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High-Frequency Thresholds: Circumaural Earphone versus Insert Earphone

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Abstract

Benefits of high-frequency audiometry in monitoring hearing sensitivity of patients administered ototoxic medications are well established. High-frequency thresholds have been reported to be variable, due in part to small differences in the placement of the earphone diaphragm over the opening of the ear canal. Reliability may be improved by using insert earphones (ER-2) when obtaining high-frequency thresholds. The purposes of this study were to determine high-frequency threshold test-retest reliability using Koss HV/1A+ and ER-2 earphones and to determine if significant differences are present between high-frequency thresholds obtained using these two earphones. Results obtained on 40 ears of 20 normal hearing adults revealed that differences between the test and retest thresholds for each earphone were not significant. Intrasubject threshold differences between the test and retest thresholds for each earphone were, for the most part, within ±10 dB at all test frequencies. Further, significantly greater intensity was required to measure threshold when using the ER-2 earphone when compared to the Koss HV/1A+ at all test frequencies.

Key Words: High-frequency audiometry, insert earphone, monitoring audiometry, ototoxic medications

High-frequency audiometry has gained popularity in recent years for early detection of the effects of ototoxic medications upon hearing thresholds (Jacobson et al, 1969; Dreschler et al, 1985, 1989; Tange et al, 1985). The deleterious effects of ototoxic medications may be detected 2 months earlier if hearing is monitored using high-frequency signals than if monitoring were performed at .25 to 8 kHz (Jacobson et al, 1969). Dreschler et al (1985) measured hearing thresholds from .25 to 20 kHz on patients receiving ototoxic medications. Poorer hearing thresholds were noted from 10 to 20 kHz in 68 percent of the subjects. In another study (1989), these investigators found poorer hearing from 10 to 20 kHz before shifts in hearing thresholds were seen at 1 to 8 kHz. Threshold shifts within the high frequency region were 15 to 20 dB greater than those obtained within the lower frequency region. Tange et al (1985) monitored high-frequency thresholds of patients receiving cisplatinum therapy and found poorer hearing in 35 percent of the cases. Initial threshold changes appeared to occur primarily above 8 kHz.

However, investigators have reported several procedural problems associated with high-frequency audiometry (Fausti et al, 1979a, 1990; Schechter et al, 1986; Stelmachowicz et al, 1988, 1989a, b; Valente et al, 1992). One variable is the presence of standing waves in the ear canal as a result of the decreased wavelength of high-frequency signals.

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This could affect inter- and intra-test reliability if the earphone is not consistently placed over the ear canal opening (Stelmachowicz et al, 1988, 1989b).

In 1984, Killion introduced the ER-1 and ER-2 insert earphones. Although the bandwidths of the ER-1 and ER-2 are similar, the ER-1 was recommended for speech stimuli whereas the ER-2 was recommended when nonspeech stimuli were used (Killion, 1984). The ER-2 has a wide frequency response, which could be used for high-frequency audiometry thereby eliminating some of the limitations of standard earphones. Killion noted that standard earphones offer minimal exclusion of low-frequency ambient noise and limited bandwidth. He introduced ER-2 because it provides a smooth wide-band frequency response extending to almost 20 kHz when measured in a Zwislocki coupler. The ER-2 consists of a transducer in a rectangular plastic case containing a receiver, two acoustic dampers, electrical equalization network, and a resonance cancellation tube. The output of the transducer is coupled to the ear canal via a sound tube (~292 mm of #16 tubing) attached to a connecting nipple and then to the ear canal via either a foam plug or an immittance probe cuff attached to the end of the tubing. The use of the ER-2 could provide greater consistency in coupling the sound outlet to the ear canal than does the placement of the cushion of a conventional high-frequency earphone.

A primary purpose of this study was to determine high-frequency threshold test-retest reliability using Koss HV/1A+ and ER-2 earphones. Since the ER-2 couples directly to the ear canal, placement could be more consistent than using a circumaural earphone over the opening of the ear canal. As such, improved test-retest reliability may be achieved when high-frequency thresholds are obtained using insert earphones compared with circumaural earphones. Using procedures that provide improved test-retest reliability is important for patients undergoing drug therapy using ototoxic drugs. Significant changes in hearing thresholds between repeated measures is often used in deciding to change the dosage or medication for patients undergoing ototoxic drug therapy. It is important that this decision be based upon the most reliable measure available.

