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Reliability of audiometric thresholds obtained with insert earphones when used by certified audiometric technicians

Barbara Bell-Lehmkuhler, Deanna K. Meinke[1], Allison Sedey[2], Cassie Tuell[3]

RidgeGate Hearing Clinic, 10099 RidgeGate Parkway, #230, Lone Tree, CO 80124, [1]University of Northern Colorado, Audiology and Speech Language Sciences, Campus Box 140, Greeley, CO 80639, [2]University of Colorado, Boulder, Speech, Language, and Hearing Sciences, 409 UCB, Boulder, CO 80309, [3]University of Northern Colorado, Audiology and Speech Language Sciences, Campus Box 140, Greeley, CO 80639, USA

Abstract

Clinical audiologists and audiometric equipment manufacturers have embraced the clinical use of insert earphones; however, their use in audiometric testing in occupational hearing loss prevention programs has been limited. This study was undertaken to research whether certified audiometric technicians *without* practical hands-on training could reliably use insert earphones when compared to a clinically experienced audiologist. Hearing thresholds were obtained on 60 human ears by six certified audiometric technicians using insert earphones for the first time. Technician-acquired audiometric thresholds were compared to thresholds obtained under the same conditions by a clinical audiologist experienced in the use of the insert earphones. Statistical analyses of audiometric thresholds were performed to investigate the relationships between audiometric threshold values at each frequency obtained by certified technicians vs. the audiologist. These relationships were examined for the group as a whole as well as when ear tip size and earphone insertion depth varied between the audiologist and the technicians. No significant differences ($p > .01$) were found between mean group thresholds at any of the test frequencies (500-8000 Hz). Mean group thresholds differed by <1.2 dB. Pearson Product-Moment correlation (PPMC) coefficients suggested that thresholds obtained by the audiometric technician were highly correlated with those obtained by the audiologist. There were no significant threshold differences ($p > .01$) even when the audiologist and technicians varied in their selection of ear tip size or in the amount of insertion depth achieved. This study suggests that CAOHC-certified audiometric technicians can reliably use insert earphones without practical training when testing in quiet environments by reading the earphone package directions provided by the manufacturer.

Keywords: Audiometric monitoring, audiometric technician, hearing test, insert earphone, occupational.

Introduction

Historically, audiometric testing in occupational hearing loss prevention programs has been performed with Telephonics TDH-39 headphones with MX-41/AR or MX-51/AR cushions calibrated to the audiometer. Etymotic Research introduced insert earphones for clinical audiometric use in 1984 as an alternative to conventional supra-aural headphones.[1] Since that time, the multiple advantages of using insert earphones for standard audiometric testing have been well documented.[2,3]

Clinical audiologists and audiometric equipment manufacturers have embraced the use of insert earphones; however, their use in audiometric testing in workplace hearing loss prevention programs has been limited. This is due, primarily, to a reference within the current U.S. Occupational Health and Safety Administration (OSHA) Occupational Noise Exposure: Hearing Conservation Amendment; Final Rule of March, 1983 that specifically references an outdated American National Standards Institute (ANSI) Specification for Audiometers S3.6-1969.[4,5] The OSHA Amendment states in Paragraph (h)(2):

"*Audiometric tests shall be conducted with audiometers (including microprocessor audiometers) that meet the specifications of, and are maintained and used in accordance with, American National Standard Specification for Audiometers, S3.6 -1969.*

The ANSI S3.6-1969 standard states in Paragraph 3.2:

"Each earphone shall be equipped with an earphone cushion for contact with the head of the subject."

In addition, paragraph 3.3, "Headbands" states:

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"*There shall be provided a spring headband which is adequate to hold the earphones against the ears to provide a satisfactory seal*."

Insert earphones have neither cushions nor headbands, so they do not meet the requirements.

Gross addressed many issues related to the cost and time efficiency of using insert earphones in hearing loss prevention programs (HLPP).[6] Insert earphone advantages include: a reduction in the impact of background noise levels on audiometric thresholds, greater interaural attenuation, elimination of collapsed ear canal artifact, greater subject comfort, greater flexibility in fitting different head sizes and improved infection control.

It is required by the OSHA Hearing Conservation Program (HCP) regulation that a trained professional or technician performs the audiometric testing in an industrial hearing loss prevention program in order to assure accurate results. The U.S. OSHA regulation (Hearing Conservation Amendment to the Occupational Safety and Health Administration Noise Rule, 29 CFR 1910.95[4] states that:

"The audiometric test shall be performed by a licensed or certified audiologist, otolaryngologist or other physician, or by a technician who is certified by the Council for Accreditation in Occupational Hearing Conservation, or who has satisfactorily demonstrated competence in administering audiometric examinations, obtaining valid audiograms, and properly using, maintaining and checking calibration and proper functioning of the audiometers being used".

