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The impact of using real ear measures to calculate prescriptive targets on hearing aid follow-up visits

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THE IMPACT OF USING REAL EAR MEASURES TO CALCULATE PRESCRIPTIVE TARGETS ON HEARING AID FOLLOW-UP VISITS

By:

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Abstract: To fit hearing aids, estimated values are used to convert dB HL to dB SPL. This does not account for variance in ear canal shape and volume. Measured RECDs can change the NAL-NL1 targets. The purpose of this study was to evaluate if patients that deviate widely from the estimated RECDs are prone to additional follow-up visits.

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ABBREVIATIONS

dB HL	Decibels Hearing Level
dB SPL	Decibels Sound Pressure Level
RECD	Real-Ear-to-Coupler Difference
REDD	Real-Ear-to-Dial Difference
RETSPL	Reference Equivalent Threshold Sound Pressure Level

INTRODUCTION

In a clinical hearing aid dispensing practice, many patients return for follow-up care after the initial hearing aid fitting due to patient's desire for adjustments to the hearing aid settings or due to continued dissatisfaction with their hearing aids. In a recent survey study, Kochkin and colleagues (2010) found a strong correlation between patient success and satisfaction with new hearing aids and the number of follow-up visits for hearing aid programming. Specifically they found that 76% of patients reporting above average success reported that they only required 1-2 follow up appointments, whereas only 7% of these successful fittings required four or more follow up visits. Furthermore, they found that close to 50% of patients who reported dissatisfaction or unsuccessful hearing aid fitting required four or more visits. In a follow-up analysis of the questionnaire data, it was shown that the utilization of both verification and validation measures during the hearing aid fitting resulted in 1.2 fewer visits (Kochkin, 2011). Verification of a hearing aid fitting is an objective measure that ensures the hearing aid is operating within the desired targets for a prescriptive formula by analyzing the electroacoustic parameters of the device in a hearing aid analyzer or through probe microphone measurements (ASHA, 1998). Validation is a subjective measure that captures the hearing aid user's perceived benefit, satisfaction, and handicap reduction by the use of hearing aids (ASHA, 1998). However, there are clinical cases that despite the Audiologist doing both verification and validation measurements as part of the hearing aid fitting protocol, the patient returns for more than the typical number of follow-up visits for hearing aid adjustments. Many of these visits result in only minor changes to the hearing aids and programmed settings that may or may not increase patient satisfaction and performance. These additional visits can take up valuable clinic time and are typically not billable visits since most hearing aids are dispensed as part of a bundle of services.

The multiple appointments may potentially lead to a higher return for credit if the patient chooses not to keep the hearing aids at the end of the trial period. There are multiple reasons for a patient to return for follow-up visits, such as unrealistic expectations or poor understanding of device handling, but for some of these patients there may be an issue with the initial hearing aid programmed settings.

Before the process of the hearing aid evaluation and subsequent fitting, the patient undergoes a complete audiometric evaluation. During this evaluation, the audiometric thresholds are obtained in decibels Hearing Level (dB HL) and are plotted as a function of frequency. This dB HL value is the listener's threshold referenced to audiometric zero which is based on average threshold values in dB sound pressure level (dB SPL) at the eardrums of a large population of healthy, normal hearing young adults (Katz, 2009). Edmund Prince Fowler was one of the original pioneers of the method of plotting hearing levels on a graph that would show hearing loss relative to average normal hearing rather than to a physical sound pressure level value (Jerger, 2013). Each audiometric frequency has a different sensation level (dB SPL) that has been calibrated as 0 dB HL. The zero referenced dB SPL is the average minimal audible pressure threshold levels as referenced to a coupler that represents the average adult ear canal acoustics. Therefore, when measuring thresholds in dB HL as part of routine audiometric testing, dB SPL at the eardrum can only be estimated using average ear canal data.

These dB HL threshold values are not only used in audiometric testing, but they are also used to generate a prescriptive output target for the hearing aid fittings. The dB HL values are converted into an estimated dB SPL value and then incorporated into the prescriptive fitting formula of choice. The dB conversion from HL to SPL uses *reference equivalent threshold sound pressure levels* (RETSPL) that relies on average 2 cc coupler values (ANSI S3.6 1989).