Another purpose was to compare high-frequency thresholds obtained using the Koss HV/1A+ and ER-2 earphones. If comparable, use of the insert earphones might be clinically superior since insert earphones using a foam tip or immittance cuff have relatively high noise reduction properties (Clemis et al, 1986; Clark and Roeser, 1988; Borton et al, 1989). This is important because many patients receiving ototoxic medications are too ill to be transported to the audiometric suite and must be evaluated at bedside. A recent study (Valente et al, 1992) revealed no significant differences in high-frequency thresholds measured in a sound suite versus a "quiet" hospital room using Koss HV/1A+ earphones. However, Valente et al (1992) reported that increased levels of ambient noise could be present in a "typical" hospital room if the oxygen supply valve located near bedside was rotated to its maximum position.

METHOD

Subjects

Twenty young adult subjects (aged 20–36 years; 17 females and 3 males; mean age = 24.7 yr; SD = 2.9 yr), with negative history of otologic pathology, took part in this study. Green et al (1987) reported no significant differences in high-frequency thresholds (.8–20 kHz) measured for 18 male and 19 female listeners. Both ears of each subject were tested. All ears passed a bilateral pure-tone screening at 15 dB HL (ANSI-1989) from .25 to 8 kHz and had normal Y_{220} tympanograms.

Equipment

All threshold measurements were performed in a double-walled sound suite. The ambient noise levels in the sound suite were measured using a ½-inch, free-field microphone (B&K 4165); sound level meter (B&K 2235); and ⅓-octave band filter (B&K 1625). The ambient noise levels were less than recommended by ANSI-1977 for ears-covered testing from 125 to 8000 Hz. The ambient noise levels at 8, 10, 12.5, 16, and 20 kHz were less than the ANSI-1977 maximum allowable level of 40 dB SPL at 8 kHz for the ⅓-octave band ears-covered condition.

High-frequency thresholds were obtained using an Interacoustics AS 10 HF high-frequency audiometer (dB SPL model) equipped with Koss HV/1A + earphones. For insert earphone threshold measures, a matched pair of ER-2 earphones was coupled to the earphone output of the same audiometer.

The ER-2 can be coupled to the ear canal using either a foam plug (length of 12 mm) or immittance probe cuff. For this study, an

Table 1 ER-2 Earphone Output Levels

Frequency (kHz)	*Coupler Output (dB SPL)*		
	HA-1	*HA-2*	*Zwislocki*
8	74.2	61.0	77.3
10	80.3	61.7	87.7
12	84.5	57.1	96.4
14	74.5	56.2	86.8
16	73.9	58.4	85.5
18	66.3	50.2	80.1

Attenuator of the Interacoustics AS HF 10 was placed at 100 dB SPL.

immittance cuff was placed on a plastic adapter (ER 3-06) connected to the sound outlet tube and coupled the ER-2 to the ear canal. Immittance cuffs were used for several reasons. First, the diameter of the ear canal of several subjects was either too large or small to use the standard foam plug successfully. In a recent article (Frank and Vavrek, 1992), 17 percent of the subjects had ear canals that would not allow the standard foam plug to be used successfully. On the other hand, the immittance cuffs used in this study have outside diameters varying from 2 to 22 mm. An appropriate sized immittance cuff was selected to comfortably fit in the ear canal and provide an adequate seal. In addition, the length of each immittance cuff is 16 mm. Insertion of the cuff by the same examiner so the outside edge was flush with the bowl of the concha ensured a consistent insertion depth of 16 mm past the opening of the ear canal. This depth is precisely the 15 to 16 mm insertion depth recommended by the manufacturer for a "deep" earplug insertion (Killion et al, 1985). Use of the foam plug requires the user to insert the plug an additional 2 to 3 mm past the opening of the ear canal to ensure proper insertion depth. For the purposes of this study, it was felt the insertion of the immittance cuff so that the lateral end was flush with the opening of the ear canal would be more efficient and accurate than having to insert the foam plug an additional 2 to 3 mm. Finally, Borton et al (1989) reported no significant threshold differences with ER-3A earphones coupled to foam plugs or immittance cuffs.

