

Reliability and Validity of High-Frequency (8–20 kHz) Thresholds Obtained on a Computer-Based Audiometer as Compared to a Documented Laboratory System

Stephen A. Fausti*

Richard H. Frey†

James A. Henry†

James L. Knutsen†

Deanna J. Olson†

Abstract

A Macintosh computer-based audiometer (Virtual 320) was evaluated for reliability and validity of high-frequency (8–20 kHz) thresholds by comparison with a well documented laboratory high-frequency evaluation system (PARVA-HF). High-frequency earphones originally provided with the V320 for high-frequency testing required modification to improve reliability in calibration and in subject threshold testing. Twenty normal-hearing adults were evaluated in the 8–20 kHz frequency range on both testing systems. Results of intrasubject multiple-session testing were evaluated to determine the reliability of high-frequency thresholds obtained. The V320 produced reliable results comparable to the PARVA-HF. Validity of high-frequency thresholds was inferred by comparing V320 responses to those obtained with the PARVA-HF. Comparable findings between systems imply validity of thresholds obtained with the V320. Conventional frequency (0.25–8 kHz) threshold evaluation with the V320 and a Grason-Stadler 1701 audiometer also yielded comparable results.

Key Words: Computer-based, high-frequency, audiometer, earphone coupling, reliability, validity

High-frequency (8–20 kHz) threshold evaluation was made feasible with the development and documentation of reliable instrumentation that addressed problems previously inherent with the presentation of high-frequency stimuli (Osterhammel et al, 1977; Fausti et al, 1979b). The recent availability of several commercially manufactured high-frequency audiometers has made the clinical utility of high-frequency auditory evaluation a reality.

Perhaps the greatest current value of obtaining high-frequency threshold data is in the serial monitoring of high-frequency auditory sensitivity during treatment with potentially ototoxic agents (Fausti et al, 1984a; Fausti et al, 1984b; Tange et al, 1985; Dreschler et al, 1989; Stelmachowicz et al, 1989). Such monitoring could provide identification of hearing loss early enough to prevent communicative impairment. This same technique may also have potential value for the monitoring of individuals subjected to noise (Fausti et al, 1981).

A multi-site study, chaired at the Portland, Oregon Veterans Affairs Medical Center (PVAMC), is conducting an in-depth investigation of the early warning capabilities of high-frequency auditory evaluation. A large sample of hospitalized patients receiving treatment with aminoglycoside antibiotics or chemother-

*Director of Auditory Research, Chief of Audiology, Portland Veterans Affairs Medical Center (PVAMC); Associate Professor, Oregon Health Sciences University, Portland, Oregon

†PVAMC Auditory Research Lab, Portland, Oregon

Reprint requests: Stephen A. Fausti, Portland VA Medical Center (151J), P.O. Box 1034, Portland, OR 97207

apeutic agents is being evaluated. It is hypothesized that the serial monitoring of high-frequency hearing will provide earlier warning of hearing loss than is possible with conventional frequency hearing evaluations.

A high-frequency hearing evaluation system (Portland Auditory Research Veterans Affairs—High-Frequency [PARVA-HF]), developed and currently in use in this lab, is comprised of commercially manufactured laboratory rack equipment and specially designed stimulus-shaping modules (Fausti et al, 1979b). Although well documented for reliability and validity (Fausti et al, 1979a; Fausti et al, 1979b; Rappaport et al, 1982), the PARVA-HF cannot be transported into the field (e.g., onto hospital wards), and does not allow for automated data management. For purposes of the multi-center study, an audiometer that was reasonably portable and could collect, store, and retrieve high-frequency threshold data for analysis was imperative.

Four high-frequency audiometers are currently commercially manufactured and sold in the United States: Beltone 2000, Demlar 20k, Maico 2400, and Virtual 320 (V320). The Beltone, Maico, and Virtual audiometers are computer-operated instruments. The Beltone audiometer uses a dedicated computer that cannot be used for any other purpose, leaving Maico and Virtual as the only audiometers with true personal computer compatibility. The Maico unit utilizes the MS-DOS operating system, designed for use with IBM-compatible computers, while the Virtual is Macintosh SE computer-based. The PVAMC Auditory Research Laboratory staff utilize Macintosh computers for data management and were interested, therefore, in evaluating the potential of the Macintosh-driven V320 as a research audiometer. Documentation of V320 reliability was essential for its utilization as a data collection tool.