The 2 cc coupler was designed to replicate the volume of the space between the tip of an insert earphone and the eardrum (Yost & Killion, 1997 p. 1550). While these average values aid in the conversion from dB HL to dB SPL, the assumption is made that each individual's ear canal is relatively uniform in volume and shape. Valente, Potts, Valente, Vass, & Goebel (1994) used probe microphone measurements to evaluate the variations of the sound pressure levels in the ear canal in response to a constant 90 dB HL pure tone played through an audiometer. The authors found differences of 12-29 dB at different frequencies among a group of participants. This means that while the tone was played at a consistent level from the audiometer (90 dB HL), the actual sound pressure measured in the ear canal varied substantially across participants.

Saunders and Morgan (2003) looked at how the NAL-NL1 hearing aid targets change when using a measure known as Real Ear to Coupler Differences (RECDs). RECDs are the differences between the dB SPL value measured at the patient's eardrum via a probe microphone and the dB SPL value measured in a 2 cc coupler at different frequencies. The RECD value can be entered into the formula for prescriptive targets so that the output dB SPL target values reflect the actual SPL in the patient's ear canal rather than in an average adult ear. They found that for some individuals the targets changed greatly depending on the RECD values entered. Additionally, the authors noted that the greatest deviations from the average values occurred in the mid-frequencies (1000-3000 Hz), which are crucial for speech understanding (Saunders and Morgan, 2003). The mid frequencies varied by more than 10 dB in some participants. Saunders and Morgan (2003) successfully demonstrated the wide variance among individuals and using average values can lead to either insufficient or excessive gain when fitting a hearing aid.

It can be postulated that these documented variations in dB SPL prescriptive targets due to ear canal differences may lead to a greater need for hearing aid adjustments if the targets are not generated from individually measured values. If there is a more accurate way to fit hearing aids to each patient, then it may help reduce the number of patients coming back repeatedly for these additional follow-up visits. In order to provide a more exact initial hearing aid fit, there are two measurements that can be used in order to generate more ear-specific fitting targets.

Real-Ear-to-Coupler Difference

Measured Real-Ear-to-Coupler Difference (RECD) is utilized in the clinic to convert the dB HL used for audiometric testing to dB SPL used for the hearing aid fitting process. The use of measured RECD can provide more accurate fitting targets than the use of averaged RECD values provided by hearing aid analyzers. RECD measurements find the difference between a measurement of the sound pressure in the ear canal and the equivalent measurement made in a 2 cc coupler using the same input level (Fikret-Pasa & Revit, 1992). Negative RECD values mean that a lower dB SPL was measured at the eardrum than in the 2 cc coupler. Positive RECD values indicate that the dB SPL measured at the eardrum were greater than the 2 cc coupler. The stimulus is a pure tone sweep from 250-8000 Hz. Once both measurements are made, the real ear measurement is subtracted from the 2 cc coupler measurement at each frequency from 250-8000 Hz (Gelfand, 2009). The size and shape of each individual's ear canal affect the RECD values as dB SPL is dependent on the volume of the space. For example, for a constant input level, the output dB SPL value near the eardrum is lower in an individual with a larger ear canal volume than someone with a smaller ear canal volume. Therefore, measuring the RECD and applying these values into the prescriptive fitting formula allows for more accurate hearing aid fitting targets to be generated.

RECD is commonly measured for pediatric hearing aid fittings due to the changing ear canal shape and volume throughout childhood. As children grow and develop, the ear canal volume and the corresponding RECD values change reflecting the change in sound pressure levels in the ear canal. Measuring the ear canal regularly using RECD measurements ensures that the hearing aids are fit properly throughout childhood. Moodie, Seewald & Sinclair (1994) stated that “The electroacoustic characteristics measured in a 2 cc coupler do not accurately reflect several factors that are known to affect real-ear hearing aid performance. These factors include the acoustic impedance properties of the child’s ear, the residual ear canal volume with an earmold in place, head diffraction/microphone location effects, and acoustic leakage of amplified sound from the occluded ear canal.” RECD has been shown to be a repeatable and reliable measurement to use when converting from dB HL to dB SPL for both adult and pediatric hearing aid users (Sinclair et al, 1996). Munro and Davis (2003) also concluded that RECD measurements are reliable and acceptable for clinical use after taking the measurement on adults and found very small test-retest differences. When the RECD measurement is not performed, averaged values are used to generate the hearing aid fitting targets. These averaged values are based on the age of the patient starting from infancy up to a standard value for adults. Research has shown that using age-dependent normative values for the RECD are not as accurate as the individually measured RECD, hereby possibly leading to imprecise hearing aid prescriptive output targets (Bagatto, Scollie, Seewald, Moodie, & Hoover, 2002).

