	33.2
400	13.8	2300	41.0	4300	33.0
500	17.8	2400	41.5	4400	33.4
600	21.6	2500	41.3	4500	34.0
700	24.0	2600	41.7	4600	34.0
800	26.2	2700	42.2	4700	33.2
900	27.7	2800	40.7	4800	32.2
1000	28.8	2900	40.0	4900	31.6
1100	29.2	3000	40.1	5000	31.1
1200	29.3	3100	39.7	5100	30.7
1300	29.7	3200	38.5	5200	30.1
1400	30.5	3300	36.8	5300	29.1
1500	30.8	3400	35.9	5400	28.3
1600	30.8	3500	35.0	5500	27.7
1700	31.6	3600	34.0	5600	27.1
1800	33.1	3700	32.5	5700	26.6
1900	34.6	3800	31.7	5800	25.9
2000	36.8	3900	31.7	5900	24.8
		4000	32.4	6000	24.3
				8000	12.3

FONIX 8000 TEST SYSTEM Real Ear Insertion Gain					
Curve Characteristics					
Curve	Source	Type	Trans	RMS	NR
Name	Titl	Type	Trans	dB	Out
PR14	REIG	DWG	S.F.	65	75.5 4X
PR2	REIG	DMP	S.F.	50	
PR3	REIG	DWG	S.F.	65	99.7 4X
PR4	REIG	DMP	S.F.	80	
PR5	REIG	PSP	S.F.	90	
PR6	REIG				
PR7	REIG				
PR8	REIG				
PR9	REIG				
AE	TARG				

Source: DigSpeech, ANSI Weighted
Sound Field, Levelled
Bias Tone: OFF
Projected Noise Reduction: 4X
Reference Mic: On
Smoother: Log
Unaided: Custom
Output Limit: 120 dB SPL
Target Formula: NAL-NL1

Right
Ear

Source 65 dB SPL

Figure 12. Mean NAL-NL1 target values compared to the mean measured REIG and ± 1 SD across conditions in the in the Dream™ 220 Fusion hearing aids.

