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Evaluation of insert earphones for high-frequency bedside ototoxicity monitoring

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Abstract—Ototoxic hearing loss is usually detected earliest through monitoring of the highest audible frequencies in individuals administered ototoxic medications. Conducting ototoxicity monitoring may require testing patients in the hospital room. This study evaluated the use of insert earphones for obtaining reliable threshold responses at bedside. Twenty adult subjects were tested during two different sessions in the sound booth and on the ward. Thresholds were obtained for frequencies from 5 to 16 kHz and at 2 kHz with the use of the KOSS Pro/4X Plus earphones and Etymotic ER-4B MicroPro insert earphones. Results indicate that ER-4B insert earphones are as reliable as KOSS earphones for testing on the ward for high-frequency ototoxicity monitoring.

Key words: circumaural earphones, early detection, hearing thresholds, high-frequency testing, insert earphones, instrumentation, intrasubject reliability, ototoxicity monitoring, test-retest reliability, threshold reliability.

INTRODUCTION

Treatment with ototoxic drugs such as aminoglycoside antibiotics and the chemotherapy agent cisplatin may cause irreversible hearing loss [1–2]. Hearing loss due to ototoxic medications has been shown to be detected first in the high frequencies, primarily above 8 kHz, followed by the lower frequencies [2–3]. Because many veterans receive ototoxic medications, a great need exists and much emphasis is placed on providing the most effective ototoxicity detection and monitoring methods at the Department of Veterans Affairs (VA) Medical Centers. Studies at the VA Rehabilitation Research and Development (RR&D) National Center for Rehabilitative Auditory Research (NCRAR) contributed toward guidelines for ototoxicity monitoring, published

Abbreviations: ANOVA = analysis of variance, ANSI = American National Standards Institute, ASHA = American Speech-Language-Hearing Association, df = degrees of freedom, IEC = International Electrotechnical Commission, IRB = institutional review board, NCRAR = National Center for Rehabilitative Auditory Research, SD = standard deviation, SPL = sound pressure level, SRO = sensitive range for ototoxicity, VA = Department of Veterans Affairs.

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by the American Speech-Language-Hearing Association (ASHA) [4]. The ASHA-mandated protocol involves monitoring a patient's entire hearing range. A shortened protocol involves monitoring behavioral thresholds near each individual's high-frequency hearing limit in a region referred to here as the sensitive range for ototoxicity (SRO). Monitoring the SRO in 1/6-octave steps has proven a sensitive, reliable, and time-efficient behavioral ototoxicity early detection and monitoring strategy [5–6].

One issue related to high-frequency behavioral threshold testing is that no normative high-frequency sensitivity standards exist because of the lack of standardization in calibration, instrumentation, and methodological procedures [7]. Also, a high degree of intersubject threshold variability exists in high-frequency sensitivity, which appears to increase with age and higher test frequencies [8–9]. However, serial monitoring of high-frequency thresholds in reference to baseline measures is the most reliable method for detecting hearing loss during treatment with ototoxic medications [2,4]. The key to serial monitoring is intrasubject reliability. To be an effective monitoring tool, high-frequency test-retest threshold variability must be within a clinically acceptable range (±10 dB).

Intrasubject threshold variability in a sound-attenuating booth is generally reported to be around ±5 dB for frequencies below 8 kHz, and it increases slightly with increasing frequency above 8 kHz [10]. Results from recent studies demonstrate that greater than 94 percent of test-retest variability was within ±10 dB for frequencies between 9 and 14 kHz with many models of transducers, such as KOSS HV/1A earphones (Milwaukee, Wisconsin) [9], modified KOSS Pro/4X Plus earphones [10], Sennheiser Electronic Corporation HD 250 earphones (Old Lyme, Connecticut) [11–12], Sennheiser HDA 200 earphones [13–14], and Etymotic Research, Inc., ER-2 earphones (Elk Grove Village, Illinois) [14]. These results suggest that high-frequency test-retest reliability is good when testing is performed in a sound booth. Unfortunately, many subjects are too ill or otherwise unavailable for transport from the hospital ward where ambient room noise may increase intrasubject variability. The reliability of ward testing with earphones is unknown. Reliability must be assessed for earphones used on the ward.

The primary advantage of insert earphones over circumaural earphones for bedside testing is the reduction of environmental background noise achieved with the use of a foam ear tip that effectively seals the ear canal [3,15–16]. Other advantages include the reduction or elimination of stimulus cross-over to the nontest ear due to increased interaural attenuation, elimination of pure-tone threshold measurement errors due to ear canal collapse, and increased comfort with extended wear [15,17–19].