Real-Ear-to-Dial-Difference

Although not used frequently in the clinical setting, Real-ear-to-dial-difference (REDD) is another measurement that can convert dB HL values to dB SPL. According to Scollie, Seewald, Cornelisse, & Jenstad (1998), “The REDD is defined as the difference between the dial reading on an audiometer and the real ear output of that audiometer's earphone in a client's ear canal”. For example, a 500 Hz pure-tone plays at 70 dB HL, and the SPL at the eardrum of an individual is recorded by a probe microphone as 76 dB SPL. The 70 dB HL value is subtracted from the value recorded at the eardrum, so the REDD in the previous example is 6 dB. Rea- ear-to-dial differences are typically recorded at each octave and interoctave frequency from 250-8000 Hz. Munro and Lazenby (2001) demonstrated that REDD is a reliable and repeatable measure that can be used clinically to perform individual conversions from dB HL to dB SPL. Scollie et al. (1998) found a test-retest reliability of .4-2 dB for both RECD and REDD, which suggests that both are acceptable measures for a dB HL to dB SPL conversion.

RECD versus REDD

In the present study, both measurements were made for comparison purposes. RECD and REDD both aim to accomplish the same goal, but they use different methods to do so. Theoretically, the two measures should match up to one another, and both have been proven to be reliable and repeatable for clinical purposes. However, little research has been done to verify that the two measures are of equivalent value for the same individual. The present study compared the two measures for each participant in order to determine if RECD and REDD found similar values.

As stated earlier, an average ear canal transfer value is used to convert from dB HL to dB SPL when generating hearing aid targets if individual measures are not taken. Although there are other methods for converting dB HL to dB SPL for an individual, RECD is the most clinically utilized. Scollie et al (1998) concluded that RECD is a highly reliable measure for transforming dB HL to dB SPL for pediatric hearing aid patients. However, adults also have varying ear canal shapes and volumes, so it would seem logical to measure these values on each patient when doing the hearing aid fitting. If these measures are carried out on a patient, then the hearing aid targets generated will be tailored to that individual's ear canal characteristics. A main aim of this study was to examine the effect of applying the individually measured RECD and REDD to calculate the actual dB SPL threshold, and to measure the impact of applying these RECD values on the calculation of NAL-NL1 prescriptive targets for hearing aid fittings. If there are large variations between the estimated dB SPL threshold and the actual measured dB SPL threshold, then it can be postulated that individuals with these larger variations return for more follow-up visits. Therefore a retrospective chart review was conducted on the study's participants to count number of follow-up hearing aid programming adjustments in the 3 months following their initial hearing aid fitting. If there is a positive correlation between large differences between measured and averaged RECD and an increased number of patient visits, then it may be assumed that measuring RECD in adults could lead to fewer patient visits, thereby possibly increasing patient satisfaction.

METHODS

Participants

All participants are current hearing aid users in at least one ear and were recruited from the Washington University Adult Audiology office at Central Institute for the Deaf. Every participant was given informed consent in accordance with the guidelines of the Institutional Review Board (IRB) of Washington University in St. Louis, Missouri. The study included 28 participants between the ages of 23-88 years old (mean age = 65.6). The study consisted of 8 women and 20 men. A total of 50 ears were tested and measured. Six subjects had only one ear included in the study due to unilateral cochlear implantation (2), use of BiCROS hearing aids (1), or the patient choosing to be fit monaurally (3).

Procedure and Measurements

Otoscopy was performed prior to audiometric testing to ensure that participants' ear canals were sufficiently clear of cerumen to use insert earphones. Pure tone audiometry was administered for each participant at the standard audiometric frequencies (ASHA, 1978) using ER-3A insert earphones.