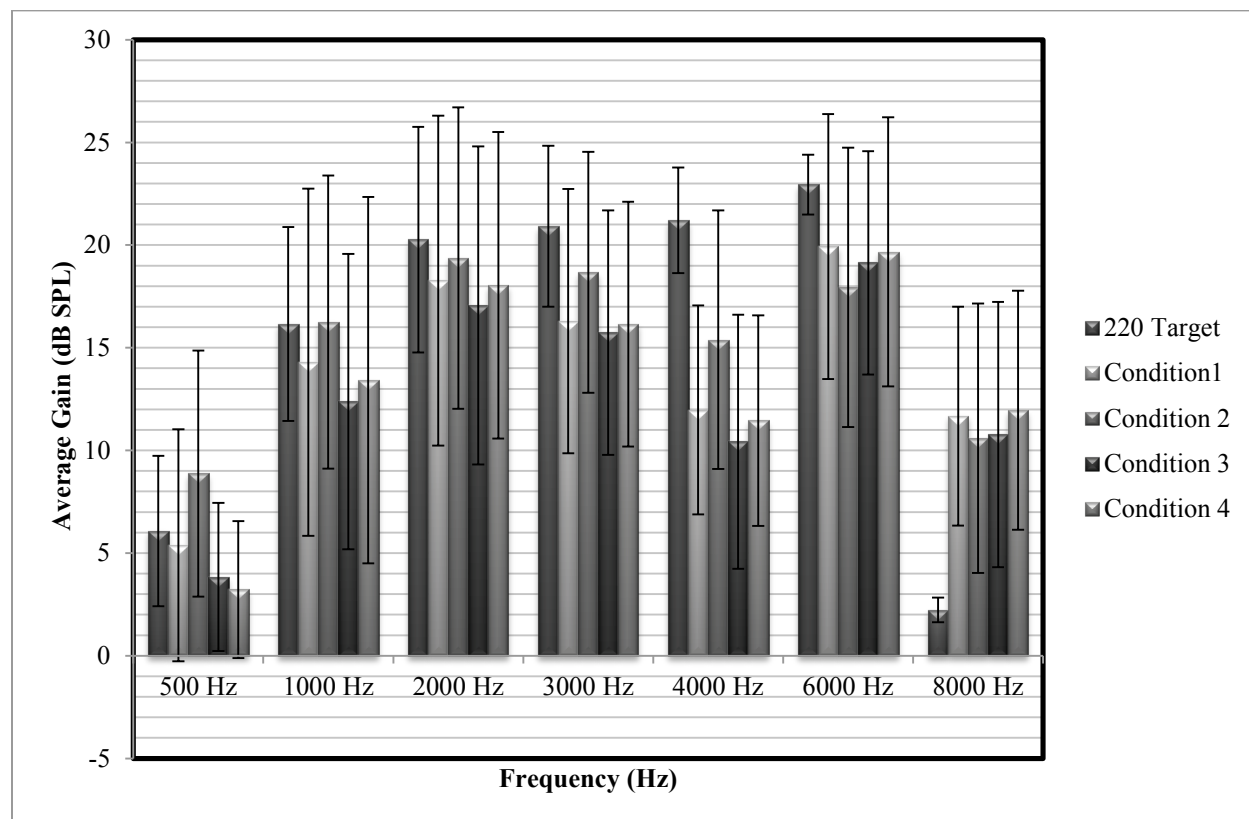


Figure 13. Mean NAL-NL1 target values compared to the mean measured REIG and ± 1 SD across conditions in the in the Dream™ 440 Fusion hearing aids.