In addition, evidence suggests that when a patient uses an earphone placed on or over the pinna, high-frequency threshold variability may be due in part to small differences in placement of the earphone diaphragm over the ear canal opening [20]. The use of insert earphones inserted to a standard depth, flush with the opening of the ear canal, could eliminate the variability inherent in headphone placement with serial monitoring protocols.

The Etymotic ER-4B MicroPro insert earphones have been shown to be reliable for testing high-frequency auditory sensitivity in a laboratory setting [21]. This study evaluated the high-frequency test-retest reliability of ER-4B insert earphones in the sound booth and on the hospital ward, comparing test-retest reliability of hearing thresholds between the ER-4B insert earphones and modified high-frequency KOSS Pro/4X Plus circumaural earphones. Our comparison ensured that the insert earphones are at least as reliable as the KOSS earphones, which are currently used in ototoxicity monitoring at the NCRAR for both booth and ward testing. This study also determined the intrasubject test-retest reliability for behavioral thresholds within the SRO.

METHODS

Subjects

Data were collected from 12 normal-hearing and 8 sensori-neural hearing-impaired subjects. The mean age of subjects was 37.5 (range 19–61). Normal hearing was defined as pure-tone hearing thresholds 25 dB hearing level (HL) at frequencies measured in 1/2-octave steps from 2 to 8 kHz. All subjects had normal middle-ear function at the time of testing, as determined by normal otoscopy and tympanometry within normal limits (compliance peak = 0.2 to 1.4 mL and peak pressure = –150 to +100 daPa with a 226 Hz probe tone). History of middle-ear pathology and current or prior treatment with ototoxic drugs were exclusion criteria for this study. An institutional review board (IRB) approved this study and all study participants signed an IRB-approved consent form.

Instrumentation

A Grason-Stadler, Inc., GSI 33 middle-ear analyzer (Northwood, New Hampshire) was used for tympanometric evaluation. A Virtual Corporation model 320 audiometer (Flanders, New Jersey) was used for all audiometric testing. We used modified KOSS Pro/4X Plus earphones in the present study because they have demonstrated good test-retest reliability for serial monitoring of ototoxicity [22]. We modified the KOSS Pro/4X Plus earphones to improve the signal-to-noise ratio for high-frequency testing, which results in improved test-retest reliability, as described in Fausti et al. [10,22]. The low-frequency transducer was disabled in the KOSS earphones by the Virtual audiometer manufacturer (no modifications were made to the high-frequency tweeter). To eliminate head noise generated from the oval, air-filled plastic cushion on the standard KOSS Pro/4X Plus earphones, we replaced the plastic cushion with the round, foam ear cushion standard on KOSS HV/1A earphones [22–23]. Modified KOSS Pro/4X Plus earphones, therefore, are coupled to the ear in the same manner as KOSS HV/1A earphones.

For insert earphone threshold testing, we used Etymotic ER-4B MicroPro insert earphones. The ER-4B earphones were chosen because they produce the greatest range of pure-tone frequencies employed in ototoxicity monitoring (0.5–16 kHz) compared to other insert earphones on the market. The ER-4B insert earphones were designed to combine a flat frequency response with isolation from external noise. The ER-4B earphones provide 100 dB sound pressure level (SPL) output from 1.5 to 16 kHz, with <3 percent harmonic distortion [24] and provide 20 to 25 dB of external-noise exclusion. The ER-4B insert earphones were coupled to the ear with standard ER-4B (ER-4-14F) black foam eartips from Etymotic. **Figure 1** compares the frequency output for the KOSS and Etymotic ER-4B insert earphones. For both earphone types, output is high across the frequency range tested (2–16 kHz) for a 500 mV root-mean-square (rms) driving voltage. The frequency response curve for the ER-4B insert earphones is flat to within 12 dB SPL between 2 and 16 kHz. The KOSS earphones frequency response curve is flat to within 21 dB SPL between 2 and 16 kHz.

Threshold measurements were conducted in a standard double-walled sound booth and in two hospital rooms on patient wards. Ambient noise levels were measured on the patient wards before and after threshold measurements. For 12 subjects, noise was measured in 1/3-octave bands with a Bruel & Kjaer (B&K, Norcross, Georgia)