Validity of threshold responses was also evaluated. For purposes of this study, response validity is based on a statistical comparison of thresholds obtained with the PARVA-HF system to those obtained with the V320. It has been demonstrated by release-from-masking studies that, during threshold testing with the PARVA-HF, the ear responds to the stimulus in question and not some distortion artifact (Fausti et al, 1982).

Results are reported from an evaluation of the V320 audiometer with respect to: (a) modifi-

cations required to achieve reliable calibration; (b) high-frequency threshold test-retest reliability; (c) validity of high-frequency thresholds with respect to the PARVA-HF; and (d) evaluation of reliability and validity of threshold measures in the conventional frequency range.

PRELIMINARY STUDIES

Prior to comparing the two high-frequency systems, substudies were conducted to investigate characteristics of the V320 as received from the manufacturer. These substudies included investigation of: (a) transducer coupling characteristics; (b) transducer frequency response characteristics; and (c) differences in test frequencies between systems.

Substudy 1: Earphone Coupling

Earphones provided with the V320 for high-frequency testing were Koss Pro/4X Plus transducers, modified by the audiometer manufacturer. Specifically, the transducer used primarily for low-frequency sound transmission was disabled, leaving a piezo-electric high-frequency transducer. Additionally, signals to each earphone were separated into two monaural phone plugs with independent grounds to eliminate electrical cross-talk potential between channels.

During initial field-testing at the PVAMC, further modification of the Pro/4X Plus was found to be necessary due to: (a) variation of auditory thresholds of as much as 12 dB during preliminary test-retest studies; (b) poor repeatability during calibration; and (c) subject reported earphone cushion noise with head movement. These problems were thought to be caused by the oval, air-filled plastic ear cushions provided as standard equipment with the Pro/4X earphones.

A consistent positional interface between the measuring microphone of the coupler and the earphone diaphragm is necessary to achieve reliable calibration. This could not be accomplished with the Pro/4X Plus due to unavoidable randomness in earphone placement on the coupler (Fig. 1A). Additionally, a coupling volume of 6 cm³, standard in artificial human ear acoustic couplers, could not be achieved. As previously described (Fausti et al, 1979b), the coupling system utilized in this lab effects a 6 cm³ volume when earphones are set into an aluminum spacing ring, centered and locked into

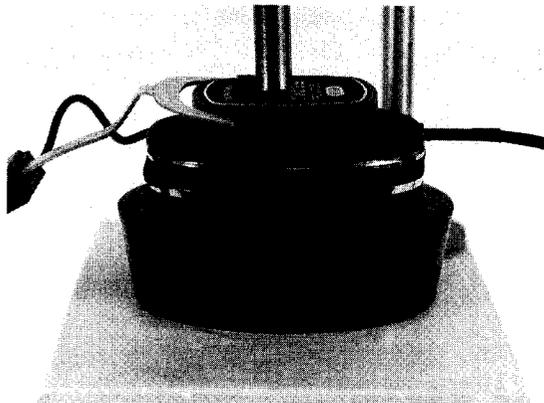


Figure 1 A, Pro/4X with oval, air-filled plastic cushions (could not be locked onto the coupler with a spacing ring).

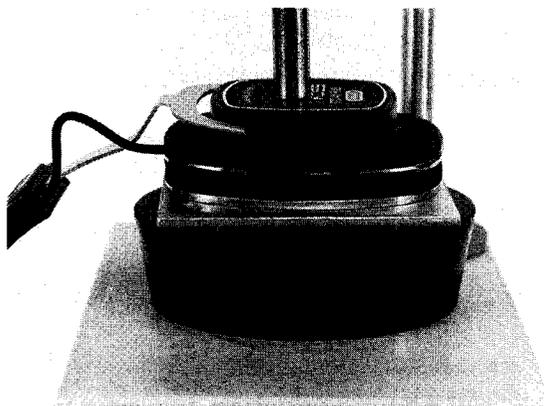


Figure 1 B, M-Pro/4X with round foam ear cushion (locked onto the coupler with a spacing ring).

place (Figs. 1B and 1C). Such coupling was not possible with the oval, plastic ear cushion.

To improve reliability, a set of Pro/4X earphones was modified by replacing the oval, air-filled plastic ear cushion with the round, foam ear cushion standard on Koss HV/1A earphones (Fig. 2) (Fausti et al, 1979b). To compare calibration test-retest variability between the various earphone configurations, a series of experiments was conducted using the PARVA-HF lab audiometer and flat-plate coupler with: (a) an unmodified Pro/4X earphone (Pro/4X); (b) a modified Pro/4X earphone (M-Pro/4X); and (c) a standard HV/1A earphone. The M-Pro/4X and the HV/1A were calibrated on the PARVA-HF flat-plate coupler in a sound-treated booth as previously described (Fausti et al, 1979b). The Pro/4X was calibrated in the same fashion except that, due to the oval plastic cushion, the use of a spacing ring was not possible.

