

# Verification of In Situ Thresholds and Integrated Real-Ear Measurements

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## Abstract

**Background:** Accurate prescriptive gain results in a more accurate fit, lower return rate in hearing aids, and increased patient satisfaction. In situ threshold measurements can be used to determine required gain. The Widex Corporation uses an in situ threshold measurement strategy, called the Sensogram. Real-ear measurements determine if prescriptive gain targets have been achieved. Starkey Laboratories introduced an integrated real-ear measurement system in their hearing aids.

**Purpose:** To determine whether the responses obtained using the Widex Sensogram were equivalent to those obtained using current clinical threshold measurement methods. To determine the accuracy of the Starkey IREMS™ (Integrated Real Ear Measurement System) in measuring RECD (real-ear to coupler difference) values compared to a dedicated real-ear measurement system.

**Research Design:** A verification design was employed by comparing participant data measured from standard, benchmark equipment and procedures against new techniques offered by hearing-aid manufacturers.

**Study Sample:** A total of 20 participants participated in this study. Ten participants with sensorineural hearing loss were recruited from the Ohio University Hearing, Speech, and Language Clinic participated in the first experiment. Ten participants with normal hearing were recruited from the student population at Ohio University participated in both experiments. The normal-hearing group had thresholds of 15 dB HL or better at the octave frequencies of 250–8000 Hz. The hearing-impaired group had thresholds of varying degrees and configurations with thresholds equal to or poorer than 25 dB HL three-frequency pure-tone average.

**Data Collection and Analysis:** The order of measurement method for both experiments was counter-balanced. In Experiment 1, thresholds obtained via the Widex Sensogram were compared to thresholds obtained for each participant using a clinical audiometer and ER-3A insert ear phones. In Experiment 2, RECD values obtained via the Starkey IREMS were compared to RECD values obtained via the Audioscan Verifit™. A repeated-measures analysis of variance (ANOVA) was used for statistical analysis, and a Fisher's LSD (least significant difference) was used as a post hoc analysis tool.

**Results:** A significant difference between Sensogram thresholds and conventional audiometric thresholds was found with the Sensogram method resulting in better threshold values at 0.5, 1.0, and 2.0 kHz for both groups. In Experiment 2, a significant difference between RECD values obtained by the Starkey IREMS and the Audioscan Verifit system was found with significant differences in RECD values found at 0.25, 0.5, 0.75, 1.5, 2.0, and 6.0 kHz.

**Conclusions:** The Sensogram data differ significantly from traditional audiometry at several frequencies important for speech intelligibility. Real-ear measures are still required for verification of prescribed gain, however, calling into question any claims of shortened fitting time. The Starkey IREMS does perform real-ear measurements that vary significantly from benchmark equipment. These technologies represent a positive direction in prescribing accurate gain during hearing-aid fittings, but a stand-alone system is still the preferred method for real-ear measurements in hearing-aid fittings.

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Starkey Laboratories and Widex Hearing Corporation provided hearing aids for this study. Outside of this provision, neither company had any influence over the design or execution (including results, analyses, and interpretation) of the study. In addition, the authors have no financial interest in the outcome of the study.

**Key Words:** Hearing aids and assistive listening devices, hearing-aid technology, integrated real-ear measurement, real-ear measurement, Sensogram

**Abbreviations:** HRTF = head-related transfer function; IREMS™ = Starkey Integrated Real Ear Measurement System; LSD = least significant difference; RECD = real-ear to coupler difference; REIG = real-ear insertion gain