For the REDD measurement, a probe microphone coupled to a Frye FONIX 7000 Hearing Aid Analyzer was measured and inserted into the ear canal approximately 6 millimeters from the tympanic membrane. Once the probe tube was properly placed, an ER-3A insert earphone was inserted into the ear canal in order to deliver the sound stimulus. The insert earphone was allowed one minute to fully expand in the ear canal before proceeding with the measurement. The stimulus used was a continuous 70 dB HL tone. The REDD measurement was taken in each ear at frequencies of 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, and 8000 Hz. The dB SPL measured by the probe microphone in response to the pure tone being played in the subject's ear canal was displayed on the Frye FONIX 7000 screen and recorded.

Next, individual RECD measurements were made in each ear using the same probe microphone in the subject's ear canal approximately 6 mm from the tympanic membrane. The same frequencies used for the REDD measurement were also recorded for the RECD measurement. For the measurement, a single ER-3A insert earphone was inserted into the earphone jack on the Frye 7000 in order to deliver the pure-tone sweep signal. Once the probe tube was in place, the insert earphone was inserted into the participant's ear canal and the earphone was given one full minute to expand in the ear canal. In order to do the measurement, the Real-Ear screen was opened up and the Menu option was changed from "Averaged RECD" to "Custom Measured." Next, the RECD curve was selected and the measurement was executed.

The coupler measurement was completed and stored in the Frye system to serve as the comparison to the on ear measures for each participant. The values obtained were then recorded for each participant. See Figure 1 for the RECD values obtained for each ear.

Data Analysis

The estimated and measured thresholds were calculated using RETSPL and the RECD measurements. To find the estimated threshold in dB SPL, the RETSPL at each frequency for insert earphones was added to the threshold in dB HL at the corresponding frequency. See Table 2 for a table of RETSPL values for insert earphones at each frequency. To find the individual threshold, the RETSPL and RECD were added to the corresponding dB HL threshold at that frequency. For example:

Participant 1 audiometric threshold at 2000 Hz in the Right ear = 45 dB HL

RETSPL at 2000 Hz using ER-3A insert earphones = 6.5 dB

Participant 1 measured RECD at 2000 Hz = 7 dB

Estimated dB SPL threshold: 45 + 6.5 = 51.5 dB SPL

Measured dB SPL threshold: 45 + 6.5 + 7 = 58.5 dB SPL

Individually measured thresholds were also calculated using the REDD values. The 70 dB HL tone was subtracted from the dB SPL value measured at the ear drum. For example, if the dB SPL measured at the eardrum of a patient for a 2000 Hz pure tone was 76, the REDD is 6 dB. If the audiometric threshold is 2000 Hz is 45 dB HL for that patient, then the measured threshold is 51 dB SPL. The individually measured thresholds that were calculated using REDD were compared to the thresholds that were calculated using estimated and measured RECDs.

Phonak Target 3.0 software was used to measure the effect of RECD on NAL-NL1 targets for each participant. The software allows the user to select either average values for RECD or to enter them manually to generate the prescriptive targets. Two Client profiles were created for each participant. For example, Participant 1 was entered under two different names: Participant 1m for measured RECD and Participant 1e for estimated or averaged RECD. Each client was set to “Long-Term User,” Sound Recover was defaulted to “off,” the NAL-NL1 (Byrne, Dillon, Ching, Katsch, & Keidser, 2001) fitting formula was chosen, insert earphones were selected as the transducer, and a Bolero Q90 SP hearing aid was selected for each participant for uniformity purposes. Due to limitations in the software, RECD values had to be entered at 758 Hz, 1516 Hz, 3031 Hz, and 6063Hz rather than the standard interoctave values of 750 Hz, 1500 Hz, 3000 Hz, and 6000 Hz. This difference in frequency was not significant enough to affect the targets generated. Targets were generated for soft (50 dB), medium (65 dB), and loud (80dB) input levels. The differences in the targets were recorded and analyzed to find the differences in prescribed output at frequencies of 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, and 8000 Hz.

After comparing the targets using averaged versus measured values, the researchers looked back at each participant’s appointment history to determine if there were more than the standard number of programming visits. The number of visits was classified from 0-2, 3-4, and 5 or more. Five or more programming visits were categorized as more than the typical number of follow-up visits following a hearing aid fitting.