The AS 10 HF audiometer was calibrated according to the manufacturer's instructions using the Koss HV/1A+ earphones, measuring amplifiers (B&K 2636), ½-inch microphone (B&K 4166), FET follower (B&K 2639), and flat plate coupler (CHF-10). The potentiometers on the audiometer were adjusted at each frequency so that the coupler output of 100 dB SPL corresponded to the attentuator setting of 100 dB SPL. During the course of this study, the coupler output levels did not shift more than 1 dB at any test frequency. This finding is in close agreement with findings reported by Fausti et al (1979b).

Using similar equipment and procedures as mentioned above, coupler output levels (HA-1, HA-2, and Zwislocki) were measured with the ER-2 coupled to the audiometer. For the HA-1 and HA-2 (B&K DB 0138), a 1-inch microphone (B&K 4144) with a FET follower (B&K 2639) was used, while a ½-inch microphone (B&K 4134) was used for Zwislocki (Knowles DB-4005) measures. Although research is not currently available concerning the calibration of the ER-2, ANSI-1989 includes interim reference equivalent threshold data for the ER-3A using HA-1, HA-2, or Zwislocki couplers. Table 1 reports the output levels (dB SPL) measured in the three couplers when the attenuator of the AS 10 HF was placed at 100 dB SPL.

Figures 1 to 3 show the frequency response of the ER-2 and HV/1A+ earphones. Figure 1 reveals the frequency response of the right ER-2 (B&K DB 0138 HA-2 coupler; B&K 4144 1-inch microphone) and HV/1A+ (Koss CHF-10 coupler; B&K 4166 ½-inch microphone) earphones. Figure 2 reveals the frequency response

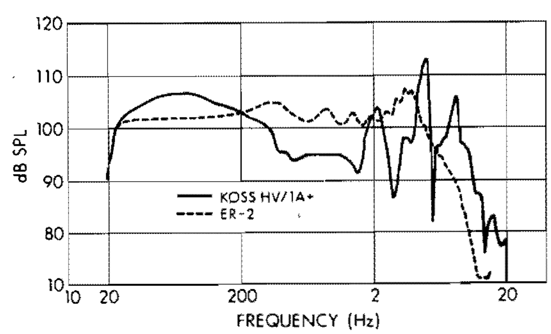

Figure 1 Frequency response of the right ER-2 and HV/1A+ earphones.

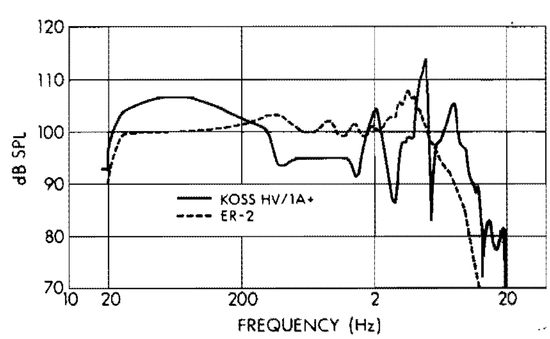

Figure 2 Frequency response of the left ER-2 and HV/1A+ earphones.

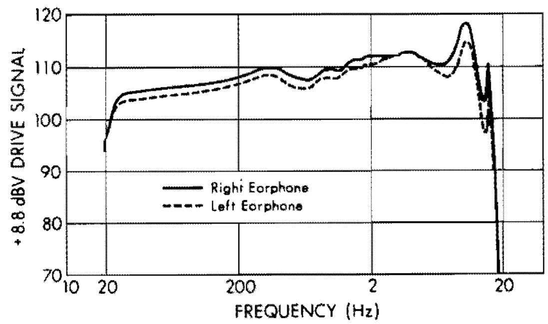

Figure 3 Frequency response of the right and left ER-2 earphones measured in a Zwislocki coupler.

for the left ER-2 and HV/1A+ earphones. These measures were obtained with each earphone driven at 0.67 volts (rms at 1000 Hz) using a beat-frequency oscillator (B&K 1014), electronic frequency counter (HP 5321B), measuring amplifiers (B&K 2636), and level recorder (B&K 2307). Figure 3 reveals the frequency response of the right and left ER-2 earphones measured in a Zwislocki coupler driven at 2.7 volts (rms at 1000 Hz) using a B&K 4134 ½-inch microphone.

