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High-Frequency Thresholds: Sound Suite versus Hospital Room

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Abstract

Benefits of high-frequency audiometry in monitoring hearing sensitivity of patients administered ototoxic medications are well established. Thresholds obtained within a sound suite have been proven reliable. It may, however, often be necessary for the audiologist to evaluate the patient at bedside. The primary purpose of this study was to determine if significant differences are present between high-frequency thresholds measured in a sound suite versus thresholds measured in a hospital room. In addition, the test-retest reliability of high-frequency thresholds was determined when measured in a hospital room. For 25 normal hearing subjects, results revealed that significant differences were not observed between thresholds measured in a sound suite versus those measured in a typical hospital room. In addition, differences between the initial and repeated thresholds obtained in the hospital room were not significant, and the differences were, for the most part, within ±10 dB at all test frequencies.

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

The value of high-frequency audiometry for detection of the effects of ototoxic medications upon hearing sensitivity has been well documented (Jacobson et al, 1969; Dreschler et al, 1985; 1989; Tange et al, 1985). High-frequency audiometry has been reported to detect the effects of ototoxic drugs as much as 2 months earlier than conventional serial monitoring techniques using traditional audiometric frequencies (Jacobson et al, 1969). In a 1985 study (Dreschler et al), hearing thresholds were obtained at .25 to 20 kHz on patients receiving ototoxic medications. These authors reported decreased hearing sensitivity in 68 percent of the patients at 10 to 20 kHz. In a follow-up study (Dreschler et al, 1989), decreases in hearing thresholds in the frequency region between 10 and 20 kHz were evident before decreases in hearing thresholds were noticed in the frequency region between 1 and 8 kHz. Threshold shifts in the higher frequency region were found to be 15 to 20 dB greater than the threshold shifts reported in the lower frequency region. Tange et al (1985) monitored high-frequency sensitivity of patients receiving cisplatinum therapy. Decreases in hearing thresholds occurred in 35 percent of the cases, with decreases initially occurring in the frequency region above 8 kHz for all subjects. One may conclude that the benefits of utilizing high-frequency audiometry for ototoxic monitoring "represents a mandate for its application" (Fausti et al, 1990).

In recent years, several portable high-frequency audiometers have been introduced for use in a clinical setting. These include the Demlar 20k (Cunningham et al, 1983; Laukli and Mair, 1985; Tange et al, 1985); Beltone 2000 (Frank, 1990); Virtual V320 (Fausti et al, 1990);

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and the Interacoustics AS10HF (Valente et al, 1990). The same degree of threshold reliability has been obtained with these audiometers as with conventional audiometric units used for testing between .125 and 8 kHz (Laukli and Mair, 1985). Investigators evaluating high-frequency audiometers reported small intrasubject variability, although intersubject variability is fairly large.

In a hospital environment, it is often necessary to establish threshold at the patient's bedside because the patient may be too ill to travel to the clinic. Unfortunately, little research is available about the validity and reliability of high-frequency thresholds obtained in an environment other than a sound suite. Consequently, audiologists often request that patients be transported to the audiology clinic to obtain reliable and valid high-frequency thresholds. This may present a hardship to the patient. One goal of this study was to determine if high-frequency thresholds measured in a typical semi-private hospital room on one day were significantly different from thresholds measured in the same room on another day. The lack of significant differences between threshold measures in the same room on different days is important for interpreting serial audiograms during drug therapy using ototoxic agents. A second goal was to determine if high-frequency thresholds measured in a typical semi-private hospital room were significantly different from thresholds measured in a sound suite. Current high-frequency audiometers are portable and lightweight; if reliable and valid audiograms can be obtained at bedside, obvious benefits may be provided for the patient. Finally, it was of interest to determine if the magnitude of differences between hospital room measures was within a clinically acceptable range (±10 dB) at each test frequency.