Provision of accurate prescriptive gain as verified by real-ear measurements during hearing-aid fittings results in a more accurate fit. This is largely due to the variability of the poor predictability of an individual's ear response from the average ear response (Mason and Popelka, 1986; Schum, 1986). It has been suggested that this may result in a lower return rate in hearing aids, increased patient satisfaction with hearing aids, and an overall increase in comfort and audibility (Fikret-Pasa and Revit, 1992, Tecca, 1994, Cunningham et al, 2002, Dillon and Keidser, 2003, Kochkin, 2005; Kirkwood, 2006, Valente et al, 2006). There are many ways to determine the prescriptive gain; and each hearing-aid manufacturer offers various fitting formulas to determine the target frequency-specific gain (Hawkins and Cook, 2003). These formulas provide the targeted amount of gain based on algorithms in which the size of the ear canal for a particular patient is assumed to equal the mean volume of normal adults. However, each patient has a unique ear canal volume with its own resonance properties. Various hearing-aid configurations are employed in hearing-aid fittings, each with their own characteristic venting and acoustics. Several methods have been developed that adjust the prescriptive gain targets based on an individual patient's ear physiology and hearing sensitivity.

In situ threshold measurements are one method used to ascertain absolute thresholds to predict aided gain. Widex Corporation has introduced an in situ threshold measurement, called Sensogram, to assess in situ thresholds to more accurately prescribe gain. A patient's thresholds are obtained via an in situ threshold method. This method allows the Sensogram software to control an in situ hearing aid to generate variable level test tones and thus generate a behavioral audiogram from the patient. The developers of this technology argue its utility in predicting aided thresholds (Kuk et al, 2003). It has been further purported that in situ thresholds obtained using the Sensogram program are more accurate and reliable than aided thresholds because they are not affected by issues related to free-field threshold measurement, namely standing waves and head-related transfer function (HRTF) (Kuk et al, 2003). While the test-retest reliability of thresholds obtained using an in situ threshold response, via the Sensogram method, mirrors that of thresholds obtained using current, clinically accepted threshold measurement techniques, the accuracy of such measurements has not been verified (Smith-Olinde et al, 2006).

Real-ear measurements provide a means by which to gauge whether prescriptive gain targets have been achieved for a given individual. These measures are obtained by inserting a probe microphone in the ear canal, placing the appropriate hearing aid and earmolds on the user, and then measuring the acoustic response at the ear drum in dB SPL (Tecca, 1994; Dillon, 2001; Yanz et al, 2007). In this manner, the acoustic response of an individual's ear can be measured without a hearing aid (the real-ear unaided gain [REUG]) and with a hearing aid turned on (the real-ear aided gain [REAG]) in order to calculate the actual hearing-aid response at the ear drum relative to that of the open-ear, the real-ear insertion gain (REIG). In a review article, Fabry (2003) illuminated that real-ear measurements were more accurate and reliable than those obtained via functional gain measures for verification of fitting targets. Verification of proper prescriptive gain via real-ear measures plays an important role in current, state-of-the-art hearing-aid fitting practice (Zelisko et al, 1992, Tecca, 1994, Hawkins and Cook, 2003).

An alternative procedure to calculating the REIG in an individual's ear is to determine the real-ear to coupler difference (RECD). To do this, the acoustic response of an individual's ear as well as that of a particular coupler (usually a 2 cc coupler) is measured. The difference between these two responses is the RECD. Knowing the RECD for a particular patient can be beneficial in a number of ways. For example, if a hearing aid is sent for repair and is returned to the clinic, the audiologist can reprogram the hearing aid and ensure that targets are met without the patient being present. As another example, pediatric patients may not tolerate well the physical setup to perform traditional real-ear measurements. Having his or her RECD will allow effective programming without a physical set up each time the hearing aid is serviced. It should be noted that the RECD should be updated more frequently for children. While real-ear measurements are important for all populations, these measurements are particularly important in the pediatric population as those ears vary to a greater extent than do adult (Bagatto et al, 2002).

Hearing-aid fitting software does not include patient-specific real-ear measures in their fitting software. The algorithms used by the fitting software of many hearing-aid companies employ simulated real-ear measurements when determining proper prescriptive gain targets. Simulated real-ear measurements usually correspond

to the average real-ear to coupler differences (RECDs) for adult ears. These simulated real-ear measures do not always emulate the unique acoustic response of a patient's ear accurately, as each patient has a unique ear canal shape and volume that produces resonance patterns that can differ substantially from those incorporated in the average real-ear measurement data.