Procedures

When using the Koss HV/1A+ earphones, every attempt was made to assure that the diaphragm was accurately placed over the opening to the ear canal. The consistent placement of the earphone by the same examiner was considered critical in obtaining valid test results. When the ER-2 earphones were used, the immittance cuff was inserted into the ear canal by the same examiner so that the lateral end of the cuff was flush with the bowl of the concha. As mentioned earlier, this procedure ensured an insertion depth of 16 mm for all measures. The size of immittance cuff was recorded for each ear of each subject so that the same size cuff was used when thresholds were retested.

Standard clinical instructions for threshold measurement were provided to each subject. All thresholds were obtained by the same examiner using pulsed tones (400 msec on–off) in 5-dB steps at 8, 10, 12, 14, 16, and 18 kHz and a modified Hughson-Westlake procedure (Carhart and Jerger, 1959). This procedure has been found to be valid for measuring high frequency thresholds (Fausti et al, 1979a). Threshold was defined as the lowest sound pressure level (dB SPL re: dial reading) at which the subject responded to 50 percent of the presentations.

Initially, thresholds were established on the same day for each ear and earphone type. For half the subjects, the right ear was tested first, while the left ear was tested first with the other half. Similarly, thresholds measured with the ER-2 earphone were obtained first for half the subjects, while thresholds with the Koss HV/1A+ earphone were obtained first with the other half. Thresholds were measured approximately 1 week later to obtain retest threshold measures for each ear and each earphone type. The same immittance cuff used for the initial test were duplicated when retest thresholds were obtained.

RESULTS AND DISCUSSION

The thresholds (dB SPL) were analyzed to determine if significant differences were present between the test and retest thresholds for both the Koss HV/1A+ and ER-2 earphones. In addition, the test and retest threshold differences were analyzed to determine if they were within a clinically acceptable range of ±10 dB. Finally, the thresholds were analyzed to determine if significant differences were present between the Koss HV/1A+ and ER-2 earphones.

Koss HV/1A+: Test and Retest Thresholds

Initially, the Hotelling's T^2 test (multivariate extension of the paired comparison t-test), revealed that the mean threshold differences between ears at each frequency and for each earphone type under both the test and retest conditions were not significant ($p > .05$). Consequently, the test and retest thresholds were collapsed across ears at each frequency. The threshold data for all subsequent conditions represent the average of the two ears.

Table 2 reports the mean thresholds, standard deviations (SD) and threshold range for test and retest thresholds for the Koss HV/1A+ earphone. Mean test minus retest threshold differences ranged from 0.2 dB at 8 kHz to 3.1 dB at 18 kHz. Statistical analysis at each frequency using the Hotelling's T^2 tests revealed that none of the threshold differences was statistically significant ($p > .05$). Assuming no change in hearing occurred between the time of test and retest, thresholds using the Koss HV/1A+ earphone should be expected to be reliable over time. Significant Pearson product correlations ($p < .01$) were found at each frequency ranging from 0.78 at 10 kHz to 0.96 at 16 kHz, indicating a strong relation between the test and retest thresholds.