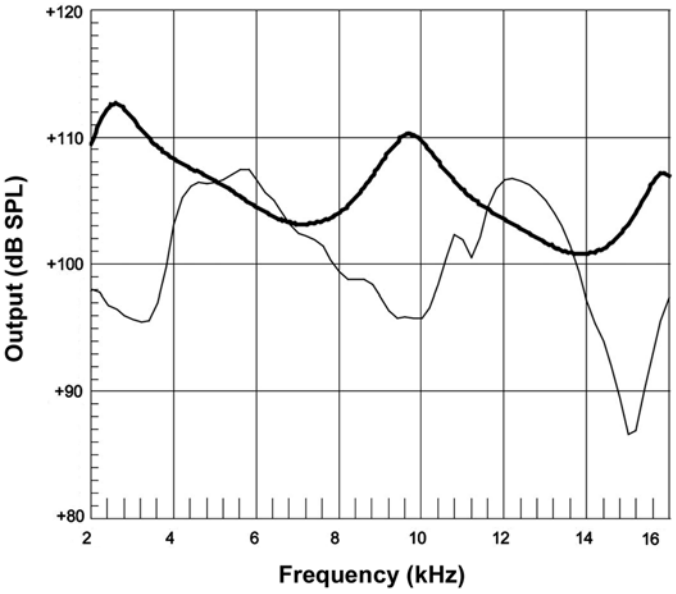

Figure 1.
Output in decibels sound-pressure level (dB SPL) of KOSS Pro/4X Plus circumaural earphones (thin line) and Etymotic ER-4B MicroPro insert earphones (thick line) for 500 mV root-mean-square driving voltage. Acoustic output for ER-4B earphones coupled to Bruel & Kjaer (B&K) 4157 coupler was measured with B&K 4192 microphone. Output of KOSS earphones coupled to flat-plate coupler was measured with B&K 4134 microphone.

type 2231 sound-level meter (set to slow, A weighted scale) fitted with a 1/3-octave filter set and a 1/2 in. microphone (B&K 4134). For the remaining eight subjects, noise was measured with a portable digital Radio Shack sound-level meter (type 33-2055).

Figure 2 shows an analysis of the ambient noise level, SPL in decibels measured with "A" weighted (dBA) scale, observed on the ward at the beginning of sessions 1 and 2. The noise levels are plotted by center frequency for 1/3-octave bands from 0.125 to 16 kHz. Only data obtained with the B&K type 2231 sound-level meter were used for the means and standard deviations (SDs) plotted in **Figure 2**, and these data were obtained for 12 of the 20 subjects tested. The ambient room-noise measurements indicated that the rooms used to test patients were typical for the ward in that noise levels increased with decreasing frequency and the noise levels did not vary between sessions.

Calibration

All audiometric testing instrumentation was calibrated according to the appropriate American National

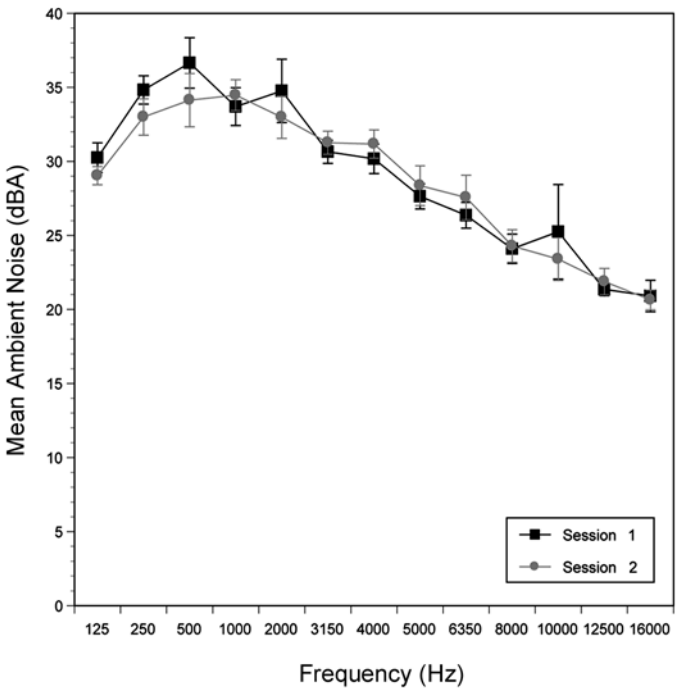

Figure 2.
Mean ambient noise (in dBA) on ward as function of frequency. Error bars indicate standard deviations.

Standards Institute (ANSI) standards [25] in a sound-attenuating booth at the beginning, midpoint, and end of the study. ANSI 1996 standards require that insert earphones be calibrated with a coupler meeting International Electrotechnical Commission (IEC) 711 specifications and that circumaural earphones be calibrated with a coupler meeting IEC 318 specifications [25]. The Virtual 320 audiometer and ER-4B insert earphones were calibrated with a black foam eartip (ER-4-14F) attached to the ER-4B insert earphones, which was inserted into and aligned flush with the base of the B&K DB 2012 ear canal extension of the specified coupler (B&K ear simulator type 4157). The output of the ER-4B insert earphones was sampled by a 1/2 in. microphone (B&K 4192) housed in the coupler, preamplified (B&K 2669), and read with a B&K 2231 sound-level meter.