The Council for Accreditation in Occupational Hearing Conservation (CAOHC) is an organization made up of representatives of different professional groups with an interest in hearing loss prevention. The organization was created to fill the need for guidelines and standards in the field of occupational hearing conservation. CAOHC's mission is to promote the conservation of hearing by enhancing the quality of occupational hearing conservation programs.[7] CAOHC has set training standards for certification of "occupational hearing conservationists" (OHC), which includes supervised practical hands-on audiometric testing experience. To become a CAOHC-certified OHC, the technician must complete a CAOHC approved 20-hour course and pass a written test, and to maintain certification they must complete an 8-hour recertification course every five years. The U.S. Mine Safety and Health Administration (MSHA), in its Health Standards for Occupational Noise Exposure (30 CFR Parts 56 and 57), requires audiometric testing to be performed under the direction of a professional supervisor and the technician must be certified by CAOHC or an equivalent certification organization.[5] Other training programs for audiometric technicians exist, such as in the various branches of the U.S. military. The Army has used audiometry technicians since 1996. Currently, the training for an Army audiometric technician is a 13-week program, which includes six weeks of classroom instruction and seven weeks of didactic experience. Many U.S. Army audiology assistants additionally take the CAOHC certification course.[8]

Several types of audiometers are available for audiometric testing and are differentiated primarily by the mode of operation; manual, automatic or Békésy, microprocessor and computer-based. The OSHA 29 CFR 1910.95 regulation states that "audiometric tests shall be conducted with audiometers (including microprocessor audiometers) that meet the specifications of, and are maintained and used in accordance with American National Standards Specification for Audiometers, S3.6-1969", as opposed to the current American National Standards Institute (ANSI) S3.6-2004.[9] According to special equipment distributors and HCP professional supervisors, the majority of OHCs performing audiometric testing use the microprocessor or computer-based type of audiometers. A 1979 study found that the results of microprocessor audiometry agree slightly better, within 4 dB, with manual audiometry than do the results of self-recording (Békésy) audiometry.[10]

Pure tone audiometry involves routine procedures that have been thoroughly documented for response reliability by studies and reporting done mainly by the military after World War II. Since that time, many studies have shown good reliability of repeated threshold measurements in the conventional-frequency range.[11] The accepted test/retest reliability, standard error of measurement for manual audiometry is 5 dB. Thus, clinical audiologists operate under the assumption that repeated thresholds within ± 5 dB reflect normal tolerance for clinical error.[11] Dobie found that test-retest variability in industry is similar to that which has been reported for clinical settings dependent upon the test frequency under consideration.[12] He states that "workers referred for otologic evaluation were found to have hearing levels which were, on the average, about 5 dB better than indicated by plant audiometry".

Concern has been expressed regarding the use of insert earphones for audiometric testing in hearing loss prevention programs and the use of insert earphones would be considered a violation of OSHA 29 CFR 1910.95 unless specific requirements are fulfilled. An OSHA regulatory letter of interpretation currently specifies the procedures required to implement insert earphones.[13] OSHA's letter of interpretation dated August 31, 1993 states "…conditions must be implemented by employers who intend to use insert earphones in order to meet the criteria of OSHA's noise standard." This extensive list includes using manufacturer's guidelines for proper use, technicians must be trained, audiometers must be calibrated in accordance with ANSI S3.6-1989, and at the time of conversion to insert earphones, testing must be performed with both types of earphones. This

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process has proved too cumbersome for general industry and has prevented widespread conversion to the use of insert earphones at this point in time.

In terms of clinical applications, it has been repeatedly demonstrated that insert earphones are reliable and audiometric results are consistent with those obtained with supra-aural headphones. Numerous studies have shown no clinically significant differences between thresholds obtained with insert earphones and supra-aural headphones when using manufacturer recommended calibration correction factors at 250, 6000 and 8000 Hz.[14-17]

Clark and Roeser found significantly better pure tone thresholds in the presence of high background noise levels when using insert earphones as compared to TDH-50P earphones.[18] Additionally, they reported that deeper insertion depth provided lower (better) thresholds at all frequencies. The deeper insertion depth resulted in a 2 to 6 dB improvement in thresholds. Lindgren and Berger also addressed insertion depth.[19] These researchers found that there was a tendency toward poorer hearing threshold levels (HTL) as the eartip was positioned further away from the eardrum. In the frequency range of 0.5 to 4 kHz, the difference amounted to 1.3 to 5.3 dB within the three categories of insertion depth: shallow, intermediate and full. However, no statistically significant differences in thresholds were found between the most appropriate (full and intermediate) insertion depths at any tested frequency.