The effect of the ambient noise present in the hospital room is a major concern related to the validity (sound suite versus hospital room) and reliability (test-retest differences in thresholds measured in the hospital room) of bedside high-frequency thresholds. Specifications for maximum permissible levels of ambient noise have been standardized for conventional threshold measures (ANSI, 1977). The ANSI guidelines provide permissible noise levels through 8 kHz and specify that elimination of all ambient noise is not necessary for threshold determination. Currently, standards do not exist for permissible ambient noise when measuring thresholds above 8 kHz.

METHOD

Subjects

Twenty-five college students, aged 21 to 25 years (mean = 23.6 years; SD = 1.4 years; 23 females; 2 males), served as subjects. Green et al (1987) reported no significant differences between high-frequency thresholds (.8–20 kHz) measured for 18 male and 19 female listeners. All subjects reported no history of middle ear disease and demonstrated bilateral air conduction pure-tone thresholds equal to or less than 15 dB HL (re: ANSI, 1989) from 250 to 8000 Hz.

Equipment

The Interacoustics AS10HF high-frequency audiometer, with Koss HV-1A supraural earphones, was utilized in this study. This audiometer is available in two models in which the attenuator is calibrated to dB HL or dB SPL. This study was based upon results using the audiometer whose attenuator is calibrated in dB SPL relative to measures obtained in the Koss silicone flat-plate 6-cc coupler (CHF-10) described by Fausti et al (1979b).

Calibration of the AS10HF was performed according to the manufacturer's instructions using a B&K 2230 sound level meter, B&K 1625 1/3 octave filter, B&K 4134 1/2 inch microphone, and CHF-10 6-cc flat-plate coupler. Potentiometers are available at each frequency to assure that the measured output in the coupler was 110 dB SPL with the attenuator set to 110 dB SPL. During the course of this study, the measured values did not shift more than 1 dB at any test frequency. This finding is in close agreement with the findings reported by Fausti et al (1979b).

Ambient noise levels were measured in a double-walled sound suite and three separate semi-private hospital rooms using a B&K 4165 1/2 inch free-field microphone connected to a B&K 2230 sound level meter and B&K 1625 1/3 octave band filter (measures at 8, 10, 12.5, 16, and 20 kHz). Although standards for maximum permissible ambient noise levels are not available for high-frequency threshold measures, Table 1 shows that the levels of ambient noise averaged across the three hospital rooms were less than the maximum allowable level of 40 dB SPL required at 8 kHz for 1/3 octave measures for the ears covered condition (ANSI, 1977). The only overt attempt to minimize bedside ambient noise levels was not allowing use of the

Table 1 Mean Ambient Noise Levels (dB SPL) at Third Octave Intervals in the Three Hospital Rooms Used in This Study

Center Freq. (kHz)	*Mean Ambient Noise Levels without Oxygen Supply Valve Open*	*Mean Ambient Noise Levels with Oxygen Supply Valve Open*
.8	18.8	55.1
10	14.6	60.2
12.5	14.8	48.1
16	28.6	39.8
20	14.9	39.8

These measures were obtained when the oxygen supply valve at bedside was inactive. For comparison, mean ambient noise levels are shown when the oxygen supply valve was rotated to maximum position.

bedside oxygen valve or television. Although the oxygen valve was not in use during this project, the second column in Table 1 shows the effect upon ambient noise by allowing maximum rotation of the oxygen valve. Finally, other patients or visitors were not present during measurements of ambient noise or when establishing thresholds. As is our standard procedure while performing conventional bedside audiograms, other patients or visitors would have been asked to refrain from talking and the television would have been turned off.

Procedures

Earphones were placed so the diaphragm was over the opening to the ear canal. The same examiner placed the earphones on all the subjects and obtained thresholds for pulsed tones (400 msec on/400 msec off) for ascending 5-dB steps at 8, 10, 12, 14, 16, and 18 kHz for the right and left ears utilizing a modified Hughson-Westlake procedure (Carhart and Jerger, 1959). This procedure provides valid high-frequency thresholds (Fausti et al, 1979a). Threshold was defined as the lowest intensity level at which subjects responded to three of five presentations. Standard clinical instructions for threshold measurement were provided to each subject.