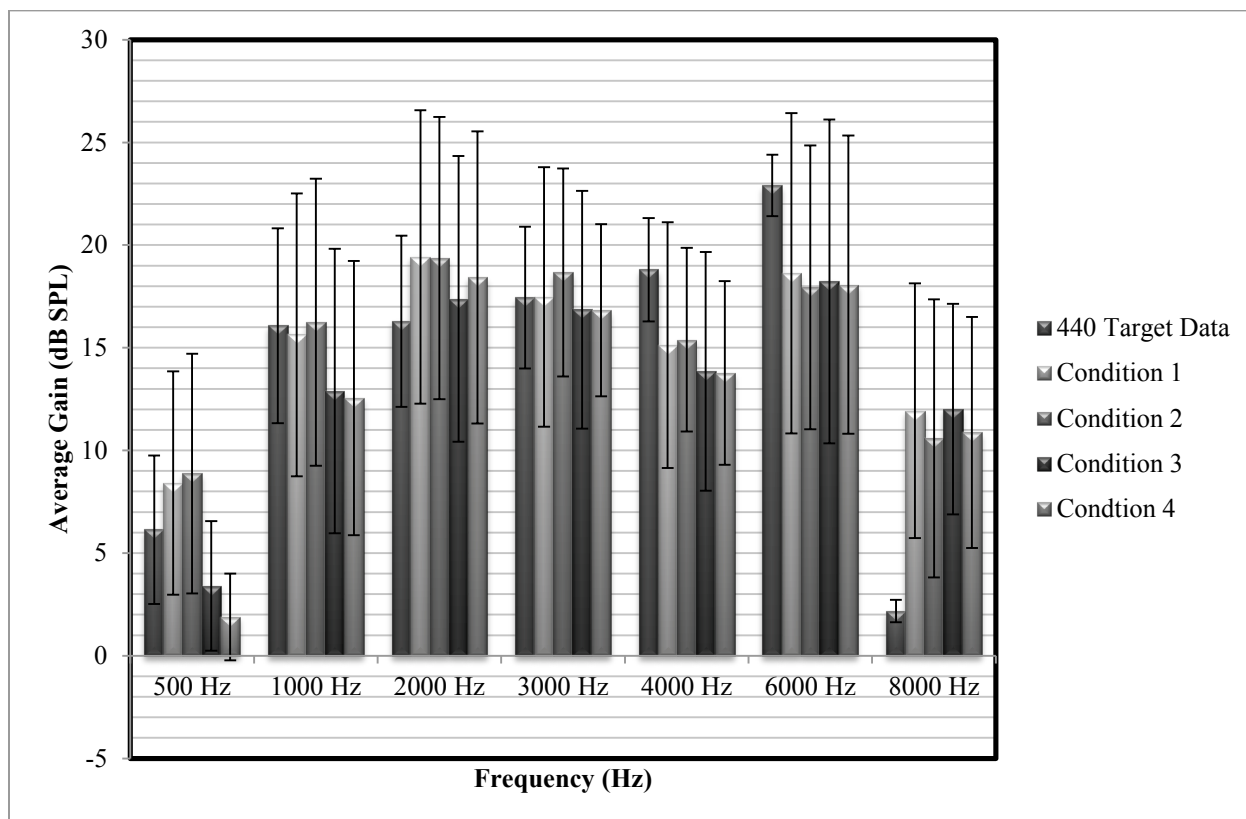


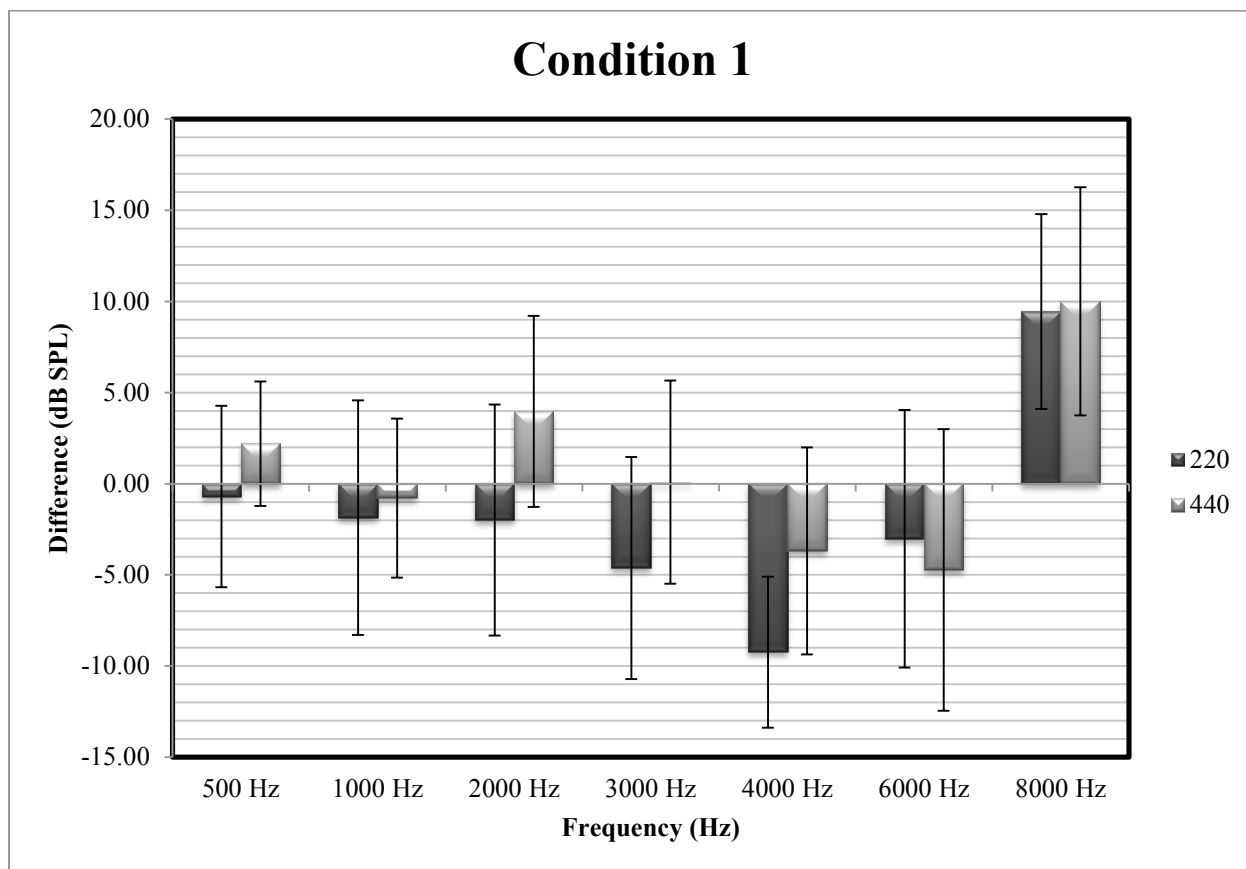
Figure 14. Mean difference ± 1 SD between NAL-NL1 and measured REIG in condition one.

