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Reference equivalent threshold levels for pure tones and 1/3-oct noise bands: Insert earphone and TDH-49 earphone

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Reference equivalent threshold sound pressure levels (RETSPLs) were determined for 20 subjects for pure tones and 1/3-oct noise bands. Two transducers were used: a Telephonics TDH-49 earphone mounted in an MX-41/AR cushion, and a Danavox SMW insert earphone coupled to an "HA-2" earmold. RETSPLs for pure tones transduced by the TDH-49 earphone were very similar to those published previously. For each transducer, RETSPLs for 1/3-oct noise bands were essentially identical to the RETSPLs for pure tones near the center of each band. Applications for threshold testing using the insert earphone and/or 1/3-oct noise bands are discussed.

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INTRODUCTION

In several audiometric applications, there are advantages associated with the use of an insert earphone coupled to an earmold to deliver test stimuli. First, many young children will consent to wear an insert earphone/earmold combination for test purposes, even when they will not agree to the use of the more typical but cumbersome supra-aural earphones. Second, during testing for hearing aid selection purposes, the insert earphone may be coupled to the client's custom earmold, thus accommodating the earmold's acoustic effects and potentially avoiding time-consuming *post hoc* adjustments to the hearing aid fitting. Finally, calibrated levels may be expressed in equivalent HA-2 coupler sound pressure levels: This facilitates comparison of clinical data with hearing aid specifications.

In threshold audiometry, noise-band stimuli may sometimes be preferred over pure tones. For example, in pediatric threshold testing, noise-band stimuli may be preferred because of their greater interest value for the young child. Also, numerous hearing aid selection procedures are based on measurements of thresholds (e.g., Byrne and Tonisson, 1976; Berger, 1976; McCandless and Lyregaard, 1983), and in this context it is sometimes desirable to utilize noise-band test stimuli in preference to pure tones. The rationale for this procedure draws on the assumption that the noise-band stimuli will elicit perceptual behavior that is more directly comparable with speech-band perception for the individual being tested, because speech, like noise, is a complex broadband stimulus. For both of these applications of noise-band testing, it seems desirable to select a noise bandwidth that is not greater than a critical band. A 1/3-oct bandwidth is a practical choice because it is readily produced and widely available. However, above about 500 Hz, 1/3-oct bands are slightly wider than critical bands for normal hearers (Scharf, 1970).

These considerations indicate that it would be advantageous in some applications to measure hearing loss utilizing an insert earphone/earmold combination. In addition, it would be useful to be able to express hearing loss for 1/3-oct noise bands as well as for pure tones. Reference equivalent threshold sound pressure levels (RETSPLs) are not available for an insert earphone. Similarly, RETSPLs have not been published for 1/3-oct noise bands. However, several investigators have reported comparisons between noise-band and pure-tone thresholds. Robinson *et al.* (1961) compared loudness of normally incident pure tones in a free field with that of 1/3-oct noise bands in a diffuse field. On the basis of their loudness data, they postulated threshold levels for these two stimuli that differed by about 5 dB at 8 kHz and by up to 3 dB at lower frequencies. Simon and Northern (1966) compared thresholds for pure tones and noise bands approximating 1/3 octave, delivered via earphone. They found no significant differences in mean thresholds for the two stimuli, and mean differences usually less than 1 dB.

An investigation was undertaken to establish RETSPLs for (1) pure tones transduced by an insert earphone coupled to a standard earmold, (2) 1/3-oct noise bands transduced by the same insert earphone/earmold combination, and (3) 1/3-oct noise bands transduced by a Telephonics TDH-49 supra-aural earphone mounted in an MX-41/AR cushion. In addition, RETSPLs for pure tones transduced by a TDH-49 earphone were determined for comparison to a previous investigation (Michael and Bienvenue, 1977).