The KOSS Pro/4X Plus earphones were calibrated with a flat-plate coupler as described in Fausti et al. [23]. The modified B&K 4153 coupler, constructed of room-temperature vulcanizing silicone rubber, houses a 1/2 in. microphone (B&K 4134) in its center. The KOSS earphones were centrally placed into an aluminum spacer and locked into place on the 6 cc coupler. The KOSS earphones acoustic output was sampled by the B&K 4134 1/2 in. microphone, preamplified (B&K 2669), and read by a B&K 2231 sound-level meter.

Procedures

Each subject was tested in the sound booth and on the hospital ward during two separate sessions. The time between sessions varied from a minimum of 2 hours to a maximum of 3 days. One of two examiners tested each subject. To maintain intrasubject consistency in earphone placement for serial monitoring, examiners were extremely careful to align the diaphragm of the KOSS earphones directly with the ear canal and place the lateral side of the ER-4B insert earphones foam tip flush with the bowl of the concha for each subject. Pure-tone behavioral thresholds were determined with the standard modified Hughson-Westlake procedure (down 10 dB, up 5 dB), with threshold recorded at the lowest intensity level at which the subject responded to 50 percent or more of the stimulus presentations [26].

Session 1

In the initial test session, a baseline pure-tone threshold evaluation was obtained and otoscopy and tympanometry performed. All subjects were tested in a standard double-walled sound-attenuating booth. Examiners read a standardized set of instructions for threshold measurement to each subject. Behavioral thresholds were obtained in the right and then the left ears for pulsed tones at 2, 3, 4, 6, 8, 9, 10, 11.2, 12.5, 14, and 16 kHz with the subjects using KOSS Pro/4X Plus earphones.

Pure-tone testing also involved the determination of an individualized SRO. This range is defined as the uppermost frequency (*R*) with a threshold of ≤100 dB SPL, followed by the adjacent six lower frequencies in 1/6-octave steps, labeled *R*-1 through *R*-6 [5]. Threshold testing in 1/6-octave steps was completed within the SRO, whether the SRO was above or below 8 kHz. KOSS earphones, currently in use at the NCRAR for ototoxicity monitoring, were used to establish the SRO for further comparisons between transducers.

Following testing with the KOSS earphones, testing with Etymotic ER-4B insert earphones was completed as follows. Behavioral thresholds were obtained at the seven individualized SRO frequencies in the right and left ears. Behavioral thresholds also were obtained at 2 kHz for comparison with the 2 kHz thresholds obtained with the KOSS earphones. This frequency, 2 kHz, is the lowest frequency

of test for the modified KOSS earphones, and it was predicted to produce thresholds that, when tested on the ward, were more variable compared to the booth thresholds because of possible interference by ambient room noise.

Immediately after the initial evaluation in the sound booth, subjects were tested on the hospital ward. We used a randomized, counterbalanced technique (i.e., subjects were randomized in pairs) so that for half the subjects, behavioral thresholds were obtained with the KOSS earphones first, followed by the ER-4B insert earphones at 2 kHz and the seven individualized SRO frequencies. For the remaining, randomly selected, other half of the subjects, behavioral thresholds were obtained first with the ER-4B insert earphones then the KOSS earphones at 2 kHz and the seven individualized SRO frequencies. Threshold measurements were obtained for the right then left ears for all subjects.

For hospital ward testing, subjects were seated or reclined in bed at a minimum angle of 45° to the testing equipment and as far away as electrical cords would allow so any cuing of stimulus presentations would be prevented. Ambient noise was measured and recorded at the beginning and end of each testing session.

Session 2

The second session began on the hospital ward. Behavioral hearing thresholds were obtained at 2 kHz and the seven individualized SRO frequencies for the right then left ears. Again, using the same randomized, counterbalancing technique, we tested half the subjects with the KOSS earphones first, followed by the ER-4B insert earphones, and the other half of the subjects with the ER-4B insert earphones first, followed by the KOSS earphones. Ambient noise was again measured and recorded at the beginning and end of the test session for each subject.

Following ward testing, each subject was tested in the sound booth. Otoscopy and tympanometry were performed. Behavioral thresholds were obtained at 2 kHz and the seven individualized SRO frequencies for the right and left ears. Test order for obtaining behavioral thresholds was again randomized between the KOSS earphones and ER-4B insert earphones so order effect could be prevented. The randomization of transducer order allowed each individual subject to be tested with a different sequence of transducers. With the exception of each subject being tested first with the KOSS and second with the ER-4B earphones in the first part of the first session, all subjects were tested in a randomized order for the two transducers. In effect, transducer order varied within and between subjects.

RESULTS AND DISCUSSION

This study set out to determine whether insert earphones were reliable for ototoxicity monitoring of patients' hearing at bedside. Three questions were of interest:

1. Are the insert earphones as reliable in the booth as the KOSS earphones?
2. Are the insert earphones as reliable on the ward as the KOSS earphones?
3. Are the insert earphones as reliable when testing between the booth and the ward as the KOSS earphones?