Thresholds were initially established for each ear within a double-walled sound suite and in one of three hospital rooms (designated as R1) on the same day. The order of presentation (ear and test condition) was counterbalanced so that half the subjects were evaluated in the hospital room first, while the other half were tested in the sound suite first. Similarly, the right ear was tested first in half the subjects. The subjects were retested in the same hospital room (designated as R2), approximately 2 to 3 weeks after the initial test to determine if the test-retest differences were within a clinically acceptable range (±10 dB) at all test frequencies. Thresholds were not retested for the sound-suite condition because results from a previous study (Valente et al, 1990) showed that test-retest thresholds were not significantly different when measured in a sound suite using the same equipment and procedures utilized in the present study.

RESULTS AND DISCUSSION

The measured thresholds (dB SPL) were analyzed to determine if significant differences were present between (1) the thresholds measured in a semi-private hospital room for an initial evaluation (R1) when compared with the repeated (R2) measure obtained in the same hospital room at a later date and (2) thresholds measured in a double-walled sound suite in comparison to thresholds measured in the hospital room ((R1 + R2)/2). In addition, the magnitude of the differences between the initial and repeated measures (R1 – R2) obtained in the hospital room were analyzed to determine if these differences were within a clinically acceptable range (±10 dB) at all test frequencies.

Test versus Retest Thresholds in the Hospital Room

Initially, Hotelling's T^2, which is a multivariate extension of the paired comparison t-test, revealed that the mean differences between the right and left ears at each frequency and condition were not significant. Consequently, threshold data were collapsed across ears at each frequency, and the data for all subsequent conditions represent the average of the two ears.

Table 2 reports the mean threshold values (dB SPL) at the six test frequencies for the initial (R1) and repeated (R2) measures obtained in the same semi-private hospital room. These mean differences (R1 – R2) ranged from 0.2 dB at 12 kHz to 2.7 dB at 16 kHz. Statistical analysis at each test frequency using Hotelling's T^2 revealed that none of these differences was statistically significant. Inspection of Table 2 indicates that the mean differences (R1 – R2) between the initial and repeated measures in the hospital room were quite small. Therefore, measures obtained in a typical hospital room

Table 2 Mean Thresholds (dB SPL) Obtained in a Hospital Room for the Initial (R1) and Repeated (R2) Measures

	Frequency (kHz)					
Condition	*.8*	*10*	*12*	*14*	*16*	*18*
Room-Initial Threshold (R1)						
Mean	25.4	32.7	33.4	45.9	64.5	96.7
SD	7.3	6.4	7.2	10.6	21.1	12.8
Range	10–45	15–40	20–55	30–70	30–105	65–110
Room-Repeat Threshold (R2)						
Mean	24.0	31.5	33.2	46.3	61.8	94.8
SD	6.3	7.4	6.6	11.1	19.6	12.6
Range	10–35	15–50	20–50	30–75	25–105	70–110
Grand Mean (R1 + R2)/2	24.7	32.2	33.3	46.1	63.2	95.8
Difference (R1 – R2)	1.4	1.2	0.2	–0.4	2.7	1.9
Correlation (R1 vs R2)	.66*	.71*	.79*	.70*	.93*	.86*
T^2 Value (R1 vs R2)	1.1	1.1	0.3	–0.2	1.8	1.1

*$p < .01$

The standard deviation and range for each condition is provided. Also, the grand mean ((R1 + R2)/2) and the mean difference between R1 and R2 are reported. Pearson product correlation coefficients and Hotelling's T^2 value are provided at each frequency for the R1 versus R2 comparisons.

may be expected to be reliable if significant changes do not occur in the levels of ambient noise present in the hospital room between threshold measures. Pearson product correlations ranged from 0.66 at 8 kHz to 0.93 at 16 kHz, indicating a strong relationship between the initial and repeated measure. These correlations were significant ($p < .01$) at all test frequencies.