I. METHOD

A. Transducers

A Danavox SMW hearing aid earphone with nominal input impedence of 100 Ω was selected to serve as the insert earphone because of its relatively good high-frequency output and adequate power capabilities. The earphone was coupled to an earmold with dimensions identical to those of the simulated earmold used in the HA-2 coupler for standard post-auricular hearing aid measurements (ANSI S3.22-1982). This earmold consists of 25 mm of tubing (i.d. = 2 mm) plus 18 mm of tubing (i.d. = 3 mm). It is referred to as the "HA-2" earmold. For this investigation, the HA-2 earmold was secured within a compressible foam earplug which was securely seated in the subjects' ears and achieved an

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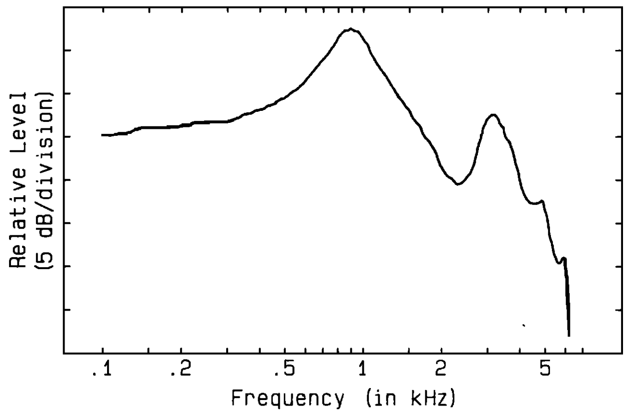

FIG. 1. Frequency response of the Danavox SMW insert earphone. This measurement was obtained with the earphone attached to its plastic adaptor mounted on an HA-2 coupler with entrance through 25 mm of tubing (i.d. = 2 mm).

excellent acoustic seal. The earphone was attached to the earmold using a plastic adaptor incorporating a cylindrical cavity (5.5×4.0 mm) that snapped over the earphone nipple and connected to a bore (12×1.4 mm) which directed the sound into the attached earmold. This adaptor was purchased from a hearing aid supply company and is readily available (Hal Hen Co., Long Island City, NY, catalog no. 309L). Figure 1 shows the HA-2 coupler frequency response for this earphone/earmold system.

A Telephonics TDH-49 earphone mounted in a Telephonics MX-41/AR supra-aural cushion and suspended using a Telephonics TC-89E headband served as the supra-aural earphone. A dummy earphone was utilized on the nontest ear and the headband was adjusted to apply a force of 400–500 g when the earphones were worn.

The sensitivity and frequency response of both transducers were in accordance with the manufacturer's specifications.

B. Stimuli

One-third-oct noise bands were produced by filtering Gaussian random white noise generated by a General Radio random noise generator type 1382 using a General Radio type 1925 multifilter. This filter set produces 1/3-oct bands that are in compliance with the characteristics specified for third-octave filters, class III in ANSI S1.11-1966 (R1976). Seven 1/3-oct bands were used as test stimuli: bands #24 (250 Hz), #27 (500 Hz), #29 (800 Hz), #30 (1000 Hz), #33 (2000 Hz), #34 (2500 Hz), and #36 (4000 Hz). Figure 2 shows the long-term rms spectrum of each band: These analyses were derived from the electrical waveform at the multifilter output. The crest factor of these stimuli, measured using a Bruel and Kjaer voltmeter type 2425, ranged from 3.5 to 4.5.

Pure-tone stimuli were produced by a Hewlett–Packard oscillator, model 4204A, at the following frequencies: 250, 500, 750, 1000, 2000, 2500, and 4000 Hz.

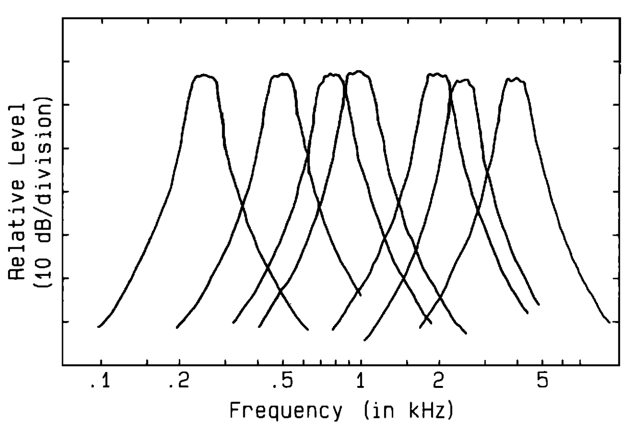

FIG. 2. Root-mean-square spectra of the 1/3-oct noise bands used as stimuli.