Another advantage of insert earphones is higher interaural attenuation. Increased interaural attenuation can help circumvent the masking dilemma as well as eliminate the need for masking altogether in some cases. Killion *et al*, found that an additional 15-20 dB interaural attenuation could be obtained with deep insertion.[2] Munro and Agnew found nearly the exact same (15 to 20 dB) improvement in interaural attenuation with the use of the ER-3A insert earphone versus the TDH-39.[20] Again, this was obtained with a deeper insertion fit, which they described as “when the outside edge of the plug was flush with the entrance of the ear canal”. Insert earphones also address the problem of collapsing ear canals.[1]

Certainly, the advantages of using insert earphones would be equally beneficial to hearing testing conducted for occupational purposes. However the reliability of thresholds obtained with insert earphones when used by certified audiometric technicians in occupational HLPPs has not been previously evaluated.

Materials and Methods

This study was designed to compare air-conduction thresholds obtained by CAOHC-certified technicians and a licensed audiologist using insert earphones. The study was approved by the Institutional Review Board (IRB) at Central Michigan University. All listener and examiner subjects signed written consent forms prior to participation in the study. Each study participant received a small gift certificate as a gratuity for study participation.

Participants: Six CAOHC-certified technicians were recruited from local industries via local CAOHC certification course directors. All of the audiometric technicians were female and had never seen nor used insert earphones prior to their participation in the research study. The technicians were all experienced in industrial hearing testing using both manual and automatic audiometry. In addition, an audiologist with over ten years of clinical experience using insert earphones conducted hearing tests for comparison. Adult listener test subjects (≥18 years of age) were recruited from the general public and university staff by emailing and distributing recruitment letters. Listener exclusion criteria were limited to any subject with a positive history of ear surgery or a cerumen-occluded ear canal. Cerumen occlusion was defined as wax, which was estimated to occlude the ear canal 50% or more during otoscopic visualization. Wax occlusion was considered an exclusion criterion due to the deep insertion procedure required. The researchers did not want to cause further wax impaction or wax displacement that could be uncomfortable to remove later. All listener subjects were eligible study participants regardless of hearing status. A second audiologist was recruited and trained to record the observations regarding insert earphone tip size used, measure insertion depth and create a photographic record for each listener’s ear following every hearing test.

Instrumentation: The research was conducted at the auditory/neurophysiology lab at the University of Northern Colorado in Greeley, Colorado. All audiometric tests were conducted in a double-walled audiometric test booth. Standard audiometric set up was used with the insert earphones and subject response button inside the booth and the audiometer and examiner located outside the booth. Hearing testing was conducted in an ambient noise environment meeting the requirements set forth by the American National Standards Institute (ANSI) S3.1-1999 (R2003).[21] A single microprocessor audiometer, Maico 800 (serial # 38657), was used for all the audiometric testing using the standard automated test mode beginning with the left ear first. The audiometer was calibrated to the E-A-RTONE® 3A insert transducers. E-A-RLINK® foam tips were used during testing. Three sizes of the E-A-RLINK® foam tips were available for use: the 3C jumbo insert, the 3A standard insert and the 3B pediatric insert (Aearo Company).[22] Equivalent supplies of the three sizes of foam tips were available in the audiometric booth for use during testing.

Audiometric test procedure: Each technician (n=6) fitted the insert earphones on and tested five listener test subjects for a total of 30 listener subjects. The audiologist, using his or

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her own separate insert earphone fitting tested the same 30 listeners (n=60 ears). The order of testing was alternated by test session between the technician and the audiologist to control for potential threshold influences related to listener learning experiences. The audiologist tested each listener first during the second, third and sixth testing sessions while the technician tested the listeners first during the first, fourth and fifth testing sessions. Each listener was tested sequentially, once by the technician and once by the audiologist. The technician and audiologist were blind to each other's test results and foam tip choice. It was not feasible to have all technicians test all of the listener subjects (n=30) due to practical limitations related to subject travel, time and scheduling constraints.

All CAOHC audiometric technicians were oriented to the automatic operation of the Maico MA 800 microprocessor audiometer prior to conducting the hearing tests. A sequence of written instructions regarding the automatic use of the audiometer was also available for reference if needed. Pure-tone air conduction audiometric testing was conducted using the automated test mode of the audiometer. The frequencies tested were: 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz. Results were printed directly from the audiometer. All testing was begun on the left ear initially per standard occupational protocol.

Prior to conducting the hearing tests, the audiometric technician was given the insert earphone manufacturer written instructions with illustrations photocopied from the back of the E-A-RLINK® foam tips package to review for a maximum of five minutes. The audiometric technician was verbally instructed to select a foam tip size, place the insert earphones on the listener and test air-conduction thresholds using the automatic mode on the Maico 800.