Hearing-aid manufacturers have introduced methods of performing real-ear measures without requiring dedicated equipment. Starkey Laboratories recently introduced a real-ear measurement system that was integrated into their Destiny 1600 series hearing aids and is now available in their entire Zōn and Destiny hearing-aid lines. This integrated system gives hearing professionals the ability to perform real-ear measurements via the patient's hearing aids without requiring specialized real-ear equipment. The integrated real-ear system utilizes a separate tone hook coupled to a probe tube microphone that is placed down into the patient's ear canal with the end close to the ear drum. The patient's earmold or custom in-the-ear (ITE) hearing aid is then placed in the ear. The RECD is then measured for the patient's ear and saved in the Starkey fitting software. All prescriptions of gain are then calculated using the patient's actual RECD values obtained by the Starkey Integrated Real Ear Measurement System (IREMS). It is important that new technologies intended to facilitate hearing-aid fittings be compared against benchmark equipment.

A clinically accepted method of threshold measurement was compared to the Sensogram method of obtaining absolute thresholds. In the first experiment, in situ threshold responses obtained using the Sensogram feature included in Widex Compass 4.5.1 software were compared to in situ threshold responses obtained using ER-3A insert earphones and a conventional audiometer. The goal was to determine whether the in situ threshold responses obtained using the Widex Sensogram were equivalent to those obtained using ER-3A inserts and a clinical audiometer. The Sensogram method might provide a convenience factor in fittings by giving ear-specific information not seen in functional gain measurements, and the Sensogram method does not require that the patient be moved to a sound attenuated booth for measurements, though it would still require real-ear measures for gain verification. It has been argued that the extra time could be used to further counsel the patient on hearing-aid use and expectations or to obtain real-ear measurements (Kuk et al, 2003). It was hypothesized that thresholds obtained using the Sensogram in situ threshold method would not differ significantly from those obtained using ER-3A insert earphones and a conventional audiometer.

The second experiment compared RECD values obtained using the Starkey IREMS to those obtained using a clinically available real-ear measurement sys-

tems (i.e., the Audioscan Verifit™ system). Our aim was to determine how accurate the Starkey IREMS was in measuring RECD values, compared to the Audioscan Verifit real-ear measurement system. It was hypothesized that no statistical difference in RECD values would be found between the hearing-aid-based and stand-alone real-ear measurement systems.

## METHODS

### Experiment 1: In Situ versus Audiometric Thresholds

#### Participants

Ten normal-hearing (aged 22–28, mean = 24.5 yr) and ten hearing-impaired (aged 24–87, mean = 62.6 yr) adult participants were recruited. The normal-hearing participants (3 males, 7 females) were recruited from the student population at Ohio University and participated in both experiments. The hearing-impaired participants (4 males, 6 females) were recruited from the population of patients with hearing impairment that were seen at the Ohio University Speech and Hearing clinic and participated in Experiment 1 only. All participants provided informed consent prior to the experiment.

Inclusion criteria for participation as a normal-hearing participant included normal tympanograms, otoscopy, and hearing sensitivity defined as hearing thresholds  $\leq 15$  dB HL, from 250 to 8000 Hz on the day of the experiment. Inclusion criteria for participation as a hearing-impaired participant included a previously documented history of a sensorineural-only hearing loss and a minimum three-frequency pure-tone average of 25 dB HL. Previous audiometric test results for hearing-impaired participants were compared to audiometric test results obtained on the day of the experiment. If the three-frequency pure-tone average shifted at least 10 dB from the previous audiometric results, then a full audiometric reevaluation was recommended to the participant. Even if an audiometric shift was identified, hearing-impaired individuals were still included in the study. Hearing thresholds obtained on the day of the experiment were used in comparison to obtained in situ thresholds.