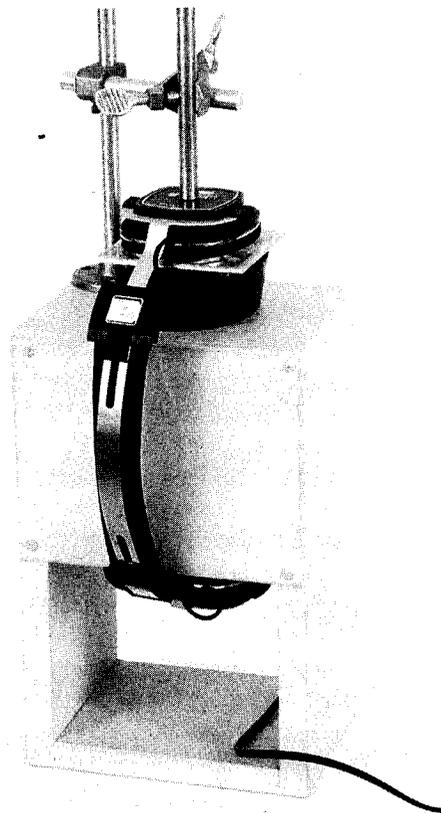


Figure 1 C, M-Pro/4X in position on the flat-plate coupler.

Four separate series of calibrations were performed each day for 2 successive days, for a total of eight calibration runs on each of the three earphones. Based on the SPL outputs during successive runs, means of standard deviations and ranges were computed for each earphone at each frequency to evaluate calibration test-retest variability (Table 1). Paired comparisons (Sheffé F) between earphones revealed the Pro/4X to have significantly greater variability than either the M-Pro/4X or the HV/1A ($p < 0.05$). The latter two demonstrated comparable and minimal variability. The M-Pro/4X revealed comparable standard deviations and ranges to the HV/1A at every test frequency.

To determine test-retest variability between the Pro/4X and M-Pro/4X during threshold testing, five normal-hearing subjects were evaluated under each of the earphone conditions, with testing repeated the following day. A compari-



Figure 2 Pro/4X showing the different ear cushions evaluated. A, Pro/4X with oval, air-filled plastic cushion.



Figure 2 C, Pro/4X with oval plastic cushion on the left and round foam cushion on the right.

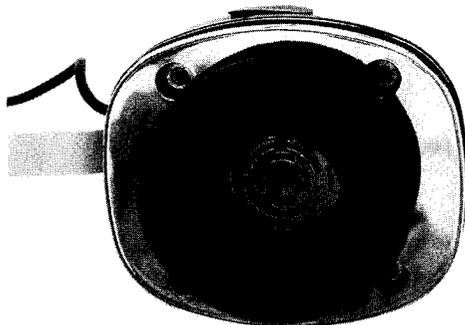


Figure 2 B, M-Pro/4X with round foam cushion.

son of threshold results demonstrated the same phenomenon observed in calibration, i.e., poorest test-retest reliability for the Pro/4X (Table 2). Sheffé F revealed a significant difference between the modified and unmodified Pro/4X ($p < 0.05$). Additionally, subjects reporting friction noise from head movement with the Pro/4X reported none from the foam cushions of the M-Pro/4X.

Combined results from these earphone evaluations revealed that, during repeated calibrations and human subject testing, the Pro/4X transducer, as modified with the foam

Table 1 Calibration Variability for Three Earphone Configurations*

| kHz | Standard Deviation (dB) | | | Range (dB) | | |
|----------------------|-------------------------|----------|-------|------------|----------|-------|
| | Pro/4X | M-Pro/4X | HV/1A | Pro/4X | M-Pro/4X | HV/1A |
| 8 | 0.3 | 0.3 | 0.1 | 1.1 | 0.6 | 0.2 |
| 9 | 1.2 | 0.1 | 0.1 | 5.3 | 0.2 | 1.3 |
| 10 | 0.9 | 0.2 | 0.8 | 3.1 | 0.4 | 1.8 |
| 11.2 | 0.5 | 0.4 | 0.2 | 1.3 | 1.0 | 0.6 |
| 12.5 | 0.6 | 0.5 | 0.2 | 1.5 | 1.1 | 1.1 |
| 14 | 1.2 | 0.1 | 0.2 | 2.6 | 0.3 | 1.6 |
| 16 | 3.1 | 0.2 | 0.1 | 8.6 | 0.5 | 1.7 |
| 18 | 1.7 | 0.2 | 0.1 | 8.0 | 0.5 | 1.6 |
| 20 | 0.4 | 0.2 | 0.1 | 5.6 | 0.5 | 1.2 |
| Frequencies combined | 1.1† | 0.2 | 0.2 | 4.1‡ | 0.6 | 1.2 |