Insert earphone depth measurement: A second audiologist was utilized to facilitate recordkeeping and to photograph and measure the depth of insertion of the insert earphones in the listeners' ears. Once an audiometric test was completed, the technician or audiologist was asked to move to a location away from the research area where they could not observe the measurements and ear photography. Recordkeeping included the following; (1) written notation regarding the tip size selected for each ear, (2) physical measurement of insertion depth and (3) photo of each ear with the insert earphone in place. Once these tasks were completed the insert earphones were removed from the listener's ears and the tips were discarded. The audiometric test printout was stapled to the observation form and placed in an envelope. This prevented visualization of the previous test results by the audiologist or technician performing the subsequent hearing test. The audiometer memory was also cleared prior to the next exam. Once the technician finished testing all listeners in the test session, they completed a brief written exit interview [Appendix A].

Insert earphone insertion depth was measured using a technique similar to that suggested by the insert earphone manufacturer (Elliott Berger, E-A-R Auditory Systems, personal communication, 2006). The posterior face of the foam tip was measured in relation to the entrance of the ear canal. When the posterior face of the foam tip was within the ear canal, measurements were noted as "intrusion" into the ear canal. When the posterior face of the foam tip extended distally from the entrance to the ear canal, the measurements were noted as "extrusion". If the posterior face of the plug was flush with the entrance to the ear canal, the measurement was recorded as 0 mm. These measurements were then utilized to calculate the insertion depth of the foam tip into the ear canal using the standard 12 mm foam tip length. For example, if a foam tip extruded 3 mm, the insertion depth would be 9 mm as illustrated in the "intermediate" example of insertion depth noted in Figure 1. If the posterior end of the foam ear tip was 3 mm inside the ear canal, then the insertion depth would be 15 mm as in the "full" insertion illustrated in Figure 1.

Data analysis: The audiometric data used for statistical analysis included audiometric thresholds obtained by the technician and audiologist at 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz for each ear tested. In addition, two commonly used frequency averages were calculated from the pure-tone test results. First, the average for the test frequencies used in the American Academy of Otolaryngology (AAO) 1979 impairment formula calculation (500, 1000, 2000 and 3000 Hz) was computed.[23] Second, the average for the test frequencies used in the OSHA (1983) significant threshold shift (STS) calculation was computed (2000, 3000 and 4000 Hz).[4] These two averages were selected due to their common applications in hearing loss prevention programs.

Data analyses consisted of descriptive statistics regarding audiometric thresholds, Student's paired *t*-tests and Pearson Product-Moment correlations (PPMC). The correlations were performed to investigate the relationships between audiometric threshold values at each frequency obtained by

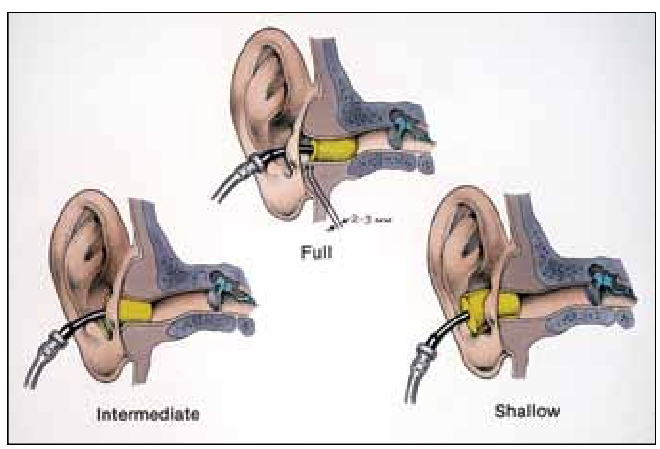

Figure 1: Illustration of insert earphone placement depths
Courtesy: Elliott H.Berger, Aearo Technologies

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certified technicians vs. the audiologist. This was examined for the group as a whole, as well as within subgroups of participants when audiologist and technician ear tip size or insertion depth differed. The statistical analyses were conducted using Statistical Package for the Social Sciences (SPSS) v.15 computer software.[24]

Results

Gender of the listener test subjects was distributed fairly equally. Thirteen (43%) were male and 17 (57%) were female.

Threshold comparisons: Comparisons of mean threshold values and standard deviations obtained by the certified audiometric technician vs. the audiologist are summarized in Table 1.

Mean threshold values were within normal limits (0-20 dB HL) for all test frequencies with the exception of 8000 Hz when tested by both the audiometric technicians and the audiologist. The audiologist's mean threshold values were consistently better, with the exception of 6000 Hz. However, these mean differences were minimal ranging from 0.3 (95% confidence interval = -1.7 to 2.6) to 1.2 dB (95% confidence interval = -0.3 to 2.7). The upper and lower limits of the 95% confidence intervals were no larger than 2.7 dB at any of the test frequencies.