#### Procedure

Otoscopy was performed via a Welch Allyn (Welch Allyn Part #: 25020) handheld otoscope. Next, screening tympanograms were obtained using a Grason-Stadler GSI Tymptstar Middle Ear Analyzer calibrated according to American National Standards Institute (ANSI) specifications (ANSI, 1987). Audiometric thresholds for each ear were obtained via air conduction at all octave and audiometric interoctave frequencies from 250 to

8000 Hz using the modified Hughson-Westlake procedure (American Speech-Language-Hearing Association, 2006). Air-conducted stimuli were generated using a Grason-Stadler GSI-61 clinical audiometer and presented via Etymotic Research ER-3A earphones to each participant, seated within a double-walled, sound-treated booth (Industrial Acoustics Company, Inc.). The audiometer was calibrated as specified by current standards (ANSI, 1996).

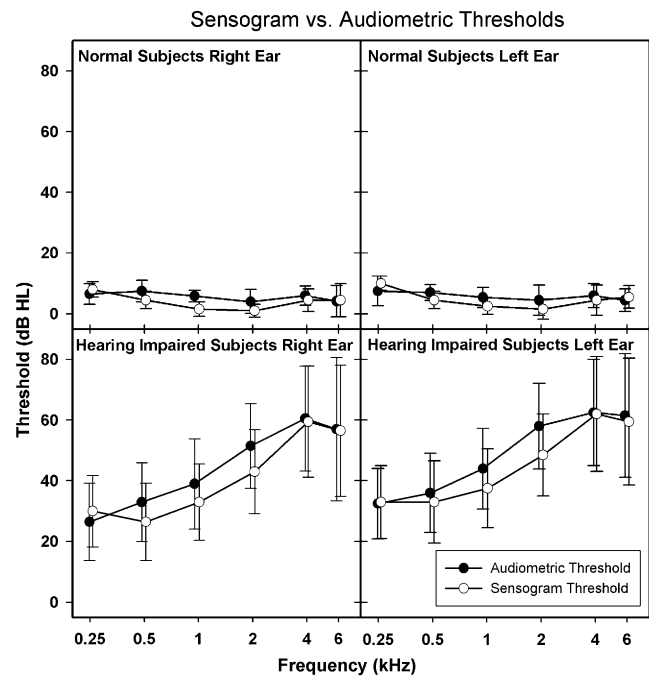
The order of audiometric and behavioral in situ threshold measurements was counterbalanced. Behavioral in situ thresholds were then measured for each ear in a double-walled sound-treated booth using the Sensogram program in the Widex Compass Fitting software V 4.5.1, with a Widex Inteo I-19 BTE hearing aid as the stimulus transducer coupled to an Etymotic Research ER-3A earphone tip. Insertion depth of the ER-3A insert was determined by aligning the distal edge of the ear phone tip with the ear canal opening. This was done to control insertion depth and maintain uniformity of sound transmission throughout participants. Thresholds were obtained using a 5 dB step size via the Modified Hughson-Westlake technique. Results from the audiometric thresholds were compared across frequency to thresholds obtained by in situ measurement.

## Experiment 1 Results

### *In Situ Threshold Response*

Thresholds from conventional audiometric methods and in situ thresholds using the Sensogram method for normal-hearing participants and hearing-impaired participants are presented in Figure 1. A repeated-measures analysis of variance (ANOVA) was performed to determine significance. The within-participants factors included method (Sensogram or conventional audiometry), frequency (250–6000 Hz), and ear (left or right). The between-participant factor was group (hearing impaired or normal hearing). Results of the ANOVA revealed significant effects of method ( $F(1,18) = 80.4, p < 0.05$ ), frequency ( $F(5,90) = 14.2, p < 0.05$ ), ear ( $F(1,18), p < 0.05$ ), group ( $F(1,18), p < 0.05$ ), and significant method by group ( $F(1,18) = 10.81, p < 0.05$ ) and frequency by method ( $F(5,90) = 24.1, p < 0.05$ ) interactions, but no and frequency by ear ( $F(5,90) = 0.31, p = 0.90$ ) or ear by method ( $F(1,19) = 0.17, p = 0.69$ ) interactions.