*Means of standard deviations and ranges based on dB SPL outputs from 8 equivalent calibration runs

†Significantly greater than standard deviations of M-Pro/4X and HV/1A ($p < 0.05$)

‡Significantly greater than ranges of M-Pro/4X and HV/1A ($p < 0.05$)

Table 2 Human Subject Threshold Variability when Tested with Pro/4X and M-Pro/4X Earphones*

| Frequency (kHz) | Threshold Differences (dB) | |
|----------------------|----------------------------|----------|
| | Pro/4X | M-Pro/4X |
| 8 | 6 | 4 |
| 9 | 8 | 3 |
| 10 | 4 | 2 |
| 11.2 | 4 | 2 |
| 12.5 | 4 | 3 |
| 14 | 3 | 1 |
| 16 | 2 | 4 |
| 18 | 5 | 3 |
| 20 | 14 | 4 |
| Frequencies combined | 4.9 [†] | 2.7 |

*Means of absolute values of intersession threshold differences (N = 5 subjects)

[†]Significantly greater than M-Pro/4X (Sheffé F; $p < 0.05$)

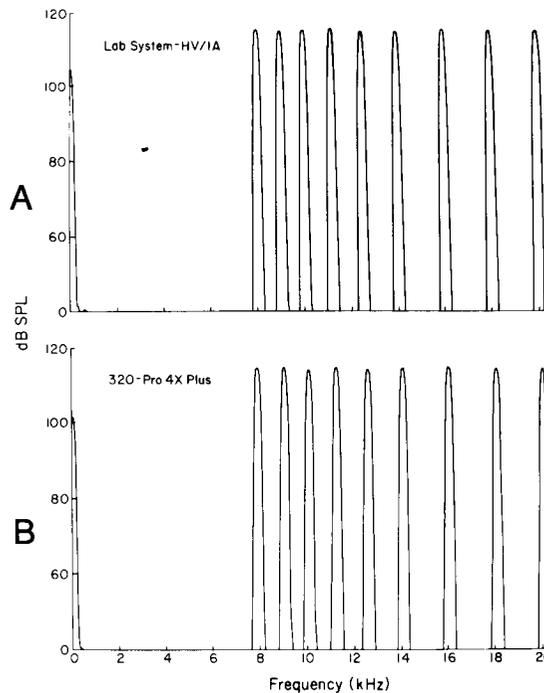


Figure 4 Pure-tone high-frequency test signals as measured on a flat-plate coupler. *A*, PARVA-HF with HV/1A transducer. *B*, V320 with M-Pro/4X transducer.

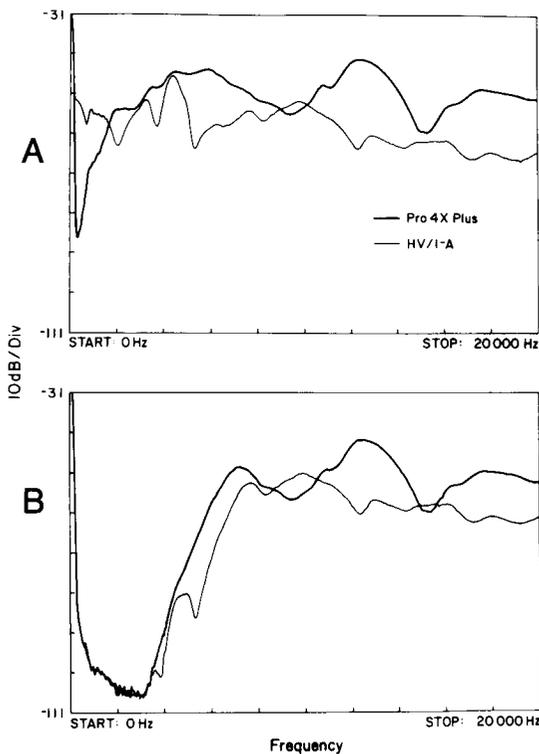


Figure 3 Frequency spectrum outputs of the M-Pro/4X and HV/1A transducers driven directly by the tracking generator from a Tektronix 5L4N Spectrum Analyzer (dB scale on the ordinate is relative due to automatic scaling): *A*, without filtering. *B*, through a high-pass filter network similar to that built into each test system.

ear cushions, was significantly more reliable than the unmodified Pro/4X. Consequently, the M-Pro/4X earphones were utilized in the subsequent comparison studies between the V320 and the PARVA-HF.