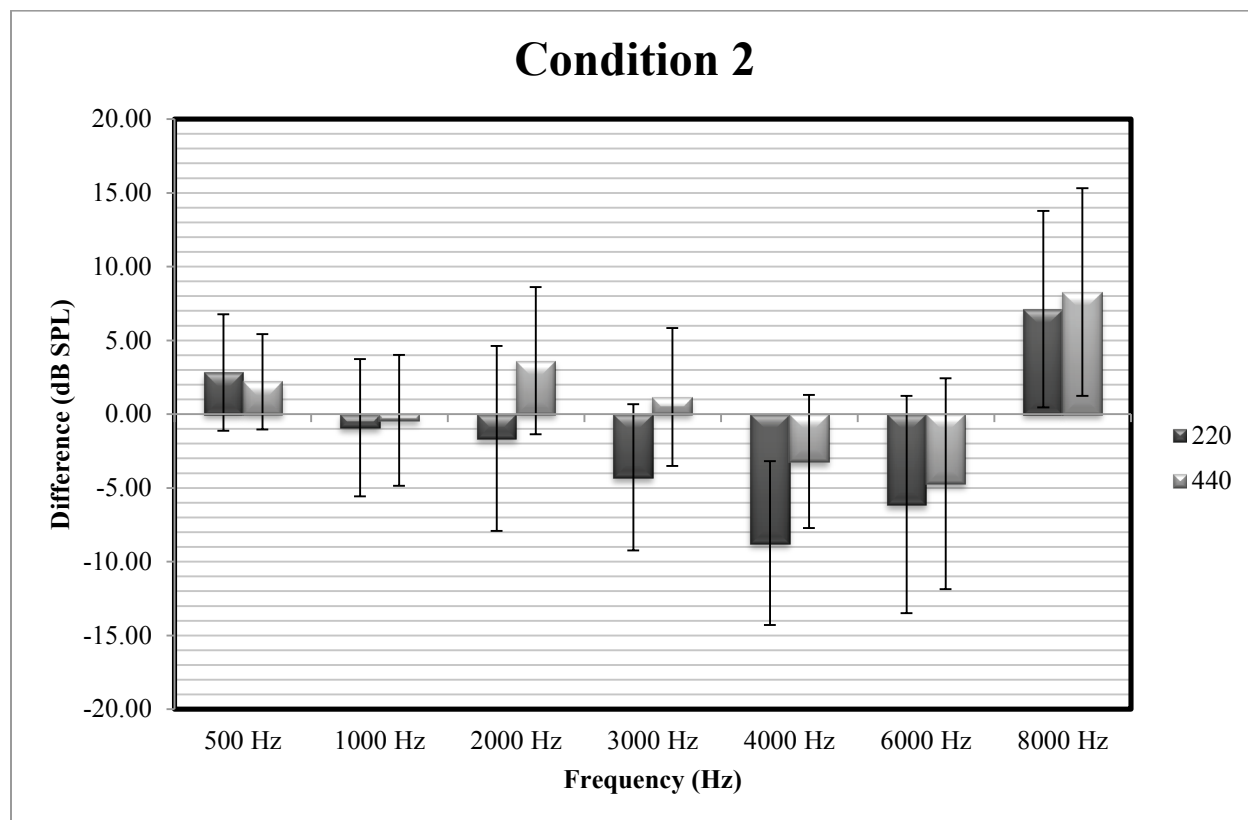
Figure 15. Mean difference ± 1 SD between NAL-NL1 and measured REIG in condition two.