The post hoc statistical analysis was performed using Fisher's LSD (least significant difference). Interactions of method by frequency revealed a statistically significant threshold difference at 500, 1000, and 2000 Hz (Sensogram vs. conventional audiogram;  $p < 0.05$ ). Thresholds obtained via Sensogram were shown to be significantly lower at 500, 1000, and 2000 Hz than thresholds obtained via conventional audiometry ( $p < 0.05$ ).



**Figure 1.** The average audiometric and Sensogram thresholds are shown for the normal and hearing-impaired groups. Error bars represent 1 SD.

## Experiment 2: Verification of Starkey IREMS™

### *Participants*

The same 10 normal-hearing adult participants used in Experiment 1 participated in Experiment 2.

### *Procedure*

RECD measures were obtained from each participant via the Starkey hearing aids, as well as a commercially available Audioscan Verifit external real-ear measurement device. The order of RECD measurement method was counterbalanced. For the measure obtained using the Audioscan Verifit, a probe tube microphone was inserted into the participant's ear canal using proper depth and insertion protocol (ANSI, 1997). Insertion depth was measured in millimeters to normalize the insertion depth of other real-ear measurement methods. The ER-3A foam tip was inserted into the participant's ear canals to simulate a hearing-aid earmold. The RECD measurement was then obtained for each normal-hearing participant bilaterally on the Audioscan Verifit.

The second RECD measurement obtained used the IREMS feature in the Destiny 1600 BTE hearing aids in the Starkey Laboratories Inspire OS™ 3.0 software. The hearing aids were assembled with a special tone hook to obtain real-ear data, according to the on-screen directions located in the software. To do this, a small probe tube connected to the front microphone and

tubing was attached to the tone hook of the hearing aids. The probe tube was inserted into the participant's ear canal using proper depth and insertion protocol (ANSI, 1997). The hearing aids were placed behind the participant's ears, and ER-3A insert earphone tips were coupled to a pair of Destiny 1600 BTE hearing aids via a piece of standard size 13 single-bend tubing and placed in the participant's ears. RECD values were obtained bilaterally for each normal-hearing participant. RECD data obtained using the Starkey IREMS feature were then compared to the RECD values obtained using benchmark equipment, namely the commercially available Audioscan Verifit external real-ear measurement system.

## Experiment 2 Results

### Integrated Real-Ear Measurement

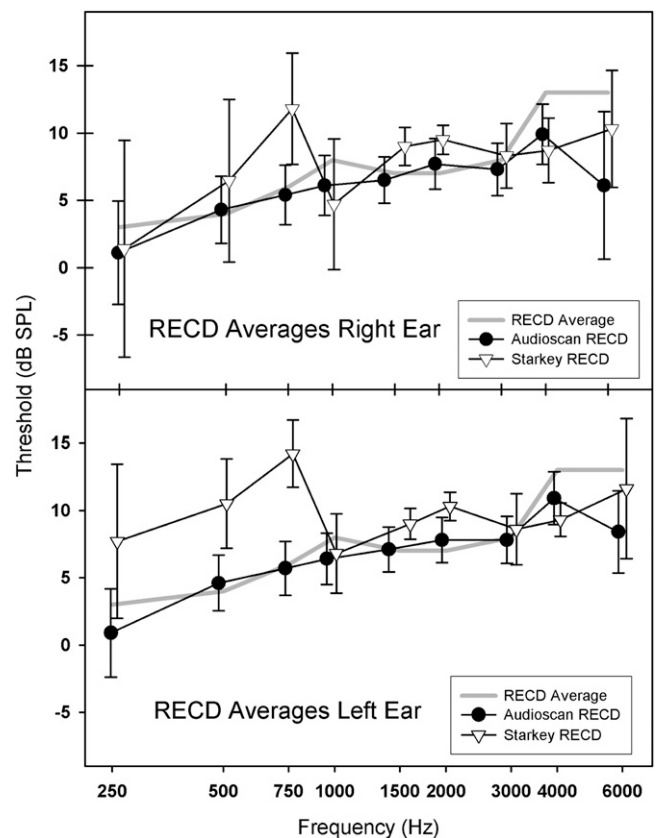
Real-ear coupler difference values from the Audioscan Verifit and Starkey IREMS are presented in Figure 2. A repeated measures ANOVA was performed to determine significance using method, frequency (250–6000 Hz), and ear as factors. Results of the ANOVA revealed a significant effect of method ( $F(1,9) = 11.59, p < 0.05$ ), a significant effect of ear ( $F(1,9) = 7.32, p < 0.05$ ), and frequency ( $F(8,72) = 13.66, p < 0.05$ ). There was also a significant frequency by method ( $F(8,72) = 8.5, p < 0.05$ ) and ear by frequency by method ( $F(8,72) = 3.1, p < 0.05$ ) interactions. The ear by method ( $F(1,9) = 1.2, p = 0.30$ ) and ear by frequency ( $F(8,72) = 1.6, p = 0.13$ ) interactions were not significant.