Table 1: Comparison of mean audiometric thresholds and standard deviations obtained by certified technician vs. audiologist when using insert earphones

Test frequency (Hz)	CAOHC technician thresholds (dB HL)		Audiologist thresholds (dB HL)	
	Mean	SD	Mean	SD
500	11.3	11.2	10.3	12.4
1000	9.1	9.9	8.7	9.7
2000	12.7	16.0	11.5	15.7
3000	14.6	19.1	14.2	19.3
4000	15.2	21.9	14.6	21.8
6000	17.1	22.3	17.9	23.7
8000	28.1	24.1	27.9	25.3
2-, 3- and 4 kHz average	14.1	18.4	13.4	18.4
0.5-, 1-, 2-, 3 kHz average	11.9	12.9	11.2	13.3

Table 2: Paired *t*-test and correlation values when comparing thresholds obtained by audiologists versus technicians

Test frequency Hz		PPMC coefficient (*r*)
500	.28	.84*
1000	.45	.91*
2000	.12	.93*
3000	.57	.96*
4000	.32	.98*
6000	.14	.98*
8000	.79	.96*
2-, 3- and 4 kHz average	.25	.97*
0.5-, 1-, 2-, 3 kHz average	.21	.94*

*$p<.0005$

Student's paired *t*-tests were computed to evaluate potential differences between the audiologist and technicians mean thresholds for each test frequency. A conservative alpha of .01 was used because multiple statistical tests were conducted. No significant differences in thresholds were found between the technicians and the audiologist at any of the tested frequencies. Pearson Product-Moment correlation (PPMC) coefficients also were computed to evaluate the relationship between the thresholds obtained by the two different examiner groups. Threshold values were significantly and highly correlated ($r \geq 0.84$) at all test frequencies and for both pure-tone average calculations. Table 2 provides a summary of the *t*-test and correlation results obtained for each test frequency.

While the mean thresholds were very similar between the two tester groups and did not differ significantly, there were notable differences between technicians and the audiologist in some of the individual threshold measurements. This was anticipated due to the inherent variability of threshold measurements. Figure 2 illustrates the percentage of time that pure-tone thresholds varied (between the audiologist and the technician) by more than 5 dB. Thresholds obtained at both 500 Hz and 8000 Hz varied 20-25% of the time, typically with the audiometric technician results being poorer. This is in comparison to the remainder of the thresholds (1000-6000 Hz) that varied by more than 5 dB less than 10% of the time.

Choice of insert earphone tip size: The audiologist and the audiometric technician chose foam insert tips that differed in size for 12 years (6 listeners), or for 20% of the ears tested. In all cases where the insert size differed, the audiologist chose

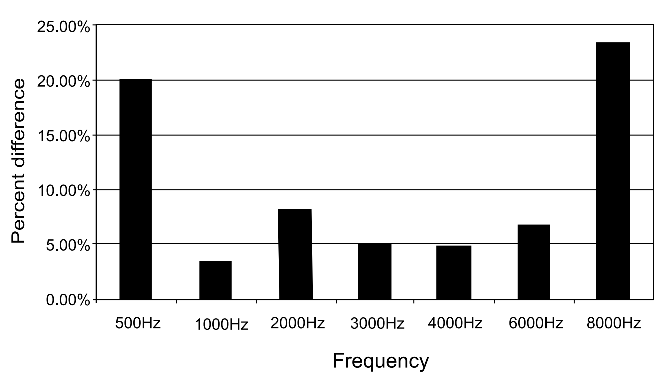

Figure 2. Percentage of time that thresholds differed by ≥5 dB between tests performed by an audiologist and tests performed by a certified audiometric technician

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a smaller size (3B) than the technicians (3A). The larger 3C jumbo size eartip was not used for any of the ears by either the audiometric technician or the audiologist. There were no instances of a tester using a different ear tip size for each ear of a single listener.

For the 48 ears where the choice of insert earphone tip size did not differ, the mean threshold differences were not significant ($p > .01$) and ranged between 0 and 1.04 dB. PPMC coefficients for this same sub-group suggest that thresholds are highly correlated (r = 0.90 to 0.98) when the choice of earphone tip size does not vary. For the 12 ears where the choice of earphone insert size did differ, mean threshold values were not significantly different ($p > .01$) and differed between 0 and 5.0 dB. In this instance, the PPMC coefficients ranged from r=0.65 (500 Hz) to r=0.97 (6000 Hz) suggesting a high correlation for all test frequencies except 500 Hz which was moderately high. Table 3 provides a summary of the PPMC statistical analysis coefficients based on the similarity of the choice of insert earphone tip size.

Insertion depth differences: Insertion depth differences were considered as a possible variable related to threshold differences. Lindgren and Berger categorized insertion depth into three categories, shallow, intermediate and full.[19] Using this same approach, categorization of insertion depth was based on the following: full insertion was measured as 2-3 mm past the floor of the concha; intermediate insertion was defined as 2-3 mm outside the floor of the concha and shallow insertion was defined as having "only the frontal part of the foam tip entered into the ear canal." Using the same Lindgren and Berger categorization approach, Figure 3 contrasts the distribution of tip insertion depths obtained by the audiologist as compared to the depths obtained by the certified audiometric technicians.