Figure 16. Mean difference and ± 1 SD between NAL-NL1 target values and measured REIG across conditions in the Dream™220 Fusion hearing aids.

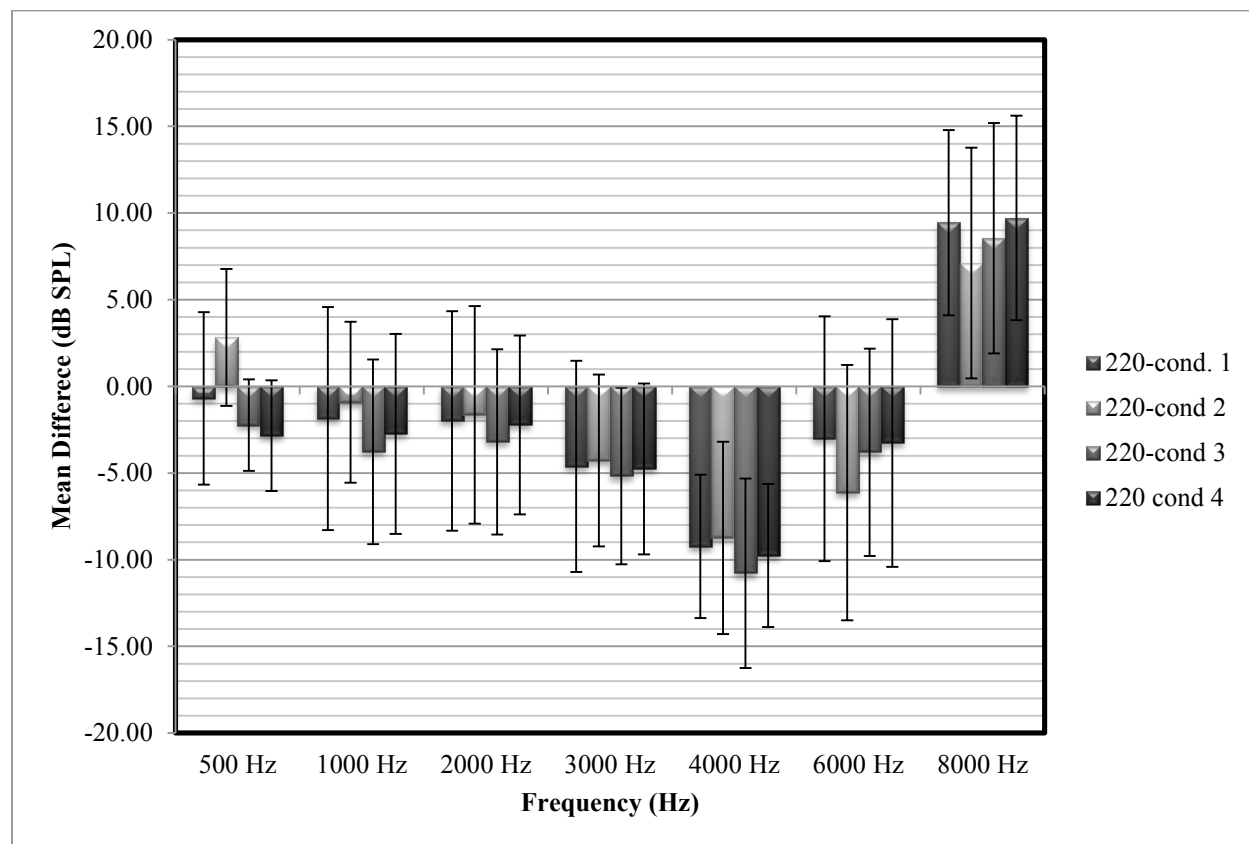


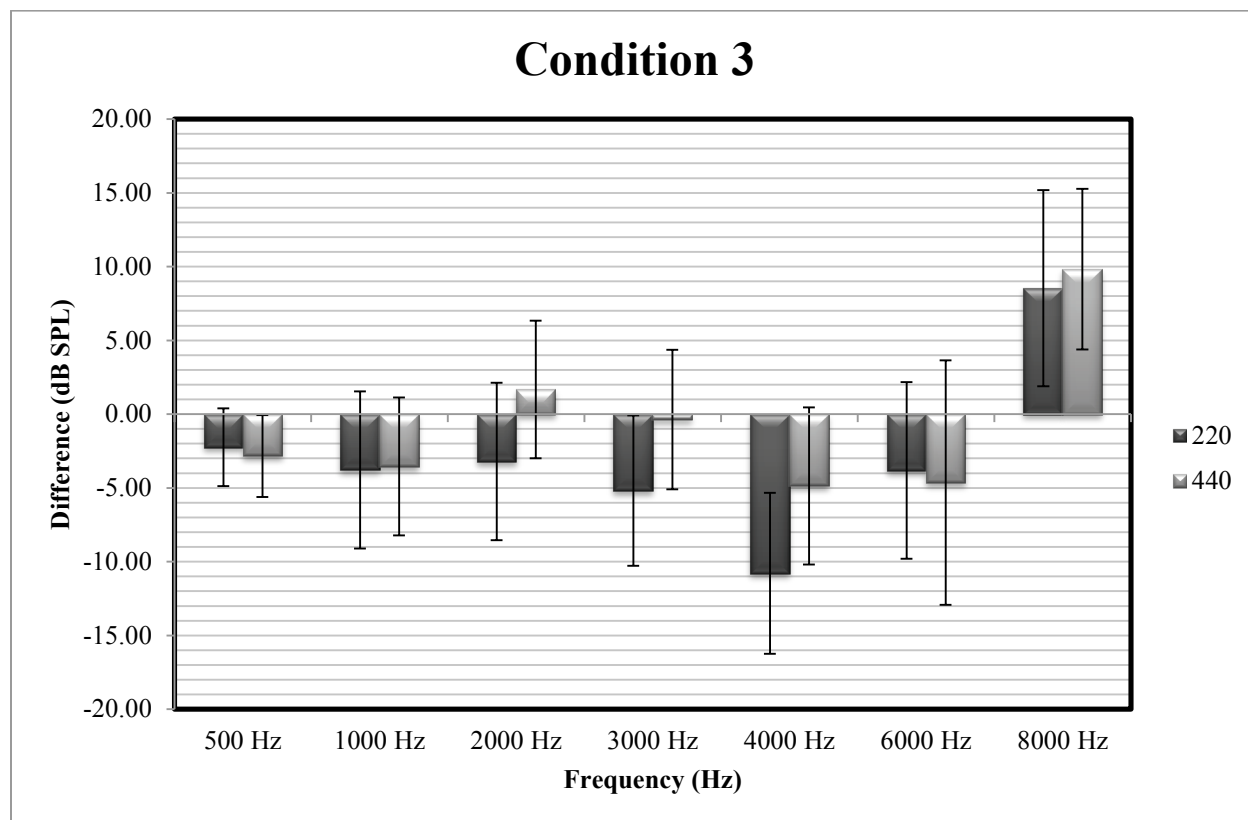
Figure 17. Mean difference ± 1 SD between NAL-NL1 and measured REIG in condition three.