The post hoc statistical analysis was performed using Fisher's LSD. Post hoc analysis revealed statistically significant differences in real-ear coupler difference values at frequencies of 250, 500, 750, 1500, 2000, and 6000 Hz ( $p < 0.05$ ) by method (Starkey IREMS and the Audioscan Verifit).

## DISCUSSION

### Experiment 1: In Situ Threshold Response

A significant difference between thresholds obtained via the Sensogram method and conventional audiometric methods was found for both groups (hearing impaired and normal hearing) at frequencies of 500, 1000, and 2000 Hz. Since these threshold differences were all within 5 dB for the normal group, these differences are not considered clinically significant. The results for the hearing-impaired participants, on the other hand, are both statistically and clinically significant at 1000 and 2000 Hz. The average difference in threshold by method at 1000 Hz was 6.25 dB HL and 9.0 dB HL at 2000 Hz with the Sensogram thresholds being better at each frequency tested. These two fre-



**Figure 2.** Average RECD values are compared against group averaged as measured by the Verifit and the Starkey IREMS. Error bars represent 1 SD.

quencies are important for speech understanding and would likely lead to under amplification at these frequencies. This under amplification may also lead to reduced audibility of the important speech frequency range, especially 2000 Hz, lowering intelligibility.

Once the unaided in situ thresholds measured via the Sensogram are used to predict aided thresholds, the free-field to microphone transfer function can be added to produce the predicted function audiogram (Kuk et al, 2003). Kuk et al's anecdotal data showed that 25% of participants differed by  $\geq 5$  dB in the measured-to-predicted difference in aided soundfield thresholds. Although the utility of a functional audiogram is passé relative to modern methods (i.e., real-ear measurements), the Sensogram utilizes the important advantages over a functional audiogram. The functional audiogram allows an estimate of gain for low-level, narrowband signals by assessing free-field, in situ thresholds. The practical utility of such a test is maximized for linear hearing aids where gain is fixed regardless of the input level. The Sensogram allows the patient to respond to signals generated by the hearing aid to determine absolute thresholds for each ear. The data can then be used to specify output levels of the Widex hearing aid accounting for venting, residual ear-canal

volume, and tympanic membrane impedance as part of the gain calculation without being affected by standing waves or the HRTF (Kuk et al, 2003). The use of in situ thresholds does not negate the need for real-ear verification, however. Widex's recent product offerings, unavailable at the time this study was executed, include an integrated real-ear system. While this innovation offers the possibility of reducing the need for expensive equipment purchases, it is unclear that it will save a significant time in the fitting process. It is plausible that the prescribed gains based on the in situ thresholds may be closer, on average, than those based on audiometric thresholds for nonoccluding earmolds. For this subset of patients, the number of required adjustments may be fewer, though it is doubtful that the time savings would have a significant impact in a clinical practice.