To answer the first two questions, we determined intersession reliability of thresholds for the KOSS earphones and the ER-4B insert earphones (booth session 1 thresholds – booth session 2 thresholds, and ward session 1 thresholds – ward session 2 thresholds). For the third question, we assessed intrasession reliability (booth thresholds – ward thresholds in session 1). Since three specific questions were of interest, we decided to perform three separate analyses (earphones × location × session × frequency) and tests of simple effects.

The top SRO frequency ranged from 10 to 16 kHz in the subjects tested, so in addition to data at 2 kHz, we obtained data for frequencies ranging from 5 to 16 kHz. **Figure 3** presents mean intersession (booth vs. booth and ward vs. ward) and intrasession (booth vs. ward) threshold differences calculated at each of the eight test frequencies (seven SRO frequencies plus 2 kHz). The error bars represent SDs of these difference measures. Intersession threshold differences were similar for ER-4B and modified KOSS earphones. Separate two-way repeated measures analyses of variance (ANOVAs) (frequency × earphone) were performed for intersession threshold differences at both test locations. For both booth and ward data, main effects and frequency by earphone interactions were not significant ($p > 0.05$). These results are consistent with a previous study that found no significant differences between booth and ward high-frequency sensitivity for KOSS HV-1A circumaural earphones [3].

Sometimes thresholds obtained in the same subject must be compared across different test locations (e.g., the

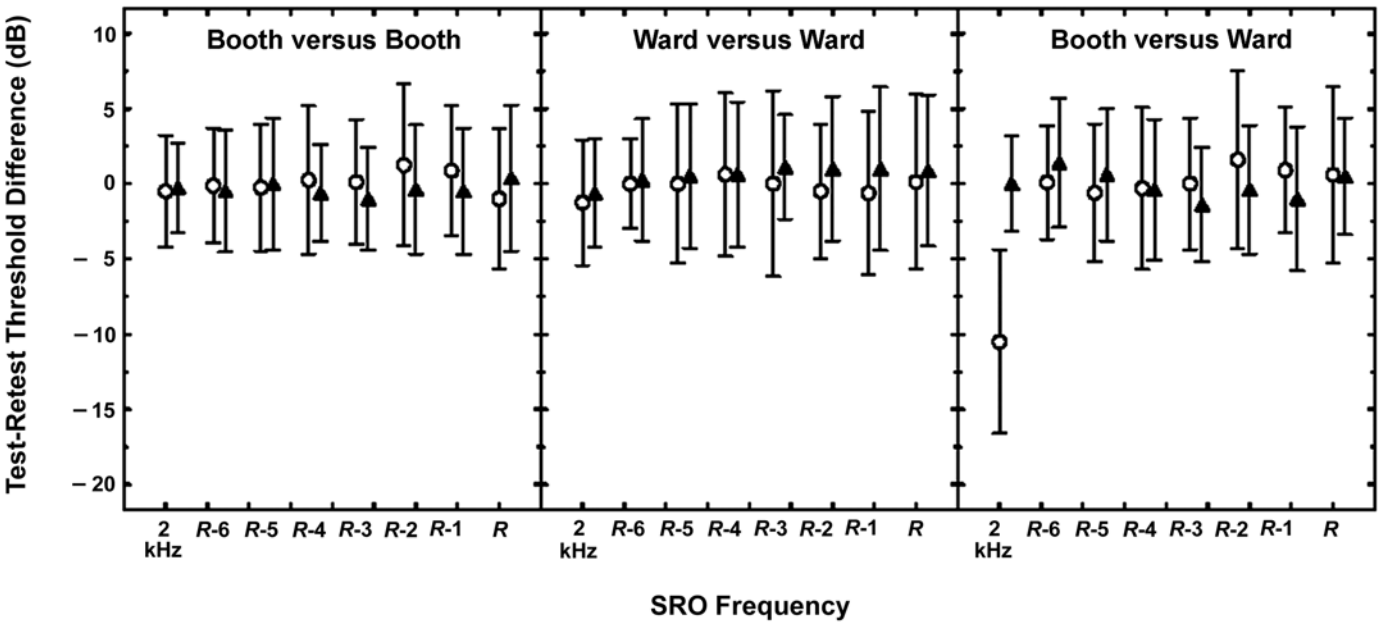

Figure 3.
Mean intersession (booth vs. booth and ward vs. ward) and intrasession (booth vs. ward) threshold differences at each of seven sensitive range for ototoxicity test frequencies plus 2 kHz. Error bars represent standard deviations. ▲ represents Etymotic ER-4B MicroPro insert earphones. ○ represents KOSS Pro/4X Plus circumaural earphones. SRO = sensitive range for ototoxicity.

booth and the ward). We computed intrasession difference scores for each subject by subtracting the hearing threshold obtained on the ward from the hearing threshold obtained in the booth for session 1 with both KOSS and ER-4B earphones. **Figure 3** shows that intrasession differences at 2 kHz are larger compared to intersession differences, particularly for the KOSS earphones. This difference is due to the slightly higher thresholds we obtained when testing on the ward compared with testing in the booth.

