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NBS-9A coupler-to-eardrum transformation: TDH-39 and TDH-49 earphones

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A transformation was derived to convert sound-pressure levels referenced to an NBS-9A coupler to corresponding eardrum sound-pressure levels. It was found that the same transformation may be used for male and female adults and for both TDH-39 and TDH-49 earphones in MX-41/AR supra-aural cushions. It was determined that from 250–2000 Hz the transformation provides an eardrum sound-pressure level estimate that is within 6 dB of the actual eardrum level for 95% of individuals. However, in the 4000–6300-Hz range, the accuracy deteriorates to $\pm$ 12 dB of actual eardrum level for 95% of individuals.

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INTRODUCTION

It is convenient to use supra-aural audiometer earphones in a variety of psychoacoustic tasks. These earphones usually are calibrated in an NBS-9A 6-cc coupler. Measurements were undertaken to determine a set of values that could be used to transform sound-pressure levels (SPLs), referenced to an NBS-9A coupler, to SPLs at the average listener's eardrum. An estimate was derived of the accuracy of the transformation in the individual case.

The most widely used audiometer earphones are Telephonics TDH-39 and TDH-49, mounted in Telephonics MX-41/AR supra-aural cushions. Both earphone types were used in this investigation. The development of the transformation was approached in two stages. First, a transformation was developed relating 6-cc coupler SPLs to SPLs at the ear canal entrance. Second, this transformation was combined with another set of values to transfer ear-canal-entrance SPLs to eardrum SPLs.

I. NBS-9A COUPLER-TO-EAR-CANAL-ENTRANCE TRANSFORMATION

Erber (1968) reported differences between coupler and ear-canal-entrance SPLs for a TDH-49 earphone at eight frequencies, from 125 Hz–4 kHz. His data indicated that female subjects developed systematically higher ear-canal levels than male subjects, suggesting that different transformations should be developed for each group. Shaw (1966a) reported corresponding differences for a TDH-39 earphone at 26 frequencies between 200 Hz and 7 kHz. He did not address the issue of possible differences between male and female subjects. In the present study, measurements were made to further explore the differences observed between NBS-9A-coupler and ear-canal-entrance SPLs.

A. Method

Five men and five women served as subjects. Each had normal-appearing outer ears. Only one ear was measured per subject.

One Telephonics TDH-49 earphone and one Telephonics TDH-39 earphone were used on all ten subjects. Both earphones were mounted in Telephonics MX-41/AR sponge rubber cushions. Each earphone-cushion assembly yielded a 6-cc coupler frequency response in accordance with the manufacturer's specifications. The two earphones were suspended in a spring headband that applied a coupling force of 350–500 g, depending on head size.

The test earphone was driven with a wideband white noise: the same level was used for all measurements. The long-term rms level produced by the earphone in the ear canal or the coupler, was spectrally analyzed using a Wavetek Rockland 400-line analyzer, model 5820A, set to the 10-kHz bandwidth.

For coupler measurements, the earphone was mounted on an NBS-9A coupler, adapted for use with a $\frac{1}{2}$-in. microphone (Bruel and Kjaer type 4134). The earphone was secured with a 500-g weight.

For ear canal measurements, the level at the entrance to the ear canal was observed using a probe-tube microphone calibrated with reference to the $\frac{1}{2}$-in. microphone used in the coupler. The probe microphone system was a Knowles XL9073 microphone coupled to 22 mm of polyvinyl tubing (o.d. = 2.0 mm; i.d. = 1.3 mm). One end of the tubing was curved to an angle of 90° (probe microphone calibration was performed with the probe tube bent as for data collection). The probe tube entered the outer ear via the notch in the inferior rim of the concha, between the tragus and the antitragus. It was taped to the subject's face immediately outside the concha rim so that the tubing end curved inward to a location in the plane of the ear canal entrance (defined as occurring at the junction of the external auditory meatus and the cavum concha). In this location, the probe microphone system did not interfere with the fit or placement of the earphones. After the probe-tube microphone was secured on a subject, each earphone in turn was placed on the subject's ear, and the noise spectrum at the ear canal entrance was recorded.