C. Instrumentation

Thresholds were measured in a double-walled sound treated room with ambient noise levels well below the 0-dB hearing level limits specified for ears-covered testing in ANSI S3.1-1977. Both transducers were driven by a Grason-Stadler E800 Bekesy audiometer; a locally built impedance matching device was inserted between the 10-Ω E800 output and the SMW 100-Ω earphone. The E800 attenuator was linear for both transducers over a 75-dB range, including the threshold zone. The 1/3-oct noise band and the pure-tone stimuli were fed into the E800 external stimulus input (thus disconnecting the E800 oscillator and substituting the test stimulus). The pure-tone stimuli were pulsed at a nominal rate of 2.5 pulses/s. The noise bands were presented continuously. The attenuation rate was set to 2.5 dB/s.

D. Procedure

1. Threshold measurements

Using conventional automatic audiometry procedure, thresholds were measured for one ear of each of 20 (17 female, 3 male) otologically normal young adults with no significant history of noise exposure. Subjects traced each threshold for a minimum of 1 min. Thresholds were defined as the midpoint of tracing excursions. Thresholds were recorded in terms of the rms voltage input to the transducer, measured using Bruel and Kjaer voltmeter type 2425 set to the "slow" meter damping (integration time, about 3 s). No subjects traced thresholds at the limits imposed by the test equipment or ambient noise.

All subjects responded to all stimuli, presented via both transducers. To minimize order effects, presentation of transducers and type of stimulus (noise band or pure tone) were counterbalanced: Presentation of stimulus frequency was randomized.

2. Coupler measurements

The mean input voltage required for threshold was calculated for each stimulus. RETSPL for each stimulus was determined by measuring the sound pressure level produced in the appropriate coupler when this voltage (plus a fixed 70 dB) was applied to the transducer input.

To measure the RETSPLs for the TDH-49, the earphone was mounted on an NBS 9A 6-cm^3 coupler and secured with a 500-g weight. The coupler was equipped with a

Bruel and Kjaer type 4144 1-in. microphone which was connected to a Bruel and Kjaer precision sound level meter, type 2209. The sound level meter was configured to display rms levels with meter damping at the standard "slow" setting. [This setting is in conformance with the slow dynamic characteristic specified in ANSI S1.4-1971 (R1976).] Two independent observers judged the level of the noise bands: Their judgments differed by less than 1 dB.

To measure RETSPLs for the SMW earphone/HA-2 earmold combination, the insert earphone was coupled via its plastic adaptor to an HA-2 coupler with entrance through 25 mm of tubing (i.d. = 2 mm) as described for standard postauricular hearing aid measurements in ANSI S3.22-1982. The coupler was equipped with a Bruel and Kjaer 4144 microphone which was connected to a Bruel and Kjaer precision sound level meter, type 2209. The sound level meter was configured as described for the TDH-49 measurements.

II. RESULTS

Table I shows the RETSPLs determined on the basis of mean data for this experimental group for pure tones transduced by the TDH-49 and SMW earphones. Also shown for comparison are the RETSPLs for TDH-49 earphones that may be derived from the report by Michael and Bienvenue (1977). The RETSPLs for the TDH-49 earphone obtained for this experimental group are very similar to those reported in the earlier investigation. This finding supports the conclusion that the subjects in this investigation accurately represented the normally hearing adult population.

Table II shows the RETSPLs determined from the mean data for 1/3-oct noise bands transduced by each earphone type. For each transducer, the noise-band values are almost identical to those determined for the pure tones near the center of each band. This is consistent with the conclusion that 1/3-oct noise bands are not significantly more detectable than subcritical-bandwidth stimuli, and suggests that the same RETSPLs may be used for pure tones and 1/3-oct noise bands in audiometric testing.

Table III shows the standard deviations associated with the RETSPL values given in Tables I (columns 2 and 3) and II. The pure-tone/TDH-49 values are quite similar to those reported by Corso (1958) for a similar group of subjects. There was no consistent trend for the variability of the noise-band data to exceed that of the pure-tone data for either earphone. However, there was a tendency for the variability of the insert earphone data to be slightly greater than that of the supra-aural earphone data, particularly for the pure-tone stimuli: This was probably due to the relatively greater influence of individual differences in ear canal volume and impedance with insert earphone testing.