Table 2 Results for the Koss HV/1A+ Earphone Test and Retest Threshold

	Frequency (kHz)					
Condition	*8*	*10*	*12*	*14*	*16*	*18*
Test						
Mean (dB SPL)	27.6	37.2	38.3	49.9	66.9	93.8
SD	6.4	9.1	10.4	15.2	22.8	18.3
Range	15–40	15–55	20–70	25–85	30–105	65–NR
Retest						
Mean (dB SPL)	27.4	36.9	35.9	48.3	65.5	90.7
SD	7.3	9.9	11.3	14.4	22.3	16.9
Range	15–45	20–55	20–75	30–75	30–105	70–NR
Difference between Means	0.2	0.3	2.4	1.6	1.4	3.1
T^2 value (Test vs Retest Thresholds)	.22	.16	.65	.32	.18	.55
Correlation (Test vs Retest Thresholds)	.83*	.78*	.84*	.86*	.96*	.84*

*p < .01.
NR = No Response.
Also reported is the mean difference between each measure. Pearson product correlation coefficients and the Hotelling's T^2 are provided at each frequency.

Table 2 also shows a trend toward larger SDs (intersubject variability) as frequency increased. This trend and similar SD magnitude have been reported by others using circumaural earphones; and was in good agreement with some of the findings previously reported (Cunningham et al, 1983; Green et al, 1987; Stelmachowicz et al, 1989a; Frank, 1990; Valente et al, 1992). The smaller SD at 18 kHz (18.3 dB), compared with the SD at 16 kHz (22.8 dB) is not related to reduced intersubject variability. Rather it is related to fewer subjects being able to respond to 18 kHz. In the present study, 100 percent of the subjects responded from 8 to 16 kHz; however, only 82 percent at 18 kHz. This finding is in agreement with an 88 percent response rate at 18 kHz reported by Cunningham et al (1983) and Schechter et al (1986), and a 90 percent response rate reported by Frank (1990).

Although not the primary purpose of this study, the mean thresholds reported in Table 2 for the Koss HV/1A+ earphone are in close agreement with the results reported in several other studies. Figure 4 reveals the mean test thresholds obtained in the present study using the Koss HV/1A+ earphone and those reported in seven other studies (Cunningham et al, 1983; Schechter et al, 1986 for ages 21–25; Green et al, 1987; Stelmachowicz et al, 1989a; Fausti et al, 1990; Frank, 1990; Valente et al, 1992). All eight studies report that greater sound pressure level is required to obtain threshold as frequency increases. The results for four of the studies (Cunningham et al, 1983; Schechter et al, 1986; Valente et al, 1992; present study) using a Koss HV/1A+ earphone are similar. Further, the mean thresholds reported by Green et al (1987) and Stelmachowicz et al (1989a), using a prototype high frequency audiometer, were in close agreement with the findings of the present study.

The mean thresholds reported by Frank (1990), using Sennheiser HD 250 earphones, were lower than those reported above at 10, 12,

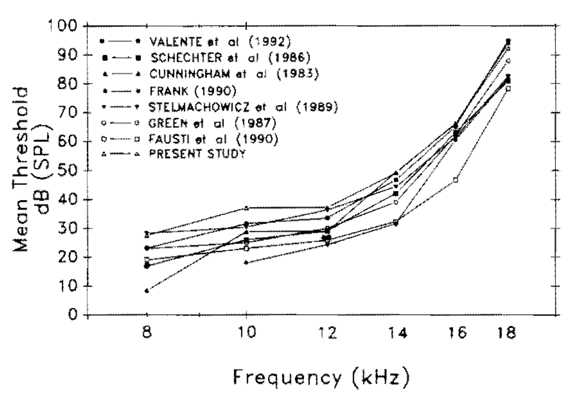

Figure 4 Mean high-frequency thresholds (dB SPL) for the Koss HV/1A+ from the present study compared with the results of seven other studies.

and 14 kHz. Earphone, coupler, and calibration differences may account for these differences. Recently, Fausti et al (1990) reported thresholds similar to those reported by Frank (1990) using Koss Pro/4X earphones. Other factors that may account for high-frequency threshold differences across studies include patient instructions, criterion for responses, selection and age differences, test environment, and method of stimulus presentation.

ER-2: Test and Retest Thresholds

Table 3 shows the mean thresholds, standard deviations and threshold range for the test and retest thresholds for the ER-2 earphones. The mean test minus retest threshold differences ranged from 0.1 dB at 10 kHz to 2.7 dB at 16 kHz. Statistical analysis at each frequency using the Hotelling's T^2 test, revealed that none of the threshold differences was statistically significant ($p > .05$). Therefore, thresholds obtained using the ER-2 earphone may also be expected to be stable over time. Significant Pearson product correlations ($p < .01$) were found at each frequency and ranged from 0.54 at 18 kHz to 0.94 at 16 kHz, indicating a strong relation between the test and retest thresholds.