B. Results

The probe-tube microphone data were averaged for the male subjects and for the female subjects for each earphone.

These averages were corrected for the effects of the probe-tube microphone. Figure 1 shows the results for the TDH-49 earphone. The solid line depicts the earphone's frequency response in the 6-cc coupler; the symbols show the level for the same earphone in the average male ear canal (×) and average female ear (O), respectively. The dashed line indicates the average of the male and female data. Figure 2 gives the same information for the TDH-39 earphone.

Both figures reveal that the mean ear canal levels for the male and female subjects were interweaving across the frequency range, with only small differences between them at any frequency. These data do not support a hypothesis that female ear canals develop higher levels than male ear canals, as suggested by Erber (1968). Hence, data for all subjects were combined to produce the best estimate of ear-canal-entrance-coupler differences. This estimate is depicted by the dashed lines in each figure.

Figure 3 shows the mean differences between ear-canal-entrance and coupler levels for the TDH-49 earphone and the TDH-39 earphone, as well as the corresponding data from Shaw (1966a, Fig. 3) for the TDH-39 and from Erber (1968, Table II) for the TDH-49. Differences across the four sets of data do not exceed 5 dB at any frequency and there is no evidence of systematic difference between the two earphone types. It was decided, therefore, to take a simple average of the four sets of data to derive the best estimate of the 6-cc coupler-to-ear-canal-entrance transformation for both earphone types (at 250 Hz, the datum from Erber was not included in the average). The average coupler-to-ear-canal-entrance transformation is shown as the dotted line in Fig. 3. Selected values are given numerically in column 1 of Table I.

II. EAR-CANAL-ENTRANCE-TO-EARDRUM TRANSFORMATION

The sound-pressure distribution in the ear canal has been studied in conditions with the ear canal open (see Shaw, 1974, for a review) and with the ear canal occluded by an earmold (Studebaker, 1974; Lawton, 1979; Stinson *et al.*, 1982). However, little attention has been given to the sound-pressure distribution in the ear canal when the ear canal is

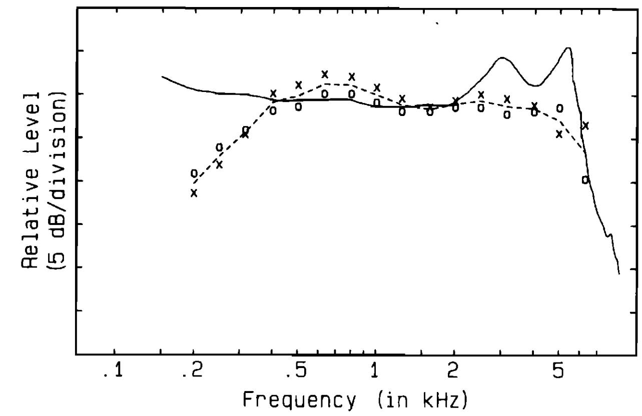

FIG. 2. Ear-canal-entrance and 6-cc coupler levels for TDH-39 earphone. The solid line shows the earphone's coupler response. The symbols show the levels for the same earphone in the average male ear canal (×) and the average female ear canal (O). The dashed line gives the average of the male and female data.

occluded by a supra-aural earphone. Shaw (1966b) concluded on theoretical grounds that the ear-canal-entrance-to-eardrum transformation would be the same when the sound is generated by a supra-aural earphone as in the free-field condition. Villchur (1969), however, reported data for three subjects in which the entrance-to-eardrum transformation was observed to be shifted downwards by 8%, 9%, and 3%, respectively, in the earphone-occluded condition, relative to the free-field condition. In the present study, measurements were performed to further explore the entrance-to-eardrum transformation for an earphone-occluded ear.

A. Method

Two men and two women served as subjects. All had normal-appearing outer ears.