Table 2 also shows the standard deviation (SD) and range of thresholds for each of the two conditions as well as the average of the initial and repeated measure ((R1 + R2)/2). The trend toward larger SDs (intersubject variability) as test frequency increased was in good agreement with some of the findings reported previously for high-frequency thresholds obtained in sound suites. Cunningham et al (1983), using a Demlar 20K, reported SDs ranging from 4.7 dB at 8 kHz to 23.2 dB at 16 kHz. Frank (1990), using a Beltone 2000, reported SDs ranging from 8.5 dB at 10 kHz to 19.0 dB at 8 kHz. Green et al (1987) and Stelmachowicz et al (1989), using a prototype high-frequency audiometer, reported SDs ranging from 5.2 dB at 8 kHz to 22.5 dB at 18 kHz. As such, the large intersubject variability revealed in the present study would seem to suggest the limited use of the Interacoustics 10ASHF audiometer with Koss HV-1A earphones as a means to establish "absolute" thresholds for high-frequency signals.

This consistent finding of noting larger intersubject differences in high-frequency thresholds continues to be the major concern for establishing a national standard for high-frequency audiometry. In addition, the finding of large intersubject variability continues to be the major reason that clinicians are hesitant to utilize high-frequency audiometry to establish "absolute" threshold values for an individual subject. A recent study by Fausti et al (1990), using the Virtual V320 computerized audiometer coupled to modified Koss Pro/4X earphones, reported SDs that were considerably smaller than SDs reported in the other studies. They reported SDs as small as 5.2 to 6.2 dB at 8 to 14 kHz rising to only 12.8 and 13.3 dB at 16 and 18 kHz, respectively.

The smaller SD at 18 kHz in the present study, as well as many of the previous studies, is not related to reduced intersubject variability, but rather to the fact that fewer subjects are able to respond at 18 kHz. In fact, in the present study, 100 percent of the subjects responded to

stimuli between 8 and 16 kHz. However, only 88 percent of the subjects in the present study responded at 18 kHz. This is in agreement with an 88 percent response at 18 kHz reported by Cunningham et al (1983), Schechter et al (1986), and a 90 percent response rate reported by Frank (1990).

Sound-Suite versus Hospital Room Thresholds

The mean thresholds (dB SPL) measured in the sound suite are shown in Table 3. Also shown are the mean thresholds reported in Table 2 for (R1), (R2), and (R1 + R2)/2. Differences in the mean thresholds between the sound suite and the means of the three hospital room measures ranged from as small as 0.0 dB (sound suite versus R1 and 18 kHz) to as great as 3.3 dB at 16 kHz for the sound suite versus R2 comparison. Most differences were less than 2 dB. Differences between the sound suite versus the (R1 + R2)/2 condition were analyzed using Hotelling's T^2 at each test frequency. Again, these differences were not statistically significant at the .05 confidence level. Thus, at each frequency, thresholds obtained in the hospital room were clinically equivalent to those measured in the sound suite. That is, thresholds measured in the hospital room were as valid as those measured in the sound suite. Finally, Pearson Product Correlations between thresholds measured in the sound suite and (R1 + R2)/2 conditions were found to be significant ($p < .01$) at all test frequencies. The mean thresholds at 8 to 18 kHz reported in Table 3 for the sound-suite condition are in close agreement with the results reported in several studies. Figure 1 shows the mean thresholds (dB SPL) reported in the present study compared to the mean thresholds reported by Cunningham et al (1983), Schechter et al (1986) for ages 21 to 25, Green et al (1987), Stelmachowicz et al (1989), Fausti et al (1990), and Frank (1990). All seven studies reported that greater intensity is required to obtain threshold as frequency in-

Table 3 Mean Thresholds (dB SPL) Obtained in a Sound Suite Compared with the Means for R1, R2 and the Grand Mean Reported in Table 1