RESULTS

Differences in dB SPL- Estimated versus Measured

A repeated measure ANOVA was performed to evaluate the main effect of difference in the dB SPL between the estimated values, RECD, and REDD. A main effect between the estimated values, RECD, and REDD was found $F\ (2, 162.8)$, $p < .000$. Interaction between the three types of threshold measurements and frequency was found $F\ (14, 76.46)$, $p < .000$. Results from the repeated measure ANOVA found significant differences between groups in threshold at 3000 Hz, 4000 Hz, 6000 Hz, and 8000 Hz. For Post Hoc tests, a test of Multiple Comparisons was completed in order to show the difference between each measurement at each frequency.

The estimated dB SPL value was significantly different ($p< .05$) than the dB value calculated from both RECD and REDD measurement at 4000 Hz and 800Hz, from the RECD calculated dB SPL value at 6000Hz. The RECD and REDD calculated dB SPL values were significantly different ($p< .05$) from one another at 3000Hz, 4000Hz, and 6000Hz. See Figure 2 for the difference in threshold between the three methods of measurement.

Differences in NAL-NL1 Targets

Phonak Target 3.0 software was used to generate NAL-NL1 prescriptive targets at input levels of 50dB, 65dB, and 80dB. An independent samples t test was used to evaluate the differences. Significant differences between estimated and measured RECD generated targets were found at 3000Hz for 50 dB $t(98)= 2.124$, $p< .05$, 65 dB $t(98)= 2.134$, $p< .05$, and 80 dB $t(98)= 2.348$, $p< .05$ input levels. At 6000 Hz, a significant difference was found at 80 dB $t(98)= 2.409$, $p< .05$. Figure 3 depicts the difference in the targets generated using average versus measured RECD values.

Correlation Between RECD and Number of Visits

A 2-tailed Pearson Correlation analysis was completed to evaluate whether or not the number of follow-up programming visits correlated to wide variances in estimated versus individually measured values. The number of visits was categorized as 0-2, 3-4, and 5 or more. Five or more was considered to be more than the typical amount following a hearing aid fitting. No correlation (-.335) was found between a large difference in average versus measured RECDs and an increased number of follow-up visits. Additionally, the RECD values were separated into two groups: low frequency (250-1000 Hz) and high frequency (2000-8000 Hz). A 2-tailed Pearson Correlation analysis was completed to evaluate whether or not large difference between averaged versus measured RECDs in the low frequencies correlated with an increased number of follow-up visits. The same correlation analysis was carried out for the high frequency RECDs. No correlation was found in the high or low frequency group (-.297) (-.321), respectively. See figure 4 for the correlation between measured RECDs and number of follow up visits.

DISCUSSION

The primary purpose of the present study was to analyze whether or not a wide discrepancy in estimated versus measured RECDs correlates to more than the typical number of programming visits following a hearing aid fitting, as well as to determine whether there is a difference in the dB SPL calculated between the estimated RETSPL values and the directly measured values using RECD and REDD. The results of the current study demonstrate that individually measured thresholds are significantly different than the estimated values, most notably in the high frequencies. The estimated thresholds underestimated the actual dB SPL in the ear canal. These differences did affect the prescribed output for the hearing aid targets. However, there was not a correlation between a large difference in the estimated versus measured values and an increased number of follow-up visits.

In the study, two participants had very large differences between the average and measured RECDs. These two individuals came back for five or more hearing aid programming visits. One of the participants had a history of middle ear surgeries, while the other did not. Both were long term hearing aid users. For these two patients, it seems that measuring the RECDs may be helpful in order to more accurately fit hearing aids.

A limitation of the study was the use of a manufacturer's software to calculate and record dB SPL output for hearing aid targets. Using Phonak Target 3.0 allowed for comparisons between the targets generated from average and measured RECDs at input levels of 50 dB, 65 dB, and 80 dB. However, each manufacturer uses proprietary fitting algorithms, and selecting NAL-NL1 does not guarantee that the software is using values found in the literature. Additionally, the estimated RECD values may be different than the RETSPL values used for calculating estimated thresholds. An article released by Phonak (2010) explained that the clinician has the option to use estimated RECDs calculated by the manufacturer software. For example, the estimated RECD will change depending on vent size and results of the feedback test. The clinician can override these estimations, but he or she may be unknowingly altering the fitting targets if the proper adjustments are not made.