Koss HV/1A+ versus ER-2

Table 4 shows the mean thresholds averaged across each ear and the test and retest thresholds for the Koss HV/1A+ and ER-2 earphones. Also shown are the ER-2 minus Koss HV/1A+ mean threshold differences.

At each frequency, the mean thresholds obtained with the ER-2 were higher than for the Koss HV/1A+ earphone. Stated another way, the audiometer attenuator had to be adjusted to provide greater sound pressure level in order to measure thresholds using the ER-2 compared with the Koss HV/1A+ earphone. The threshold differences varied from as little as 2.5 dB at 16 kHz to as great as 19.4 dB at 12 kHz and were analyzed at each frequency using the Hotelling's T^2 test. The threshold differences were significant ($p < .01$) at 8 to 14 kHz, but were not significant at 16 to 18 kHz.

It should be noted that the audiometer was calibrated to the output of the Koss HV/1A+ earphones using a flat plate coupler (CHF-10) and not to the coupler (HA-1, HA-2, or Zwislocki) SPL output of the ER-2 earphones. Consequently, when an ER-2 is used with an AS 10 HF audiometer calibrated for Koss HV/1A+ earphones, greater sound pressure level is necessary to elicit thresholds using an ER-2 earphone.

Intrasubject Variability

Clinically, the primary use of high-frequency audiometry is to monitor hearing thresholds for patients undergoing ototoxic drug therapy. Consequently, it is important to determine intra-

Table 3 Results for the ER-2 Insert Earphone Test and Retest Threshold

	Frequency (kHz)					
Condition	*8*	*10*	*12*	*14*	*16*	*18*
Test						
Mean (dB SPL)	43.5	52.0	57.1	63.3	70.1	101.8
SD	7.9	9.9	10.4	13.5	21.1	10.5
Range	30–60	40–70	40–85	45–100	40–105	70–NR
Retest						
Mean (dB SPL)	42.1	51.9	55.9	62.3	67.4	100.3
SD	9.1	9.0	10.4	15.3	20.9	12.4
Range	25–60	35–75	40–85	40–100	40–105	70–NR
Difference between Means	1.4	0.1	1.2	1.0	2.7	1.5
T^2 value (Test vs Retest Thresholds)	.52	.25	.08	.23	.76	.53
Correlation (Test vs Retest Thresholds)	.87*	.75*	.86*	.92*	.94*	.54*

*p < .01.
NR = No Response.
Also reported is the mean difference between each measuring condition. Pearson product correlation coefficients and the Hotelling's T^2 are provided at each frequency.

Table 4 Overall Results for Koss HV/1A+ and ER-2 Earphones

	Frequency (kHz)					
Condition	*8*	*10*	*12*	*14*	*16*	*18*
Koss HV/1A+ Grand Mean	27.5	37.0	37.1	49.1	66.2	92.2
ER-2 Grand Mean	42.8	51.9	56.5	62.8	68.7	101.1
Difference between Means	15.3	14.9	19.4	13.7	2.5	8.9
T^2 value (Koss HV/1A+ vs ER-2)	6.3*	5.1*	5.8*	3.0*	0.4	1.7

* p <.01.

Grand mean thresholds = mean of test and retest thresholds for the Koss HV/1A+ and ER-2 insert earphones. Also reported is the mean difference between the transducers and the Hotelling's T^2 for each frequency.

subject threshold variability. Using the equipment and procedures specified in the present study, intrasubject threshold variability was determined by comparing the individual subject threshold differences between the test and retest threshold at each frequency and for each earphone.

Table 5 reveals the percentage of individual subjects having test-retest threshold differences within ±0 dB, ±5 dB, ±10 dB, and greater than ±11 dB. For the Koss HV/1A+ earphone, approximately 80 percent of the subjects had test-retest threshold differences of within ±5 dB and 95 percent were within ±10 dB from 8 to 16 kHz. Threshold differences greater than ±11 dB occurred for only 0.0 to 7.0 percent of the subjects from 8 to 16 kHz.