Substudy 2: Earphone Characteristics

Figure 3A displays frequency spectrum outputs of the M-Pro/4X and HV/1A transducers when driven directly by the tracking generator from a Tektronix 5L4N Spectrum Analyzer. This unit produces a constant voltage source that sweeps through frequencies from DC to 20 kHz. Although the HV/1A produces a flatter response, the M-Pro/4X earphone provides greater acoustic output than the HV/1A at most frequencies. In Figure 3B, the tracking generator constant voltage source was routed through a high-pass filtering network to simulate filtering as it would occur in both evaluation systems. It can be seen that there is a significant reduction in the low-frequency response of each transducer, while high frequencies are essentially unaffected.

Electrical and acoustical analyses of each test frequency revealed negligible distortion, linearity, and signal-to-noise ratio (S/N) differences between systems (Fig. 4). Comparable signal characteristics were determined in each system to the level of measurement capability of our monitoring instrumentation (Hewlett-Packard 3561A Dynamic Signal Analyzer and Tektronix 5L4N Spectrum Analyzer). It should be noted, however, that instrumental and environmental limitations prevented direct acoustic measurement of S/N.

Substudy 3: Test Frequencies

The V320 hardware and software were designed to deliver high-frequency test stimuli at 9, 10, 11.2, 12.5, 14, 16, 18, and 20 kHz. All previous threshold testing on the PARVA-HF system included the frequencies 11 and 12 kHz. This raised the question as to whether there was variability in normal subjects between 11 and 11.2 kHz and/or between 12 and 12.5 kHz. To answer this question, five normal-hearing subjects were tested five times each at 11, 11.2, 12, and 12.5 kHz. Results revealed no significant threshold differences between 11 and 11.2 or between 12 and 12.5 kHz within or between subjects ($p < 0.05$; ANOVA). The assumption can then be made that thresholds obtained at 11.2 and 12.5 kHz closely reflect thresholds at 11 and 12 kHz respectively for normal-hearing individuals. It is recognized, however, that when testing individuals with hearing disorders this assumption is not valid. In order to directly compare the two systems, 11.2 and 12.5 kHz were selected on the PARVA-HF laboratory system to coincide with those frequencies on the V320.

METHOD

Subjects

Following system documentation, 20 subjects, including 10 males and 10 females, were selected. Ages ranged from 18 to 25 years with a mean of 21.5 years. Acceptance criteria for subjects were based upon no history of ear disease, normal aural immittance results, and normal conventional and high-frequency thresholds.

An auditory case history was obtained that included chronic or recent middle ear pathology, recent treatment with ototoxic medications, or

other aural pathology or confounding factors with probable effects upon stability of hearing levels. A positive response in any of these categories precluded the candidate from participation.

Tympanometry and acoustic reflex thresholds were obtained to ensure against any active middle ear pathology that might influence results. Subject candidates were required to have normal 226 Hz probe tone tympanograms, with ipsilateral and contralateral acoustic reflexes elicited at normal levels (85–100 dB HL) bilaterally from 0.5, 1, and 2 kHz stimuli (Shanks et al, 1988; Wiley et al, 1987).

Pure-tone air conduction threshold screening for conventional frequencies (0.25, 0.5, 1, 2, 4, and 8 kHz) was obtained with a Grason-Stadler 1701 (GS1701) clinical audiometer, and threshold responses were required to be no greater than 15 dB HL (ANSI, 1969) in the ear selected for the study. Screening for normal hearing in the high-frequency range was accomplished by obtaining thresholds at 8, 9, 10, 11, 12, 14, 16, 18, and 20 kHz on the PARVA-HF lab audiometer. Acceptance criterion required thresholds within one standard deviation of the mean reported by Schechter et al (1986) at each frequency. One representative ear from each subject was chosen for the study. If the subject had a better ear (i.e., showing overall lower thresholds), this ear was selected. Otherwise, if a subject's threshold curves were identical a balance of left and right ears was accomplished.