	Frequency (kHz)					
Condition	*.8*	*10*	*12*	*14*	*16*	*18*
Sound Suite						
Mean	23.2	31.6	33.0	46.7	65.1	94.8
SD	6.8	6.3	7.1	9.1	18.9	12.8
Range	10–40	20–45	20–60	30–70	35–100	60–110
Room–Initial Threshold (R1)						
Mean	25.4	32.7	33.4	45 9	64.5	96.7
Room–Repeat Threshold (R2)						
Mean	24.0	31.5	33.2	46.3	61.8	94.8
Grand Mean						
(R1 + R2)/2	24.7	32.2	33.3	46.1	63.2	95.8
A. Difference between the sound suite and:						
Room (R1)	–2.2	–1.1	–0.4	0.8	0.6	–1.9
Room (R2)	–0.8	0.1	–0.2	0.4	3.3	0.0
Grand Mean						
(R1 + R2)/2	–1.5	–0.6	–0.3	0.6	1.9	–1.0
B. Correlation between sound suite and (R1 + R2)/2:						
Correlation	.63*	.71*	.79*	.70*	.93*	.86*
C. Hotelling's T^2 (sound suite versus (R1 + R2)/2):						
T^2 value	–1.5	0.7	0.3	0.5	1.3	–0.7

*$p < .01$

Also reported are the standard deviation and range for the sound-suite condition. Mean differences between thresholds obtained in the sound suite and hospital room, (R1), (R2), (R1 + R2)/2, are provided. Pearson product correlation coefficients and Hotelling's T^2 value are also given for sound-suite versus (R1 + R2)/2 comparisons.

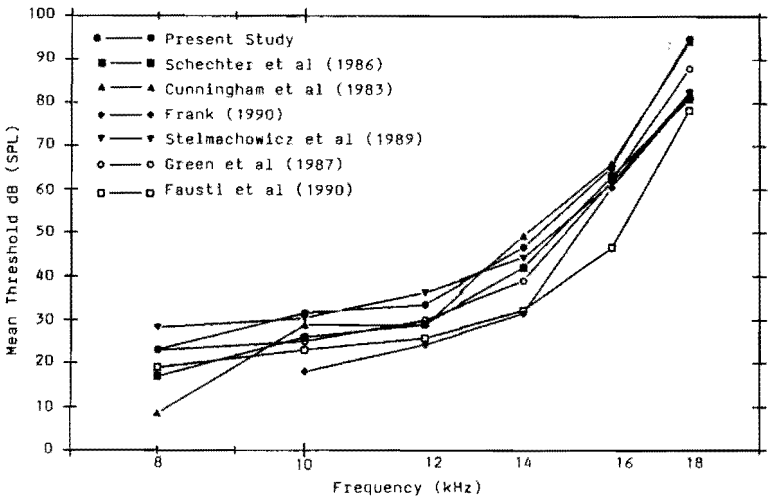

Figure 1 Mean high-frequency thresholds (dB SPL) measured in a sound suite at six discrete frequencies from the present study compared with the results of six other studies.

creases. In addition, the results for three of the studies (the present study in addition to Cunningham et al, 1983, and Schechter et al, 1986) are similar even though different audiometric equipment coupled to the same earphone (Koss HV-1A) was used in each study.

A recent study by Frank (1990) using a Beltone 2000 with Sennheiser HD 250 earphones reported high-frequency thresholds that were considerably better than those reported above. In addition, Frank (1990) used the B&K flat-plate coupler, while the previously mentioned studies used the Koss silicone flat-plate 6-cc coupler for calibration. The differences in earphones and calibration methods may account for the improved thresholds reported by Frank (1990) in comparison to the other three studies. A recent study by Fausti et al (1990) reported findings similar to those reported by Frank (1990). Fausti et al (1990) used the Virtual V320 high-frequency audiometer coupled to modified Koss Pro/4X earphones.

Other factors which may account for differences between the various studies may include (a) patient instructions; (b) patient criterion for responses; (c) patient selection and age differences; (d) test environment; and (e) method of stimulus presentation.