A two-way repeated measures ANOVA performed for the intrasession threshold differences showed that the earphone main effect was not significant ($p > 0.05$). However, both the frequency main effect ($F = 18.71$; degrees of freedom (df) = 7, 273) and the frequency by earphone interaction ($F = 19.06$; df = 7, 273) were significant at $p < 0.0001$. The difference at 2 kHz appears to be the cause of the significant frequency main effect and the frequency by earphone interaction. When the data for 2 kHz were eliminated from the statistical analysis, neither of the main effects or the interaction was significant.

To ensure that the observed difference at 2 kHz was repeatable, we computed difference scores between the ward and booth at 2 kHz using data from session 2. These data were analyzed with a repeated measures *t*-test, and the results were significant at $p < 0.0001$ ($t = 9.07$; df = 39). The mean intrasession threshold difference at 2 kHz was –11.25 dB SPL (±6.58 SD) for the KOSS earphones and –0.38 dB SPL (±2.86 SD) for the ER-4B insert earphones. Results suggest that when one is switching between booth and ward settings, test-retest reliability decreases, at least when testing at the low frequencies.

Tables 1 and **2** show the number of ears with booth versus booth, and ward versus ward threshold differences that were ±5 dB, ±10 dB, and >10 dB. These data are presented as a function of SRO frequency in **Table 1** and are reexamined as a function of test frequency in **Table 2**. When data were collapsed across frequency, the percentage of ears with test-retest differences within a clinically acceptable range of ±10 dB was 95 percent for both the KOSS and ER-4B insert earphones on the ward. The percentage of ears with test-retest differences within ±10 dB was 97 percent for the KOSS earphones and 96.5 percent for the ER-4B insert earphones in the booth. Test-retest variability in the booth was greater than 10 dB on just three occasions for the KOSS earphones and on one occasion for the ER-4B earphones. Intersession threshold differences on the ward also were similar between earphones. Test-retest variability was greater than 10 dB in

Table 1.
Numbers of ears with test-retest threshold differences of ±5, ±10, and >10 dB for intersession comparisons (booth vs. booth and ward vs. ward) with either KOSS Pro/4X Plus circumaural or Etymotic ER-4B MicroPro insert earphones as function of individual's sensitive range for ototoxicity (SRO) frequencies, which span 1-octave range. $N = 40$. R = uppermost frequency (kilohertz) with threshold of ≤100 dB sound pressure level. R-1 to R-6 are adjacent (lower) SRO frequencies (kilohertz) measured in 1/6-octave steps.

Test Setting, Transducer	No. of Subjects at Each SRO Frequency (kHz)						
	R **10–16**	***R*-1** **9–14**	***R*-2** **8–12.5**	***R*-3** **7.1–11.2**	***R*-4** **6.4–10**	***R*-5** **6.4–9**	***R*-6** **5.7–8**
Booth ±5 dB							
KOSS	37	38	35	37	37	38	38
ER-4B	36	39	38	39	39	36	38
Booth ±10 dB							
KOSS	3	2	3	3	2	2	2
ER-4B	3	1	2	1	1	4	2
Booth >10 dB							
KOSS	0	0	2	0	1	0	0
ER-4B	1	0	0	0	0	0	0
Ward ±5 dB							
KOSS	31	33	37	34	34	35	40
ER-4B	35	35	37	38	37	35	38
Ward ±10 dB							
KOSS	9	6	3	4	5	4	0
ER-4B	5	4	1	2	1	5	2
Ward >10 dB							
KOSS	0	1	0	2	1	1	0
ER-4B	0	1	2	0	2	0	0

five instances for each transducer. Results suggest that ER-4B earphones are as reliable for high-frequency testing as the KOSS earphones, whether testing is completed in the sound booth or on the hospital ward.

The ASHA guidelines for identification of ototoxic hearing change include a change of ≥20 dB at any one frequency, ≥10 dB at any two consecutive test frequencies, or a loss of response at three consecutive test frequencies where responses were previously obtained. Change must be confirmed by repeat testing if possible [4]. None of the subjects in our study had threshold changes greater than 20 dB, regardless of the transducer or test setting. Because subjects in our study were not receiving ototoxic drugs, this percentage was taken as a "false positive rate" for ototoxic hearing change. False positive rates were low. The largest false positive rate for intersession threshold comparisons was 5 percent (KOSS earphones, ward vs. ward at 10 kHz; ER-4B earphones, ward vs. ward at 8 kHz).