An arbitrary insertion depth difference of ±2 mm between the technicians and the audiologist was used to determine if insertion depth was the "same" or "different". Twenty-six ears (43%) were considered to have the same insertion depth and the remaining 34 ears (57%) were considered to differ in insertion depth. Most insertions differed by more than1-2 mm when comparing technicians to audiologists.

Table 3: Correlation coefficients for thresholds obtained when choice of insert earphone tip size is the same for both the audiologist and technician versus when the choice differed

Test frequency (Hz)	Insert tip size same (n=48)	Insert tip size differs (n=12)
500	.91*	.65*
1000	.93*	.86*
2000	.95*	.92*
3000	.96*	.95*
4000	.98*	.95*
6000	.99*	.97*
8000	.96*	.94*
2-, 3- and 4 kHz average	.97*	.95*
0.5-, 1-, 2-, 3 kHz average	.96*	.89*

*p<.0005

The 3A insert earphone instruction manual recommends an insertion depth of 14-15 mm into the ear canal (Etymotic Research, 2007). Figure 4 illustrates differences in earphone tip insertion depth from another perspective. In this case, insertion depth is calculated in terms of the absolute depth of insertion into the ear canal for the foam earphone tip.

Figure 4 illustrates that the technicians were less consistent in the placement of the earphone as compared to the audiologist. Both extremes of shallow insertions and deeper insertions occurred more commonly for technicians than audiologists. The audiologist, on the other hand, was more consistently in the area of + or – 3mm from the canal aperture. Technicians achieved full insertion as defined by the manufacturer on 12 (20%) insertions, while the audiologist achieved full insertion on 4 (7%).

When insertion depths were considered the same (26 ears), mean threshold differences were again not significantly different ($p > .01$) and ranged from 0.19 to 2.1 dB. PPMC coefficients were again high with a range of r=.727 to r= .984 [Table 4]. Essentially the same outcomes were evident for the 34 ears that were categorized as having different insertion.

Exit Interviews: Each audiometric technician was given a brief exit interview at the end of each testing session. All of the technicians indicated that the written earphone instructions were easy to understand and helpful. The majority of the technicians also reported that the size of the insert was easy to choose and that the inserts were easy to attach to the earphones. The majority of the technicians reported that the inserts were easy to insert into the listeners' ears. Five out of six rated the insert earphones as "overall

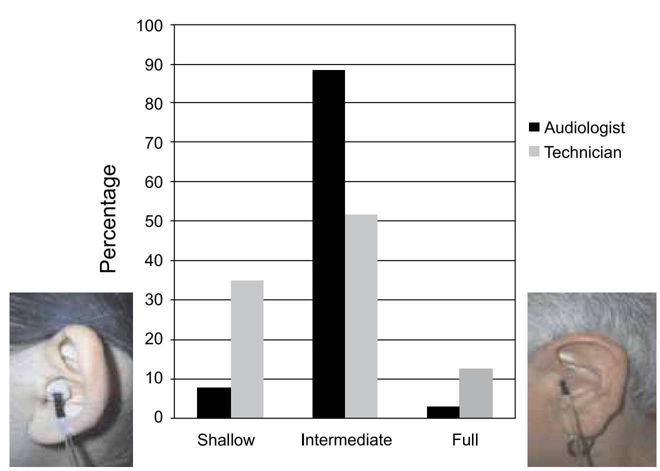

Figure 3. Distribution of insertion categories by percentage

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Table 4: Results of the correlation analyses of mean thresholds obtained by the technicians and the audiologist computed separately for when insertion depths were the same versus different

Test frequency (Hz)	Insertion depth is the same (≤2mm) (n=48)	Insertion depth is different (>2mm) (n=12)
	PPMC coefficient (r)	PPMC coefficient (r)
500	.73*	.89*
1000	.79*	.95*
2000	.93*	.94*
3000	.95*	.96*
4000	.97*	.98*
6000	.98*	.99*
8000	.95*	.96*
2-, 3- and 4 kHz average	.96*	.97*
0.5-, 1-, 2-, 3 kHz average	.89*	.96*