Equipment and Procedure

High-frequency (8–20 kHz) thresholds were obtained for 20 subjects with the PARVA-HF and the V320. Conventional frequency (0.25–8 kHz) thresholds were obtained with a GS1701 and the V320. The evaluation systems incorporated the following earphones: (a) V320 with M-Pro/4X at high frequencies; (b) PARVA-HF with HV/1A at high frequencies; (c) V320 with TDH-50P in MX-41/AR cushions at conventional frequencies; and (d) GS1701 with TDH-49 in MX-41/AR cushions at conventional frequencies.

Subjects were seated in an Acoustic Systems 19701A double-walled sound-treated booth. Pulsed pure tones of 300 ms duration and rise-fall times of 25 ms were presented at a 50 percent duty cycle with the PARVA-HF. Pure-tone stimuli from the V320, also presented at a 50 percent duty cycle, were of 250 ms dura-

tion with rise-fall times of 25–50 ms. Responses were based upon subject activation of a hand-held response button. Five-dB steps were utilized in obtaining all threshold results with the clinically accepted, modified Hughson-Westlake ascending-descending audiometric test technique (Carhart and Jerger, 1959). All subjects were tested twice under each stimulus condition, with the first and second tests occurring on separate days. Testing order was counter balanced to minimize order effects.

To establish reliability of thresholds obtained on the V320 in the high-frequency range, variability of intrasubject thresholds across sessions was determined and compared to threshold variability of the PARVA-HF system. Validity of high-frequency threshold measurements was determined by comparing thresholds obtained on the V320 to those obtained on the PARVA-HF. In addition, conventional frequency thresholds were obtained and compared between the V320 and a GS1701 clinical audiometer.

RESULTS

High-Frequency Threshold Reliability

High-frequency threshold reliability was evaluated on both the PARVA-HF and V320 by performing repeat threshold testing on separate days. Intrasubject threshold differences between test sessions 1 and 2 were calculated at each frequency, and mean absolute value difference scores were determined for each system (Table

Table 3 Means of Absolute Values of Intrasubject, Intersession Differences between High-Frequency Thresholds*

| Frequency (kHz) | Means of Differences (dB) Between Sessions | |
|----------------------|--|------|
| | PARVA-HF | V320 |
| 8 | 2.5 | 2.0 |
| 9 | 2.1 | 2.8 |
| 10 | 2.4 | 2.5 |
| 11.2 | 3.8 | 1.5 |
| 12.5 | 3.9 | 2.5 |
| 14 | 2.5 | 3.0 |
| 16 | 5.0 | 3.5 |
| 18 | 3.2 | 3.8 |
| 20 | 3.7 | 4.0 |
| Frequencies combined | 3.2 | 2.8 |

*No significant intersystem differences between mean thresholds at individual frequencies, or when frequencies were combined (Sheffé F; $p < 0.05$). (N = 20 subjects).

Table 4 Means and Standard Deviations of High-Frequency Thresholds Collapsed across Test Sessions*

| Frequency (kHz) | Mean Threshold (dB SPL) | | Standard Deviation (dB) | |
|-----------------|-------------------------|------|-------------------------|------|
| | PARVA-HF | V320 | PARVA-HF | V320 |
| 8 | 18.4 | 19.1 | 5.8 | 5.3 |
| 9 | 23.9 | 23.9 | 6.3 | 6.4 |
| 10 | 25.4 | 23.0 | 6.8 | 6.2 |
| 11.2 | 24.9 | 22.2 | 5.6 | 5.7 |
| 12.5 | 24.9 | 25.8 | 4.3 | 5.2 |
| 14 | 35.3 | 32.2 | 7.2 | 5.3 |
| 16 | 46.1 | 46.6 | 13.9 | 13.3 |
| 18 | 79.3 | 78.3 | 12.8 | 12.8 |
| 20 | 98.5 | 99.4 | 7.8 | 9.0 |

*No significant differences in mean dB SPL thresholds or standard deviations found between systems at any frequency (Sheffé F; $p < 0.05$). (N = 20 subjects).

3). A two-way analysis of variance with repeated measures on both factors (Frequency and Systems) was done and Sheffé Fs were used to determine if there were statistically significant variability differences between systems (Collyer and Enns, 1986). No significant differences were found at any frequency, or when frequencies were combined ($p < 0.05$).

High-Frequency Validity

Since test-retest results from each system showed no significant differences, mean thresholds at each frequency were determined by collapsing thresholds across sessions for each audiometer. High-frequency mean threshold and standard deviation data are shown in Table 4. Analysis of variance, followed by Sheffé Fs revealed no significant mean threshold differences between audiometers at any test frequency ($p < 0.05$).