Table 6 shows the test versus retest SDs and the 95 percent confidence interval. For the Koss earphone, the 95 percent confidence interval was less than 10 dB from 8 to 16 kHz and greater than 15 dB at 18 kHz. Overall, these findings suggest that intrasubject variability is rather small and that a clinically acceptable range would be ±10 dB from 8 to 16 kHz and perhaps ±15 dB at 18 kHz.

In summary, these findings suggest that changes in audiometric thresholds revealed during serial high-frequency audiometry of greater than 10 dB at 8 to 16 kHz or greater than 15 dB at 18 kHz may indicate real changes in hearing sensitivity and are not related to the inherent variability of the test procedure. These findings are in very close agreement with those reported by Frank (1990) showing test-retest differences of ± 10 dB in 95 percent of the cases from 10 to 20 kHz.

Intrasubject threshold reliability for the ER-2 earphone reveals findings similar to those reported for the Koss earphone. For example, almost 80 percent of the subjects had test-retest threshold differences within ±5 dB from 8 to 14 and 18 kHz. Moreover, approximately 95 percent had test-retest threshold differences within ±10 dB from 8 to 16 kHz. The 95 percent confidence interval for the ER-2 earphone was less

Table 5 Percentage of Individual Ears having Test Minus Retest Threshold Differences for Each Transducer and Test Frequency

Test Minus	Frequency (kHz)					
Retest Thresholds	*8*	*10*	*12*	*14*	*16*	*18*
Koss HV/1A+						
± 0 dB	55.0	43.0	35.0	28.0	43.0	30.0
± 5 dB	95.0	75.0	83.0	83.0	83.0	74.0
±10 dB	100.0	98.0	95.0	93.0	95.0	83.0
>± 11 dB	0.0	2.0	5.0	7.0	5.0	17.0
ER-2						
± 0 dB	40.0	43.0	38.0	40.0	38.0	49.0
± 5 dB	90.0	85.0	80.0	83.0	58.0	83.0
± 10 dB	98.0	95.0	97.0	95.0	93.0	88.0
>± 11 dB	2.0	5.0	3.0	5.0	7.0	12.0

Table 6 Test and Retest Threshold Data for Each Transducer and Test Frequency

Measure	Earphone Type	Frequency (kHz) 8	10	12	14	16	18
SD	Koss	2.6	4.3	4.7	4.3	4.9	8.1
	ER-2	3.6	4.6	3.8	4.6	5.3	5.2
95% CI	Koss	5.1	8.4	9.2	8.4	9.5	15.8
	ER-2	7.0	8.9	7.4	8.9	10.3	10.1

Koss = Koss HV/1A+.
Also provided is the 95 percent confidence interval (CI) for each condition.

than 10 dB from 8 to 14 kHz and greater than 10 dB at 16 to 18 kHz (see Table 6).

CONCLUSIONS

High-frequency test-retest threshold reliability was found to be rather good and essentially equivalent for Koss and ER-2 earphones. Either transducer yields reliable threshold data over time and changes in hearing noted with the use of serial audiometry appear to be true changes, rather than changes caused by testing artifact.

Comparison of the mean threshold differences between earphones indicated the need for significantly greater sound pressure level to achieve thresholds using the ER-2 at most frequencies. If ER-2 earphones are used with an AS 10 HF audiometer calibrated for Koss HV/1A+ earphones, the examiner may reach the limits of the audiometer sooner than if the Koss HV/1A+ earphone had been used. This situation is especially true at higher test frequencies, where greater intensity is required, even for listeners with normal hearing. If "no response at the limits of the audiometer" is recorded, the clinician is less likely to observe changes in hearing sensitivity resulting from ototoxic medications. Since test-retest threshold differences were similar with either earphone, these authors recommend the use of the Koss HV/1A+ earphone since less intensity was required to establish threshold. Use of the Koss HV/1A+ would result in a higher audiometric "ceiling" and, therefore, provide a wider dynamic range to monitor changes that may occur in hearing sensitivity.