The design of the experiment was set up with a foam insert mimicking the same occlusion effect observed when using a full shell earmold or ITE hearing aid with no venting. In this manner, the Sensogram condition was matched making comparison to standard audiometry appropriate. Since the conditions were matched, any effect of occlusion would be reflected in both measures equally. The Sensogram is designed to account for changes in frequency response the ear canal undergoes with the insertion of an earmold, so we are only testing one type of hearing-aid or earmold style in our current experiment. Naturally, a full-shell nonvented earmold is not the only earmold style that patients are currently fit with in the clinical setting; patients can now be fit with earmolds with various vent sizes or even open-fit technology. The Sensogram was designed to account for the effects of earmold venting in measured threshold. The design of the current study allowed for a direct test of the Sensogram. If the Sensogram produces accurate audiometric thresholds, the Sensogram data and the audiometric data would agree. However, if a study is performed using different types of earmolds, namely ones including venting or open fits, a different study design would be required. From the results of our experiment, it appears plausible that the Sensogram would approximate the *changes* due to venting and earmold style noting that the absolute measurements may not accurately portray absolute thresholds under those conditions. Further testing using various configurations of earmolds and open-fit style hearing aids needs to be performed to verify this prediction.

## Experiment 2: Verification of the Starkey IREMS

Comparison of RECD values obtained via the Audioscan Verifit and the Starkey IREMS revealed a statistically significant difference in the two real-ear measurement methods by frequency. The RECD values we obtained from our participants using the Verifit were close to the average RECD values for adults pre-

sented in the Verifit software (Seewald et al, 2005). To quantify the degree of "closeness" to the average RECD, a root mean square (RMS) difference was calculated between both the Verifit compared to the adult average RECD and the Starkey IREMS compared to the adult average RECD. The RMS difference for the Verifit-to-average RECD was 1.25 dB. This contrasts with the Starkey IREMS-to-average RECD RMS difference of 2.80 dB, over double that of the Verifit system. This supports the notion that the Verifit system (or other stand-alone real-ear systems with calibration ability) is still the preferred method for making real-ear measurement. The Starkey IREMS RECD values were statistically different at all frequencies tested except at 1500 and 3000 Hz. These results suggest the Starkey IREMS system is not as accurate as the Audioscan Verifit real-ear measurement system. Differences in acoustic impedance of a particular hearing instrument and insert earphones have been attributed to measured differences in RECD (Munro and Toal, 2005). It is possible, therefore, that differences in acoustic impedance between the Verifit and Starkey systems may have contributed to the differences in RECD.

One reason for the large degree of variability across participants observed in RECD values obtained by the Starkey IREMS could be lack of an in-office method for calibration of the reference microphone to the probe tube. In the Starkey IREMS the receiver of the hearing-aid functions as the signal generator, and the front microphone of the hearing aid serves as the probe microphone. The receiver is calibrated to the Inspire software when the hearing aid leaves the factory, and no other calibration of the receiver is performed (Yanz and Galster, 2008). If any microphone drift or receiver movement occurs during the shipping process or daily use of the hearing aids, or changes due to replacing the probe tube, then decreased accuracy of RECD values could be observed. A difference in the microphone response or probe tube that is not accounted for in the measurement could explain why there was a significant effect of ear in the present study. The Audioscan Verifit real-ear measurement system, however, is calibrated on a daily basis and when a new probe tube is used before each real-ear measurement occurs. While the reference microphone is not active during RECD measurements, the daily calibration takes into account any changes that have occurred, including microphone drift or physical changes with the probe microphone tube or the signal generator speakers. Speech mapping requires the use of the reference microphone to actively monitor and control the level of the free-field stimulus during real-ear testing. Speech mapping is the use of calibrated recorded speech stimuli in a real-ear measurement to determine that amplification targets have been reached during a hearing-aid fitting. The real-time results for the amplified speech region are overlaid on

a patient's audiogram and presented visually on a computer monitor (Moore, 2006). The Starkey IREMS has no way to calibrate the system to a new probe tube, and this could cause inaccurate gain measurements during speech mapping procedures using the Starkey IREMS.