Between-system threshold differences for each subject were also computed at each frequency. Neither system was seen to yield higher or lower thresholds consistently. The mean intrasubject threshold differences between systems, collapsed across frequencies and sessions, was less than 0.5 dB.

Conventional Frequencies

Reliability and validity of conventional frequency thresholds obtained on the V320 were evaluated in the same manner as described for high-frequency thresholds. Intrasubject differences between thresholds obtained over two test

Table 5 Means of Absolute Values of Intra-subject, Intersession Differences between Conventional Frequency Thresholds*

| Frequency (kHz) | Means of Differences (dB) Between Sessions | |
|----------------------|--|------|
| | GS1701 | V320 |
| 0.25 | 2.3 | 2.3 |
| 0.5 | 2.0 | 1.8 |
| 1 | 1.8 | 1.8 |
| 2 | 1.8 | 1.8 |
| 4 | 2.3 | 2.0 |
| 8 | 2.3 | 1.5 |
| Frequencies combined | 2.1 | 1.9 |

*No significant intersystem differences between mean thresholds at individual frequencies, or when frequencies were combined (Sheffé F; $p < 0.05$). (N = 20 subjects).

sessions were computed and averaged at each frequency to determine reliability of conventional frequency thresholds (Table 5). No significant differences were found between systems at any frequency (Sheffé F; $p < 0.05$). Validity was inferred by comparing mean thresholds obtained on the V320 to thresholds obtained on the GS1701 (Table 6). Sheffé F revealed no significant differences between systems ($p < 0.05$).

DISCUSSION

This study was motivated by the need for a reasonably portable computer-based audiometer, capable of reliably evaluating hearing in the high-frequency region and having data management capabilities compatible with this laboratory's Macintosh data control systems. The Virtual Model 320 audiometer appeared to

have the greatest potential for meeting these needs. It was, therefore, necessary to ascertain the reliability and validity of threshold measurements obtained with the V320 in the high-frequency range. A series of experiments was required to resolve problems associated with the Koss Pro/4X Plus high-frequency earphones originally issued as standard equipment with the V320 audiometer. These earphones revealed poor reliability for both calibration and human testing purposes. When placed on a flat-plate calibration coupler, the oval, air-filled plastic ear cushions could not be repeatably stabilized, resulting in inconsistent positioning of the earphone relative to the measuring microphone. Additionally, subjects reported friction noise from the plastic ear cushion during head movement. These oval plastic cushions were replaced with the round foam ear cushions provided with Koss HV/1A transducers. This modification was found to improve test-retest reliability significantly during calibration measurements and on human subject threshold evaluations, as well as eliminating the perceived friction noise. These foam cushions are now being supplied as standard equipment.

The most critical element of high-frequency hearing evaluation is related to the threshold-of-audibility curve. This requires an extremely good signal-to-noise ratio (S/N) for stimuli presented in the high-frequency range of human hearing. It is imperative that, when testing high frequencies in persons with normal low-frequency hearing, the electrical S/N ratio be at least 110 dB to reduce the possibility of artifactual response to lower frequency energy (Fausti et al, 1979b). When presenting high-frequency stimuli at the highest output levels (115 dB SPL or greater), there may be a question of response validity. Because maximum output levels can exceed the S/N ratio of the test instrument, it is possible that, if the ear under test has normal lower frequency sensitivity, the resulting response can be to perception of the lower frequency gated floor noise. The PVAMC high-frequency laboratory evaluation system (PARVA-HF) was carefully designed to ensure against artifactual responses to noise when high-frequency stimuli are presented. Floor noise analysis of high-frequency pure-tone stimuli from the V320 has revealed S/N characteristics comparable to the PARVA-HF.

Results of this investigation demonstrate the PARVA-HF lab evaluation system and the V320 audiometer to be comparable in their

Table 6 Means and Standard Deviations of Conventional Frequency Thresholds*

| Frequency (kHz) | Mean Threshold (dB HL) | | Standard Deviation (dB) | |
|-----------------|------------------------|------|-------------------------|------|
| | GS1701 | V320 | GS1701 | V320 |
| 0.25 | 6.6 | 8.7 | 4.0 | 3.8 |
| 0.5 | 3.3 | 4.8 | 3.5 | 3.3 |
| 1 | 2.1 | 2.3 | 3.2 | 3.5 |
| 2 | 2.9 | 5.2 | 3.6 | 4.2 |
| 4 | 3.6 | 6.6 | 3.4 | 3.7 |
| 8 | 5.9 | 7.1 | 4.2 | 4.7 |

*No significant differences in mean dB HL thresholds or standard deviations found between systems at any frequency (Sheffé F; $p < 0.05$). (N = 20 subjects).

abilities to measure high-frequency hearing. Consequently, data regarding validity of the PARVA-HF system can be generalized to this computer-based audiometer. Repeated measures demonstrated V320 reliability consistent with test-retest differences observed in previous high-frequency reliability studies conducted in the PVAMC laboratory. It was, therefore, determined that the V320, utilizing M-Pro/4X earphones, can be used as a reliable, effective high-frequency auditory monitoring tool.