Our results indicate that if a patient is always going to be tested in the same location, whether in a sound booth or on the hospital ward, either KOSS Pro/4X Plus circumaural or Etymotic ER-4B MicroPro insert earphones may be used reliably. This finding is important because high-frequency threshold monitoring often provides earlier identification of ototoxic hearing loss compared to conventional testing alone [2,5], and to be viable for an ototoxicity monitoring program, such testing must be shown to be reliable at bedside. However, the clinician is cautioned against switching between transducer types. If switching earphones or test locations becomes necessary, one must take into account differences in SPL thresholds related to differences between the two transducer outputs using clinical normative data and one must use caution when interpreting results. The two transducers are not interchangeable with respect to serial monitoring of ototoxicity. Because of the construction of each transducer's housing and the manner in which it is applied to the head, the attenuation of external noise by insert earphones is likely to be greater than that of circumaural earphones, which could lead to threshold differences between the earphones. Differences in calibration procedures between earphones also could result in

Table 2.
Numbers of ears with threshold test-retest threshold differences of ±5, ±10, and >10 for intersession comparisons (booth vs. booth and ward vs. ward) with either KOSS Pro/4X Plus circumaural or Etymotic ER-4B MicroPro insert earphones at each of 12 test frequencies in kilohertz (2 kHz plus seven frequencies within sensitive range for ototoxicity).

Test Setting, Transducer	No. of Subjects at Each Test Frequency (kHz)											
	16	**14**	**12.5**	**11.2**	**10**	**9**	**8**	**7.13**	**6.35**	**6**	**5.66**	**2**
Booth ±5 dB												
KOSS	26	30	33	34	37	39	37	10	8	4	2	39
ER-4B	26	31	33	38	39	36	39	10	7	4	2	40
Booth ±10 dB												
KOSS	3	2	2	3	3	0	3	1	0	0	0	1
ER-4B	2	1	3	0	1	4	1	1	1	0	0	0
Booth >10 dB												
KOSS	0	0	1	1	0	1	0	0	0	0	0	0
ER-4B	1	0	0	0	0	0	0	0	0	0	0	0
Total *N**	29	32	36	38	40	40	40	11	8	4	2	40
Ward ±5 dB												
KOSS	22	26	34	33	32	34	39	11	8	4	2	38
ER-4B	27	28	32	36	37	36	36	10	7	4	2	40
Ward ±10 dB												
KOSS	7	6	2	4	6	5	1	0	0	0	0	2
ER-4B	2	3	3	2	2	4	2	1	1	0	0	0
Ward >10 dB												
KOSS	0	1	0	1	2	1	0	0	0	0	0	0
ER-4B	0	1	1	0	1	0	2	0	0	0	0	0
Total *N**	29	32	36	38	40	40	40	11	8	4	2	40

**N* = total number of ears in each category. Not all ears were tested at all frequencies, so *N* varies within frequencies.

threshold differences. Using the same type of earphone for all test comparisons in a serial monitoring protocol reduces potential sources of measurement variability.

SUMMARY AND CONCLUSION

Monitoring patients receiving ototoxic medications sometimes requires testing at bedside. Because of the many advantages offered by insert earphones over circumaural earphones, this study evaluated the use of Etymotic ER-4B MicroPro insert earphones for serial monitoring on hospital wards. For comparison, behavioral thresholds were also obtained with modified KOSS Pro/4X Plus circumaural earphones currently used at the NCRAR for research testing.

Behavioral threshold test-retest reliability was found to be good for the KOSS circumaural earphones and the ER-4B insert earphones for both sound booth and hospital ward settings. Further, the two earphones tested here were found to be equally reliable whether testing was performed in the booth or on the ward. In particular, high-frequency test-retest threshold differences in the present study were in the range of values reported recently for KOSS HV/1A earphones [9], modified KOSS Pro/4X Plus earphones [10], Sennheiser HD 250 earphones [11–12], Sennheiser HDA 200 earphones [13–14], and Etymotic ER-2 earphones [14]. Therefore, the ER-4B insert earphones are a viable choice for ototoxicity monitoring on the patient ward.

Our results indicate that both earphones are reliable when testing patients in the same setting. However, the two earphones are not interchangeable between the two locations for serial monitoring of ototoxicity. If switching earphones or test locations becomes necessary, one must use caution when interpreting results.