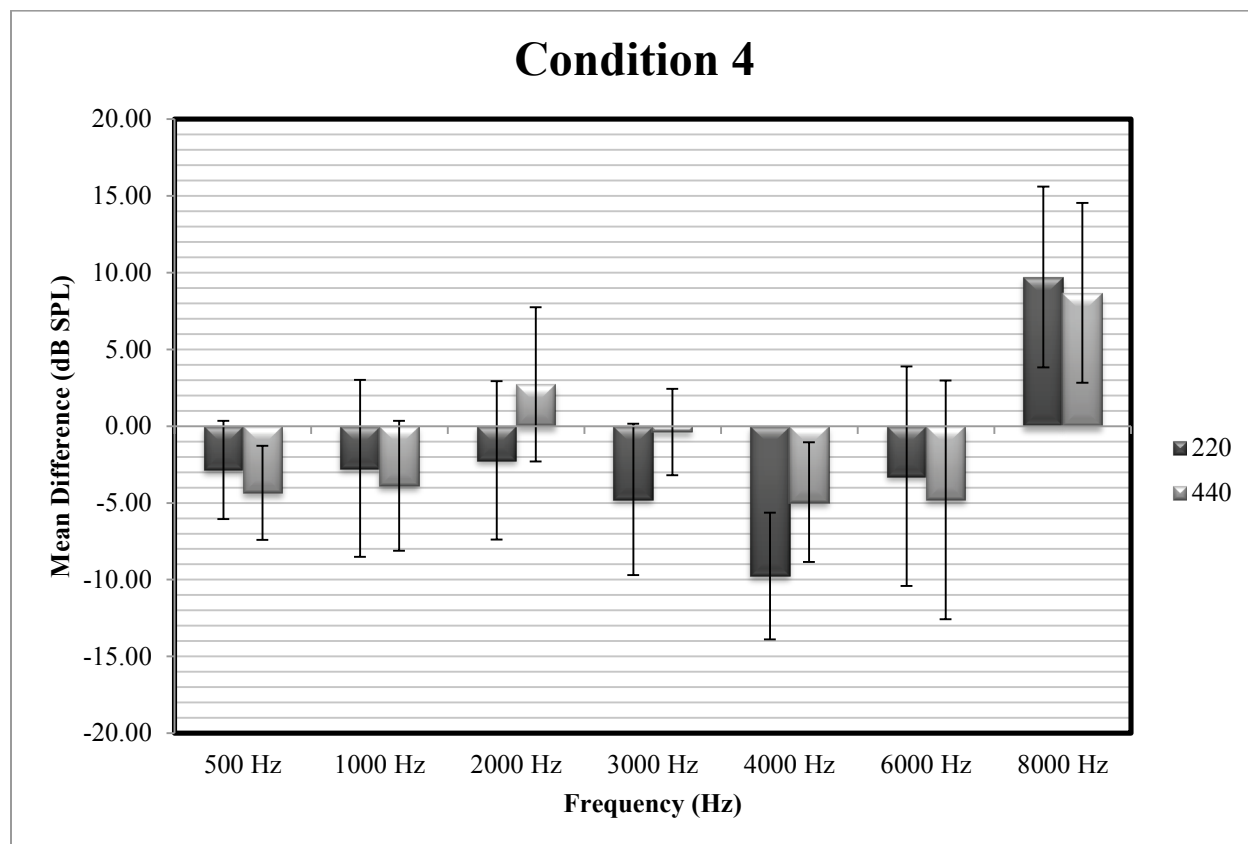
Figure 18. Mean difference ± 1 SD between NAL-NL1 and measured REIG in condition four.

Figure 19. Mean difference and ± 1 SD between NAL-NL1 target values and measured REIG across conditions in the Dream™ 440 Fusion hearing aids.