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REFERENCES

American National Standards Institute. (1989). *Specification for Audiometers.* (ANSI S3.6–1989). New York: ANSI.

American National Standards Institute. (1977). *Criteria for Permissible Ambient Noise During Audiometric Testing.* (ANSI S3.1–1977). New York: ANSI.

Borton T, Nolen B, Luks S, Meline N. (1989). Clinical applicability on insert earphones for audiometry. *Audiology* 28:61–70.

Carhart R, Jerger J. (1959). Preferred method for clinical determination of pure tone thresholds. *J Speech Hear Disord* 24:330–345.

Clark J, Roeser R. (1988). Three studies comparing performance of the ER-3A, tubephone with the TDH-50P earphone. *Ear Hear* 9:268–274.

Clemis J, Ballad W, Killion M. (1986). Clinical use of insert earphones. *Ann Otol Rhinol Laryngol* 95:520–524.

Cunningham D, Vise L, Jones L. (1983). Influence of cigarette smoking on extra-high-frequency auditory thresholds. *Ear Hear* 4:162–165.

Dreschler W, van der Hulst R, Tange R, Urbanus N. (1985). The role of high-frequency audiometry in early detection of ototoxicity. *Audiology* 24:387–395.

Dreschler W, van der Hulst R, Tange R, Urbanus N. (1989). Role of high frequency audiometry in early detection of ototoxicity. II. Clinical aspects. *Audiology* 28:211–220.

Fausti S, Frey R, Erickson D, Rappaport B. (1979a). 2AFC versus standard clinical measurement of high frequency audiometry sensitivity (8-20kc/s). *J Aud Res* 19:151–157.

Fausti S, Frey R, Erickson D, Rappaport B, Cleary E, Brummett R. (1979b). A system for evaluating auditory function from 8000–20,000 Hz. *J Acoust Soc Am* 66:1713–1718.

Fausti SA, Frey RH, Henry JA, Knutsen JL, Olson DJ. (1990). 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* 1:162–170.

Frank T. (1990). High-frequency hearing thresholds in young adults using a commercially available audiometer. *Ear Hear* 11:450–454.

Frank T, Vavrek MJ. (1992). Reference threshold levels for an ER-3A insert earphone. *J Am Acad Audiol* 3:51–59.

Green D, Kidd G, Stevens K. (1987). High-frequency audiometric assessment of a young adult population. *J Acoust Soc Am* 81:485–494.

Jacobson E, Downs M, Fletcher J. (1969). Clinical findings in high-frequency thresholds during known ototoxic drug usage. *J Aud Res* 9:379–385.

Killion M. (1984). New insert earphones for audiometry. *Hear Instr* 35:45–46.

Killion M, Wiber L, Gudmundsen M. (1985). Insert earphones for more interaural attenuation. *Hear Instr* 35:34,36.

Schechter M, Fausti S, Rappaport B, Frey R. (1986). Age categorization of high frequency auditory threshold data. *J Acoust Soc Am* 79:767–771.

Stelmachowicz P, Beauchaine K, Kalberer A, Jesteadt W. (1989a). Normative thresholds in the 8-to-20-kHz range as a function of age. *J Acoust Soc Am* 86:1384–1391.

Stelmachowicz P, Beauchaine K, Kalberer A, Langer T, Jesteadt W. (1988). The reliability of auditory thresholds in the 8-to-20 kHz range using a prototype audiometer. *J Acoust Soc Am* 83:1528–1535.

Stelmachowicz P, Beauchaine K, Kalberer A, Kelly W, Jesteadt W. (1989b). High frequency audiometry: test reliability and procedural considerations. *J Acoust Soc Am* 85:879–887.

Tange R, Dreschler W, van der Hulst R. (1985). The importance of high tone audiometry in monitoring for ototoxicity. *Arch Otorhinolaryngol* 242:77–81.

Valente M, Potts LG, Valente M, French-St. George M, Goebel J. (1992). High-frequency thresholds: sound suite versus hospital room. *J Am Acad Audiol* 3:387–394.