TABLE I. Reference equivalent threshold sound pressure levels (dB SPL) for pure tones. Column (1) shows the levels for a TDH-49 earphone mounted in an MX-41/AR cushion that can be derived from Michael and Bienvenue (1977). Column (2) gives the TDH-49 levels determined in this study. Column (3) gives the RETSPLs determined for the SMW earphone/HA-2 earmold combination.

Freq. (Hz)	(1) TDH-49	(2) TDH-49	(3) SMW/HA-2
250	25.1	25.5	21.0
500	11.4	11.8	12.7
750	7.7	7.5	8.2
1000	7.3	6.1	7.1
2000	8.3	7.4	8.1
2500		6.1	7.6
4000	9.7	10.2	1.9

TABLE II. Reference equivalent threshold sound pressure levels (dB SPL) for 1/3-oct noise bands.

Band no.	TDH-49	SMW/HA-2
24	24.3	21.0
27	13.1	12.0
29	8.5	10.5
30	7.1	7.5
33	7.6	7.7
34	5.7	6.4
36	9.4	2.7

III. DISCUSSION

With RETSPL values derived from Table I, it is possible to obtain a threshold audiogram using a Danavox SMW 100-Ω insert earphone coupled to an HA-2 earmold to deliver the stimulus. Typically, this audiogram will be identical, within measurement error, to the conventional audiogram obtained with a TDH-49 earphone and MX-41/AR cushion assembly. Although, as shown in Table III, the intersubject variability of thresholds obtained with an insert earphone is slightly greater than that seen with a TDH-49 earphone, the size of this effect is small and would not outweigh the advantages associated with insert earphone testing in a clinical setting.

The insert earphone/HA-2 earmold assembly has been found to be especially useful for threshold testing in the pediatric population. However, there are two factors that may cause the insert earphone audiogram to differ slightly from the conventional audiogram. First, when the insert earphone/earmold configuration is utilized with a small child, thresholds may appear more sensitive than those obtained with supra-aural earphone testing. This may occur because the child's smaller ear canal volume results in a higher sound pressure level in the ear canal for a given electrical input to the earphone: It is unlikely that this effect would exceed 5 dB. Second, the acoustical seal created by the earmold will affect the level produced in the ear canal at low frequencies,

TABLE III. Standard deviations (dB) associated with the RETSPLs shown in Table I, columns (2) and (3), and in Table II.

Freq. (Hz)	Pure tones		Noise bands	
	TDH-49	SMW/HA-2	TDH-49	SMW/HA-2
250	6.5	7.3	6.8	6.7
500	4.9	7.2	6.2	6.2
750	5.4	6.2		
800			5.1	5.7
1000	5.8	5.9	5.2	5.5
2000	5.0	6.9	5.1	5.2
2500	5.8	6.8	4.9	5.9
4000	4.2	4.6	4.8	4.0

and thus will influence the outcome of the threshold test: A loose or vented earmold will cause low-frequency thresholds to appear worse than they would appear with a tight earmold. (The RETSPLs given here assume a tightly fitting earmold.) Both of these effects are at work in supra-aural earphone testing also, but they may be somewhat more conspicuous in insert earphone test results.

The insert earphone/earmold assembly may also be used to generate stimuli in tests for hearing aid selection. In this application, the client's own custom earmold is coupled to the insert earphone. Differences in transmission characteristics and/or acoustic seal between the custom earmold and the HA-2 earmold used for standard hearing aid performance specifications are readily accounted for using this approach (Cox, 1982).

The RETSPLs obtained for 1/3-oct noise bands (Table II) are sufficiently similar to those found for pure tones that it should not be necessary to use different values for the two stimuli with either of the transducers used in this investigation. This is in agreement with the report of Simon and Northern (1966). Moreover, although random noise stimuli might be postulated (because of their time-varying nature) to give more variable thresholds than pure-tone stimuli, no such effect was observed in this study (Table III). This is consistent with the finding of Myers (1957) for hearing-impaired subjects. These results indicate that 1/3-oct noise bands may be substituted for pure tones in threshold testing, provided that the slopes of the filters are known to be sharp enough to preclude off-band responses. However, it must be kept in mind that the noise-band stimulus will be examining the sensitivity of a wider area of the basilar membrane than is the case with a pure-tone stimulus: This is both the strength and the limitation (depending on application) of noise-band testing.

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