Intrasubject Variability

Clinically, the primary use for high-frequency audiometry is to monitor hearing thresholds for patients undergoing therapy using ototoxic drugs. For this use, it is important to determine the anticipated intrasubject variability one can reasonably expect when using the equipment and procedures specified in the present study. To determine this, the measured thresholds were examined to establish intrasubject variability by comparing the individual differences between the initial threshold (R1) and retest (R2) threshold.

Table 4 reveals the percentages of individual subjects having test-retest differences within ±0 dB, ±5 dB, ±10 dB, and > ±11 dB for each frequency. Inspection of this table indicates that between 8 and 14 kHz, approximately 80 percent of the individual cases had test-retest differences within ±5 dB, while approximately 95 percent had differences within ±10 dB. Finally, differences of > ±11 dB occurred in only 2.0 to 8.0 percent of the individual cases at 8 to 14 kHz. These findings suggest that intrasubject variability is rather small and that a clinically acceptable range would be ±10 dB at 8 to 14 kHz and ±15 dB at 16 to 18 kHz. In this regard, these findings suggest that changes in audiometric thresholds obtained during serial audiometry of greater than 10 dB at 8 to 14 kHz or greater than ±15 dB at 16 to 18 kHz may indicate real changes in hearing sensitivity and

Table 4 Percentage of Individual Ears Having Test Minus Retest Threshold Levels within ±0 dB, ±5 dB, ±10 dB, or > ±11 dB for Each Test Frequency

Test minus Retest Thresholds	*Frequency (kHz)*					
	.8	*10*	*12*	*14*	*16*	*18*
±0 dB	48.0	44.0	60.0	36.0	24.0	32.0
±5 dB	84.0	78.0	89.0	78.0	70.0	66.0
±10 dB	96.0	98.0	98.0	92.0	88.0	84.0
> ±11 dB	4.0	2.0	2.0	8.0	12.0	16.0

are not related to the inherent variability of the test procedure.

The finding of small intrasubject variation is in close agreement with the findings reported by Frank (1990). He reported test-retest differences of ±10 dB in 95 percent of the cases at 10 to 20 kHz.

CONCLUSIONS

This study compared high-frequency thresholds measured in a sound suite with those measured in a hospital room, thereby examining the validity of hospital room measures. In addition, the measures obtained in the hospital room were repeated, to determine test-retest reliability. Finally, the magnitude of threshold differences obtained via test and retest within the hospital room were examined.

The present study revealed that high-frequency threshold testing can be used in a hospital room, with the same degree of reliability as the same type of testing within a sound suite. Mean differences between sound-suite versus hospital room thresholds indicate no significant differences between the two test environments. However, until standards are developed for maximum allowable ambient noise levels for measuring high-frequency thresholds, it is strongly suggested that ambient noise levels be monitored each time thresholds are obtained in an environment other than a sound suite. During the course of this study the ambient noise levels were measured on several occasions and variation was not greater than 5 dB at any of the 1/3 octave intervals. As was shown in Table 2, opening the oxygen supply valve had a significant effect upon increasing the ambient noise level. For the purposes of reducing test-retest variability, it is important that ambient noise levels be documented at the time of each test and that repeat testing be performed under conditions that are similar to the ambient noise levels present during the initial threshold measure.

The current study may have implications for serial monitoring of hearing at bedside, with critically ill patients. High-frequency thresholds obtained at bedside for normal hearing subjects were found to be consistent with thresholds obtained within a sound suite. Monitoring noise levels produced by specialized hospital equipment and minimization of ambient noise within the hospital room are certainly a concern, and a basis for further study. It appears that good test-retest reliability is seen with thresholds obtained within the hospital room. This finding may have implications where serial monitoring is concerned. The physician and audiologist may feel reasonably comfortable that changes seen with time are valid and not due to artifact.

Differences in thresholds obtained at the time of the initial test and at the time of repeated measure were within ±10 dB, for 8 to 14 kHz. Exceptions existed at 16 to 18 kHz, where differences closer to ±15 dB were apparent.

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