It should be noted that large differences in the prescriptive targets were not seen at 6000 Hz and 8000 Hz. This may be due to the NAL-NL1 formula (Byrne et al., 2001). The formula is designed to roll off gain in the highest frequencies, so even if there is a significant difference in estimated versus measured RECDs it may not have a large impact in the amount of prescribed gain at those frequencies.

The results indicate that there are other factors that lead to a patient coming back for additional programming visits. Kochkin et al. (2010) carried out a study looking at why patients are dissatisfied with their hearing aids. The authors listed factors such as poor performance in noise, poor overall benefit, feedback, poor fit and comfort, and patient not "buying in" to wearing amplification. Kochkin (2011) also found that an increased number of programming visits did not correlate to increased satisfaction. In fact, half of the hearing aid users that reported below average success had four or more follow-up visits following the hearing aid fitting. The users that had one or two follow-up visits were more likely to be successful users (Kochkin, 2011). A study by McCormack & Fortnum (2013) speculated that age and gender may be another factor in overall satisfaction with hearing aids. More specifically, the authors mentioned lack of clarity, discomfort, and overall disappointment with the aids as reasons for diminished satisfaction with their hearing aids (McCormack & Fortnum, 2013). It is the responsibility of the clinician to determine the reason(s) for dissatisfaction following a hearing aid fitting and provide appropriate counseling and recommendations.

The clinician can still choose to measure RECDs in order to more accurately fit a hearing aid, but it does not guarantee patient satisfaction. As stated above, there are multiple reason as to why a patient may feel the need to come back for additional programming visits. However, in certain cases where a patient has a surgically altered ear or pre-existing anomaly, it may be useful to perform a RECD measurement due to an increased possibility of measured values that differ widely from the averaged values. The RECD measurement will allow the clinician to make proper adjustments to the fitting targets in order to ensure that the hearing aids are not underamplifying or overamplifying the hearing loss.

CONCLUSIONS

The results of the current study did not find a correlation between variance in measured RECDs and an increased number of follow-up visits. However, for patients with surgically altered ear canals or existing anatomic anomalies, measured RECDs may be beneficial in order to achieve a more accurate hearing aid fit. Significant differences were found between the averaged versus individually measured dB SPL thresholds in the high frequencies. Measuring

RECDs for each patient at the very minimum provide a more accurate fit, but it does not ensure that the patient will not need additional programming visits. Patients come back for additional follow up for multiple reasons.

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Figure 1: This figure shows the measured RECDs for each participant in the study to look at individual differences.