*p<.0005

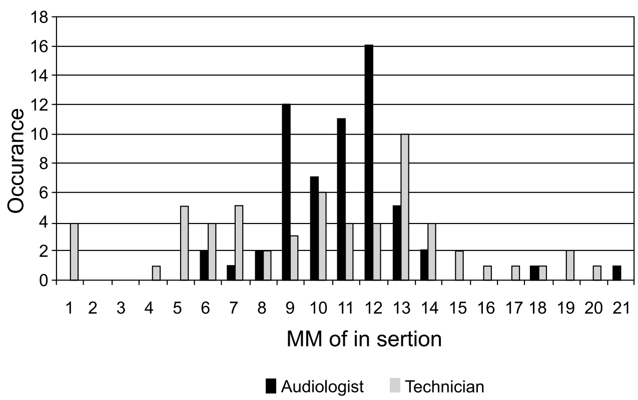

Figure 4. Insert earphone tip insertion depth, audiologist vs. technician

easy to use." However, three out of six reported they would prefer to continue to use traditional, supra-aural headphones, two stated they preferred the inserts and one stated that they would be comfortable with either. Some of the notable written comments included the following: (1) "instruction on how to pick the size of inserts to use would be helpful"; (2) "the more I used them, the more comfortable I felt with the inserts"; (3) "the inserts took longer to put in" and (4) one technician stated that she was concerned because she did not know if the earphones were comfortable to the listener.

Discussion

Audiometric threshold reliability

In general, the results of this study suggest that certified audiometric technicians can reliability obtain hearing thresholds when using insert earphones coupled to a microprocessor automated audiometer without practical training. Mean threshold differences were <1.2 dB for all test frequencies with the largest lower/upper limit of the 95% confidence intervals being 2.7 dB. Such minute differences are not felt to be clinically or occupationally relevant. It may be worth noting that the high correlation coefficients may not only be related to the ability of the technician to use insert earphones properly, but perhaps also to the consistent threshold determination strategy inherent in microprocessor controlled audiometry. These results parallel the improved reliability noted by Harris[10] for microprocessor-controlled audiometry as compared to manual audiometry.

Contrary to expectations, it appears that insertion depth is not critical for reliable audiometric thresholds in this controlled laboratory context. Despite large variations in insertion depths obtained by the audiometric technicians and those obtained by the audiologist, the threshold values were still highly correlated and without any significant differences. These findings are consistent with Lindgren and Berger,[19] who found no statistically significant differences in hearing thresholds across three categories of insertion depth (shallow, intermediate and full) or over a 4 to 6 mm change of insertion depth. It is interesting, however, that the insertion depths of the technicians were more variable, with half (52%) falling within the intermediate category vs. 88% of the audiologist insertions which were within the intermediate category.

The results of the present insertion depth analysis are also consistent with Clark and Roeser when testing under "quiet" conditions.[25] It should be noted that Clark and Roeser found that insertion depth was a critical factor when testing under high ambient noise conditions as compared to quiet test conditions. A deeper insertion depth was necessary to achieve maximum real ear attenuation. Audiometric technicians may encounter higher ambient noise levels when testing in industry and this situation is not reflected in the test conditions used in the present study. This consideration may be especially important since audiometric technicians are more likely to have a shallow earphone insertion. Therefore, additional study is needed to evaluate the influence of tip insertion depth obtained by audiometric technicians when testing in high ambient noise environments.

The possibility of wax occlusion is a potential disadvantage of insert earphones. The insert phones may come into direct contact with cerumen and the lumen of the insert earphone could become occluded and reduce the sound pressure level of the stimuli and lead to invalid threshold measurements. In comparison, a supra-aural earphone diaphragm is less likely to be in direct contact with cerumen, however thresholds obtained with supra-aural earphones on ears with partial or complete wax impactions are also potentially invalid.[25] Certainly audiometric testing is ideally performed on ears without evidence of wax occlusion regardless of earphone type.

Choice of ear tip size may potentially be a test reliability concern. It is interesting to note that the technicians tended

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to choose larger tip sizes, and those thresholds were poorer in comparison to the ones obtained with a smaller tip size. Although, this study did not find a significant difference in mean thresholds obtained with larger vs. smaller tip sizes, the number of subjects was small (n=12) and this may have limited the statistical power for this analysis. Additional studies should be undertaken to ascertain whether the choice of tip size alone influences audiometric thresholds when tested on the same individual. It is worth mentioning that in one instance, the audiologist measuring the insertion depth of the earphones noted that the sound bore tubing was crimped when visually inspecting the tip after removal from the listener's ear. It is possible that larger tip sizes are more vulnerable to distorting the sound tube bore or perhaps the sound tube aperture becomes occluded against the first bend of the ear canal.

Technician training implications

The results of this study suggest that trained technicians can follow and use the written package directions provided by the insert earphone manufacturer and obtain reliable audiometric results without practical hands-on training in advance. So, it appears that the current written directions are adequate for these purposes. However, as was stated by some of the technicians, written guidance about which insert size to choose for certain listeners would be helpful. Insert earphone directions could be modified to include information about fitting. For instance information could be provided to the user suggesting that they visualize the opening to the individual ear canal prior to selecting the tip size. Additional information about the distributions of sizes according to gender might be helpful, e.g., a technician might be more likely to choose a smaller tip size for a woman if the percentage of adult women using that size were known. Perhaps the instructions might include a statement to encourage the technician to select an alternative tip size when the first choice does not seal deeply within the ear canal. It may also be necessary to suggest that different sized eartips may be necessary for each ear of an individual listener.