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REFERENCES

1. Dreschler WA, van der Hulst RJAM, Tange RA, Urbanus NAM. The role of high-frequency audiometry in early detection of ototoxicity. Audiology. 1985;24:387–95.
2. Fausti SA, Larson VD, Noffsinger D, Wilson RH, Phillips DS, Fowler CG. High-frequency audiometric monitoring strategies for early detection of ototoxicity. Ear Hear. 1994; 15:232–39.
3. Valente M, Potts LG, Valente M, French-St. George M, Goebel J. High-frequency thresholds: Sound suite versus hospital room. J Am Acad Audiol. 1992;3:287–94.
4. American Speech-Language-Hearing Association (ASHA). Guidelines for the audiologic management of individuals receiving cochleotoxic drug therapy. ASHA. 1994;36 (Suppl 12):11–19.
5. Fausti SA, Henry JA, Helt WJ, Phillips DS, Frey RH, Noffsinger D, Larson VD, Fowler CG. An individualized, sensitive frequency range for early detection of ototoxicity. Ear Hear. 1999;20:497–505.
6. Vaughan NE, Fausti SA, Chelius S, Phillips D, Helt W, Henry JA. An efficient test protocol for identification of a limited, sensitive frequency test range for early detection of ototoxicity. J Rehabil Res Dev. 2002;39:567–74.
7. Fausti SA, Frey RH, Rappaport BZ, Schechter MA. High-frequency audiometry with an earphone transducer. Sem Hear. 1985;6:347–57.
8. Schechter MA, Fausti SA, Rappaport BZ, Frey RH. Age categorization of high-frequency auditory threshold data. J Acoust Soc Am. 1986;79:767–71.
9. Matthews LJ, Lee FS, Mills JH, Dubno JR. Extended high-frequency thresholds in older adults. J Speech Lang Hear Res. 1997;40:208–14.
10. Fausti SA, Henry JA, Hayden D, Phillips DS, Frey RH. Intrasubject reliability of high-frequency (9–14 kHz) thresholds: tested separately vs. following conventional-frequency testing. J Am Acad Audiol. 1998;9:147–52.
11. Frank T. High-frequency hearing thresholds in young adults using a commercially available audiometer. Ear Hear. 1990;11:450–54.
12. Frank T, Dreisbach LE. Repeatability of high-frequency thresholds. Ear Hear. 1991;12:294–95.
13. Frank T. High-frequency (8–16 kHz) reference thresholds and intrasubject threshold variability relative to ototoxicity criteria using a Sennheiser HDA 200 earphone. Ear Hear. 2001;22: 161–68.
14. Schmuziger N, Probst R, Smurzynski J. Test-retest reliability of pure-tone thresholds from 0.5 to 16 kHz using Sennheiser HDA 200 and Etymotic research ER-2 earphones. Ear Hear. 2004;25:127–32.
15. Clemis JD, Ballad WJ, Killion MC. Clinical use of an insert earphone. Ann Otol Rhinol Laryngol. 1986;95:520–24.
16. Berger EH, Killion MC. Comparison of the noise attenuation of three audiometric earphones, with additional data on masking near threshold. J Acoust Soc Am. 1989;86:1392–1403.
17. Killion MC, Wilber LA, Gudmundsen GI. Insert earphones for more interaural attenuation. Hear Instrum. 1985;36:34–36.
18. Borton TE, Nolen BL, Luks SB, Meline NC. Clinical applicability of insert earphones for audiometry. Audiology. 1989; 28:61–70.
19. Stuart A, Stenstrom R, Tompkins C, Vandenhoff S. Test-retest variability in audiometric threshold with supraaural and insert earphones among children and adults. Audiology. 1991; 30:82–90.
20. Valente M, Valente M, Goebel J. High-frequency thresholds: Circumaural earphone versus insert earphone. J Am Acad Audiol. 1992;3:410–18.
21. Henry JA, Flick CL, Gilbert A, Ellingson RM, Fausti SA. Reliability of hearing thresholds: Computer-automated testing with ER-4B canal phone earphones. J Rehabil Res Dev. 2001;38:567–81.
22. Fausti SA, Frey RH, Henry JA, Knutsen JL, Olson DJ. Reliability and validity of high-frequency (8–20 kHz) thresholds obtained on a computer-based audiometer as compared to a documented laboratory system. J Am Acad Audiol. 1990;1:162–70.
23. Fausti SA, Frey RH, Erickson DA, Rappaport BZ, Cleary EJ, Brummett RE. A system for evaluating auditory function from 8,000 to 20,000 Hz. J Acoust Soc Am. 1979;66: 1713–18.
24. Henry JA, Flick CL, Gilbert A, Ellingson RM, Fausti SA. Reliability of tinnitus loudness matches under procedural variation. J Am Acad Audiol. 1999;10:502–20.
25. American National Standards Institute (ANSI). American National Standard Specification for Audiometers (S3.6-1996). New York: ANSI; 1996.
26. Carhart R, Jerger J. Preferred method for clinical determination of pure-tone thresholds. J Speech Hear Disord. 1959; 24:330–45.

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