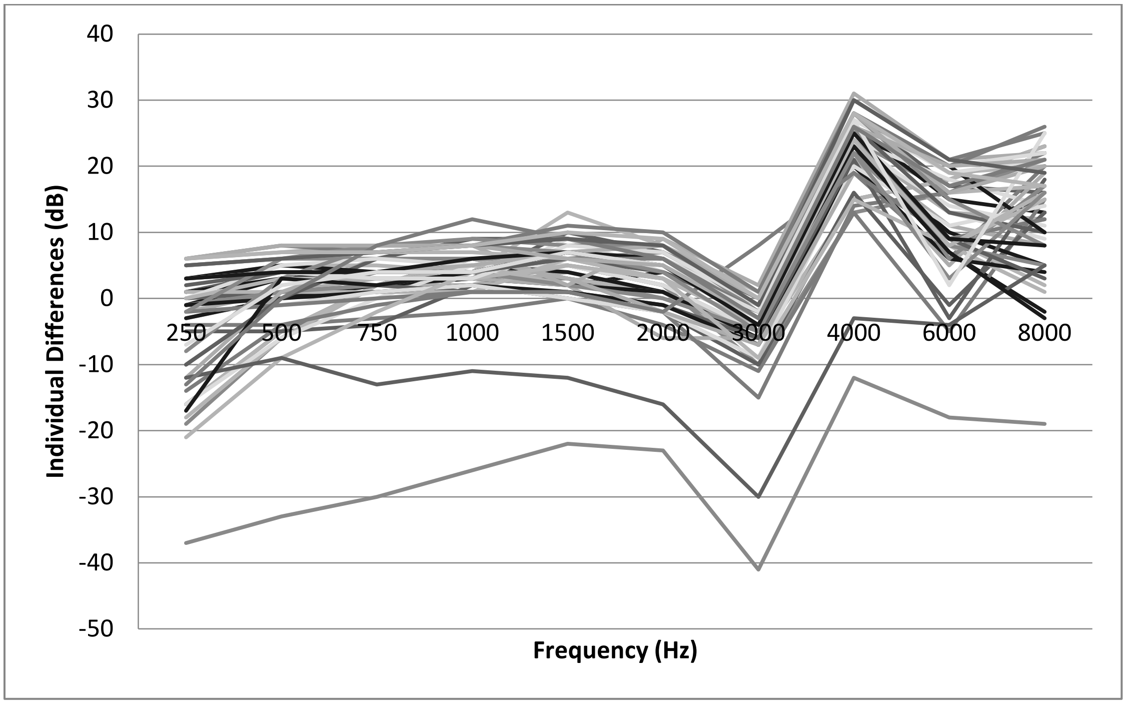
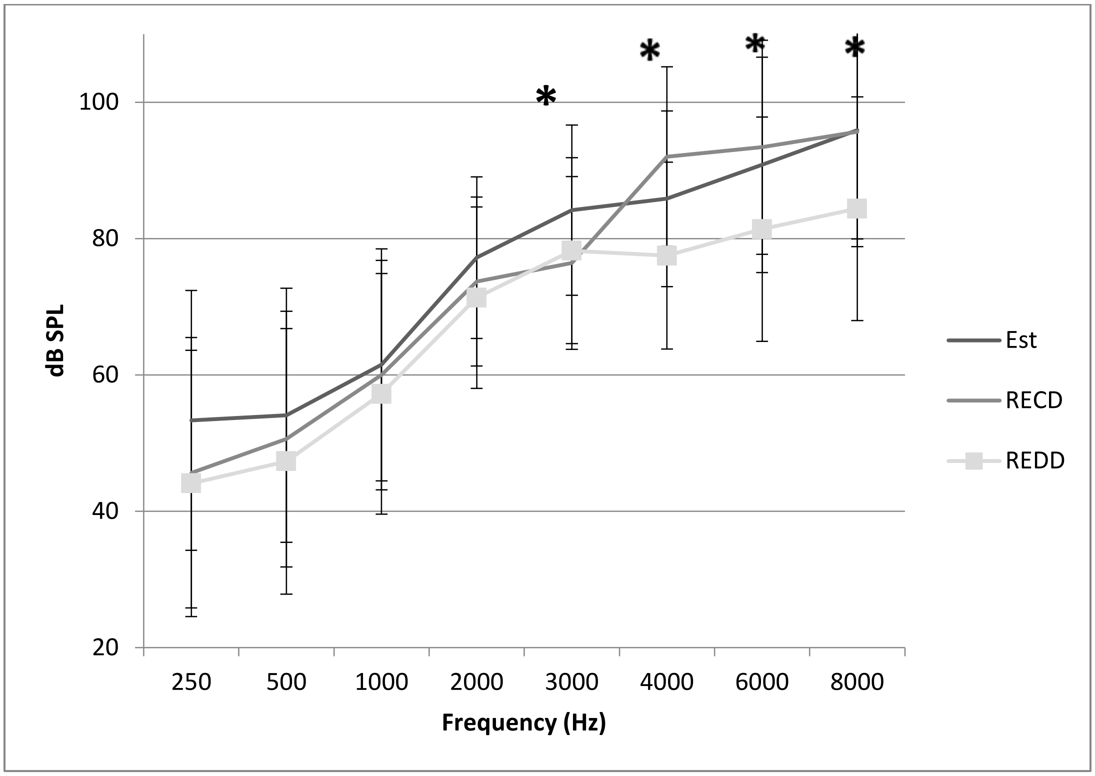


Table 1: This table shows the RETSPL Thresholds for 3A insert earphones.