CAOHC-certified technicians are trained to use supra-aural headphones but also are instructed in the insertion/fitting of hearing protection. Consequently, it is not surprising that the technicians were comfortable manipulating the insert earphones since this application is similar to fitting a foam hearing protector on a worker. The same degree of skill and comfort may not be applicable to audiometric technicians practicing without CAOHC training. Even though reliable test results were obtained in this study, some of the individual threshold variability might be reduced with additional practical training in the use of insert earphones.

Clark and Roeser had their subjects open and close their mouths 3-4 times to properly seat the insert earphone tip.[26] This was not evaluated in this research; however it may be beneficial to consider some additional written directions regarding the stability of the fit of the earphone. For instance, a shallow fitted tip might easily dislodge from the ear canal during testing. It would be beneficial for audiometric technicians to be aware of this potential situation and how to prevent it from occurring. In other instances, audiologists report inserting the earphone deeply until patient discomfort is detected and then readjusting the insertion to a slightly less deep and comfortable position. This fitting technique was also suggested by Etymotic Research.[27] Audiometric technicians may be less likely to use this technique due to limited familiarity with auditory disorders and patient comfort issues.

It would seem that CAOHC certification training curricula could easily incorporate insert earphone use and practical skill development during the standard 20-hour training course. The hearing protector training component could easily be adapted to include insert earphone tip choice and fitting. The audiometric practicum could also include hands-on testing experience with insert earphones. If insert earphones are to be implemented by industrial hearing loss prevention programs, the training opportunities and requirements for audiometric technicians will be an important consideration.

Hearing loss prevention program implications

Although this research project was not conducted in an industrial setting, the implications are felt to be relevant to such programs. The study suggests that insert earphones could be used reliably in hearing conservation programs when testing is done by certified audiometric technicians in quiet test environments. This is encouraging when one considers that the clinical advantages of using insert earphones can potentially be reaped in the industrial test environment. In fact, it may be more critical to use insert earphones in this environment due to the higher ambient noise levels encountered during on-site audiometric testing and in mobile test vans. Audiometric technicians are perhaps more likely to overlook a collapsing ear canal and the use of insert earphones might alleviate this potential test artifact. In addition, other benefits related to the use of insert earphones such as greater interaural attenuation, greater subject comfort, improved hygiene, and less maintenance are all desirable attributes to incorporate into audiometric monitoring protocols used in industry.

One last consideration for hearing loss prevention programs relates to threshold averaging used for STS or worker impairment determinations. There is no evidence from this study that the threshold averaging contributes to any increased differences when certified audiometric technicians use insert earphones. Consequently, the use of insert earphones by audiometric technicians testing in a quiet environment would not be expected to impact regulatory compliance or workers' compensation claim status.

Future implications

Additional research into the actual field benefits of insert

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earphone use in industry is warranted. It is necessary to pursue additional investigations regarding the practical implementation and reliability of insert-earphones using both certified and non-certified audiometric technicians when testing on-site and in mobile vans. It is also not known if audiometric thresholds obtained with insert earphones using a manual audiometric technique would suggest the same level of reliability as those obtained with automated audiometry.

Finally, this research may ultimately benefit the workers in hearing loss prevention programs. If the field (industrial) transition to insert earphones takes place in the future, the employees in an employer-based audiometric testing program will benefit from receiving hearing testing that may improve threshold measurement accuracy, reduce subjective complaints regarding ambient noise levels, minimize clinical referrals and provide for a more hygienic test technique. All of these potential benefits would contribute towards effective hearing loss prevention programs aiming to prevent noise-induced hearing loss in the workplace.

Address for correspondence:
Dr. Barbara Bell-Lehmkuhler,
RidgeGate Hearing Clinic,
10099 RidgeGate Parkway, #230,
Lone Tree, CO 80124, USA.
E-mail: bbell@integratedent.com

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Appendix A

Exit Interview sheet for subject technicians

Exit interview for technicians using insert-earphones

Please answer the following questions regarding your experience using the insert earphones for hearing testing:

The written earphone instructions were easy to understand.	□ .Yes	□ No
The pictures on the written instructions were	□ Helpful	□ Not Helpful
It was difficult to choose the correct size of foam inserts	□ Yes	□ No
The foam inserts were easy to put on the earphones	□ Yes	□ No
The foam inserts were easy to put in the ears	□ Yes	□ No
Overall, I think the insert earphones were	□ Easy to use	□ Not easy to use

I would like to use insert earphones for all hearing tests I conduct

□ Yes □ No □ Don't Know

Please write any comments, observations or concerns you have about using insert-earphones and the hearing testing that you conducted today ____

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