Until an appropriate normative standard for high frequencies is established, the primary value of high frequency audiometry lies in its serial monitoring capability. The potential that high-frequency audiometry holds for early detection of toxic effects on the auditory system from therapeutic drugs and/or noise, before irreversible communication deficit is incurred, represents a mandate for its application.

Acknowledgments. The authors wish to acknowledge contributions to this manuscript made by Drs. David Lilly, Curt Mitchell, and David Phillips.

Funding for this study provided by Rehabilitation Research & Development and Medical Research Services, Department of Veterans Affairs.

REFERENCES

- ANSI. (1969). ANSI S3.6-1969 (revised 1989) *Specifications for audiometers*. New York: American National Standards Institute.
- Carhart R, Jerger J. (1959). Preferred method for clinical determination of pure-tone thresholds. *J Speech Hear Disord* 24:330-345.
- Collyer CE, Enns JT. (1986). *Analysis of variance: the basic designs*. Chicago, IL: Nelson-Hall, Inc.
- Dreschler WA, van der Hulst RJAM, Tange RA, Urbanus NAM. (1989). Role of high-frequency audiometry in the early detection of ototoxicity. *Audiology* 28:211-220.
- Fausti SA, Erickson DA, Frey RH, Rappaport BZ, Schechter MA. (1981). The effects of noise upon human hearing sensitivity from 8,000 to 20,000 Hz. *J Acoust Soc Am* 69:1343-1349.
- Fausti SA, Frey RH, Erickson DA, Rappaport BZ. (1979a). 2AFC versus standard clinical measurement of high-frequency auditory sensitivity (8-20 KC/S). *J Aud Res* 19:151-157.
- Fausti SA, Frey RH, Erickson DA, Rappaport BZ, Cleary EJ, Brummett RE. (1979b). A system for evaluating auditory function from 8,000-20,000 Hz. *J Acoust Soc Am* 66:1713-1718.
- Fausti SA, Rappaport BZ, Schechter MA, Frey RH. (1982). An investigation of the validity of high-frequency audition. *J Acoust Soc Am* 71:646-649.
- Fausti SA, Rappaport BZ, Schechter MA, Frey RH, Ward TT, Brummett RE. (1984a). Detection of aminoglycoside ototoxicity by high-frequency auditory evaluation: selected case studies. *Am J Otolaryngol* 5:177-182.
- Fausti SA, Schechter MA, Rappaport BZ, Frey RH, Mass RE. (1984b). Early detection of cisplatin ototoxicity: selected case reports. *Cancer* 53:224-231.
- Osterhammel D, Osterhammel P, Terkildsen K. (1977). A quasi-free-field transducer system for high-frequency audiometry. *Scand Audiol* 6:91-95.
- Rappaport BZ, Fausti SA, Schechter MA, Frey RH. (1982). Investigation of interaural attenuation factors for frequencies above 8,000 Hz. *J Acoust Soc Am* 72:1297-1298.
- Schechter MA, Fausti SA, Rappaport BZ, Frey RH. (1986). Age categorization of high-frequency threshold sensitivity data. *J Acoust Soc Am* 79:767-771.
- Shanks JE, Lilly DJ, Margolis RH, Wiley TL, Wilson RH. (1988). Tympanometry: ASHA working group on aural acoustic-immittance measurements committee on audiologic evaluation. *J Speech Hear Disord* 53:354-377.
- Stelmachowicz PG, Beauchaine KA, Kalberer A, Kelly WJ, Jesteadt W. (1989). High-frequency audiometry: test reliability and procedural considerations. *J Acoust Soc Am* 85:879-887.
- Tange RA, Dreschler WA, van der Hulst RJAM. (1985). The importance of high-tone audiometry in monitoring for ototoxicity. *Arch Otorhinolaryngol* 242:77-81.
- Wiley TL, Oviatt DL, Block MG. (1987). Acoustic-immittance measures in normal ears. *J Speech Hear Res* 30:161-170.