The Starkey IREMS required more changes to the hearing instrument to perform the real-ear measurement compared to the Audioscan Verifit. The Starkey IREMS required the back microphone of the hearing aid be covered with a sleeve, the tone hook switched to a tone hook that was compatible with the probe microphone, and then the patient's earmold attached to the new tone hook with the probe microphone inserted into the ear canal. Starkey IREMS, as available at the time of data collection, lacked a reference microphone, since the front microphone of the hearing aid is acting as the probe microphone. These issues persisted in the subsequent model, the S-series with Live Real Ear Measurement System (Starkey Laboratories, Inc., 2009). The use of the Audioscan Verifit to perform real-ear measurements requires a daily calibration of the probe microphone and placement of the probe microphone into the ear canal, the unaltered hearing aids placed on the patient, and the reference microphone placed on the patient's ears. Both methods of real-ear measurement can be performed quickly by a trained hearing health-care professional, but the Audioscan Verifit method appeared to be faster due to no modifications to the hearing aid being required for real-ear measurements. Results from the experiment show the stand-alone Audioscan Verifit real-ear measurement system to still be the preferred method for performing real-ear measurements on a patient during the fitting of hearing aids clinically. Both the Starkey IREMS and Audioscan Verifit can be used to perform speech mapping, but accurate RECD values are required to obtain valid data.

## GENERAL DISCUSSION

The Widex Sensogram appears to have provided thresholds that varied at several important frequencies from standard audiometric procedures. Such variations could lead to over- or underamplification. The current data shows that at higher levels of output during threshold testing, the hearing aids appear to be producing signals that are of greater intensity than specified at 0.5, 1.0, and 2.0 kHz providing artificially low thresholds and likely leading to underamplification. This large difference in thresholds was not observed for the normal group. It is reasonable to assume, therefore, that the hearing aid is not simply outputting levels higher than intended at all times but, rather, could be a result of a nonlinear transducer or amplifier. Also, this effect was remarkably consistent for both ears,

meaning that the effect remained for both devices, and therefore is not likely to be a function of a bad hearing-aid unit.

As discussed earlier, the technology, as promoted by Widex, is intended to serve as a replacement for a functional audiogram. Given a well-functioning version of this technology, several aspects would lead one to prefer this over a functional audiogram, including accounting for vent effects and ear drum impedance. Real-ear measures, however, are still required for accurate gain to be verified once the hearing aid is programmed. Widex has since integrated this feature on their newer models. Since no objective data are currently available, the accuracy of this feature is unknown at this time.

Data from the Starkey IREMS did not match or even parallel data obtained from benchmark equipment for several frequencies. The Starkey IREMS performed real-ear measurements providing objective information that is required for gain verification, although not in alignment with benchmark equipment. This is possibly due to the fact that there is no reference microphone as well as there being no ability to calibrate the Starkey IREMS prior to testing. A possible design modification, such as using the rear microphone (in a two-microphone directional system) and the addition of calibration, could resolve these issues. However, if a hearing health-care professional has the financial ability to purchase a piece of stand-alone real-ear measurement equipment for the fitting of hearing aids on patients, it would be a more reliable and accurate piece of equipment.

Hearing-aid technology is progressing in a direction to not only benefit the patient during the listening experience but to improve fitting as well. Traditionally, these latter improvements were achieved by enhancing the manufacturer's software. The technologies tested here represent an important step in that this is one of the first instances where hardware design has included the ability to make measurements typically reserved for specialized equipment. It is not uncommon for the first implementation of technology to fall short of its potential, as appears to be the case with the two innovations included in this study. Regardless of the shortcomings of these first iterations, technologies to improve the fitting process and, more important, to facilitate real-ear measures as is intended with Starkey's IREMS have great potential to increase the number of audiologists using real-ear measurement systems.

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