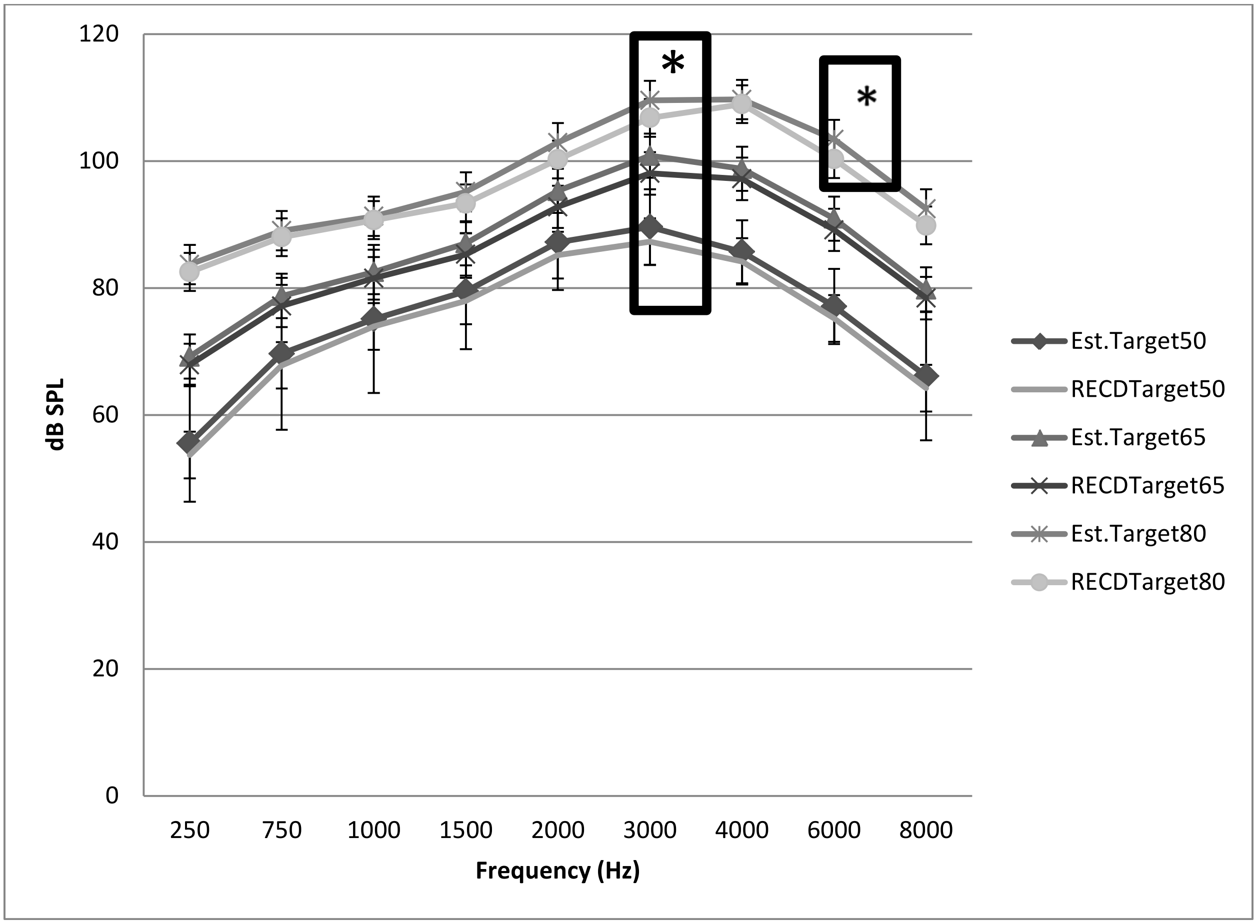
Frequency (Hz)	250	500	1000	2000	3000	4000	6000	8000
RETSPL (dB)	15.5	8.5	3.5	6.5	5.5	1.5	-1.5	-4

Figure 2: This figure displays the differences in dB SPL threshold using calculations based on the average ear, RECD, and REDD.



* denotes significance

Figure 3: This figure displays the difference in prescriptive output targets between averaged versus measured RECD as generated by Phonak Target 3.0 software.



*** denotes significance**

Figure 4: This figure displays the correlation between RECD values and the number of follow-up visits.