Measurements were made close to the eardrum and at the ear canal entrance. A Knowles XL9073 microphone was coupled in turn to each of two identical flexible polyethylene probe tubes (length = 103 mm; o.d. = 1.2 mm; i.d. = 0.8

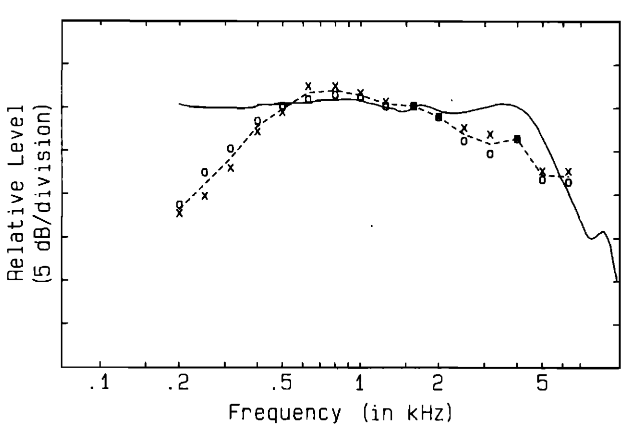

FIG. 1. Ear-canal-entrance and 6-cc coupler levels for TDH-49 earphone. The solid line shows the earphone's coupler response. The symbols show the levels for the same earphone in the average male ear canal (×) and the average female ear canal (O). The dashed line gives the average of the male and female data.

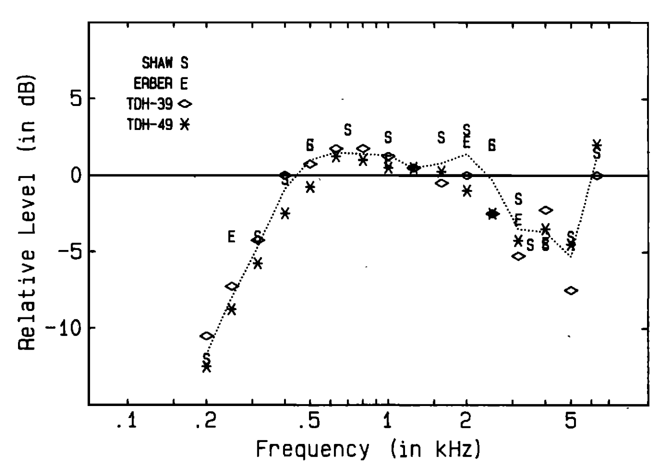

FIG. 3. Mean differences between ear-canal-entrance and coupler levels for this study and previous studies. The data from Shaw (1966a, Fig. 3) and from Erber (1968, Table II) are for the TDH-39 earphone and the TDH-49 earphone, respectively. The dotted line depicts the average across all data.

mm), one placed at each measurement location. As it exited the ear canal, each probe tube was curved to an angle of 90°. The frequency response effects of the two curved probe tubes were identical up to 6500 Hz.

One probe tube entered the outer ear via the notch just below the tragus and curved to a position in the plane of the ear canal entrance. The subject inserted the other probe tube into his/her own ear canal until it contacted the eardrum. It was then withdrawn 2–3 mm and positioned to enter the outer ear via the notch just above the tragus. Each tube was taped to the subject's face to secure its position. Earphones could be worn without disturbing the probe tubes.

SPLs were measured near the eardrum and at the ear canal entrance for two conditions: (1) with the ear unoccluded and sound presented from a loudspeaker at 0-deg azimuth, and (2) with the ear occluded, and stimulated, by a supra-aural earphone suspended in a spring headband that applied a coupling force of 350–500 g. The stimulus was a wideband noise. In each condition, the long-term rms level at each probe tube location was spectrally analyzed using a Hewlett–Packard 3561A 400-line analyzer, set to the 10-kHz bandwidth. For each subject, the ear-canal-entrance-to-eardrum transformation was derived for the unoccluded condition as the difference between the SPLs measured at the eardrum and entrance positions with the ear unoccluded. A second entrance-to-eardrum transformation was derived in the same way for the earphone-occluded condition.

B. Results

The results were very similar to those reported by Villchur (1969). The transformation observed in the earphone-occluded condition was the same shape as that observed in the unoccluded condition, but shifted downward in peak frequency. Typical data for one subject are shown in Fig. 4. The four subjects yielded peak shifts of 8%, 10%, 11%, and 22%, respectively. When these data were combined with the peak shift data reported by Villchur for three subjects, the average peak shift for the seven subjects was found to be 10.1%.

To derive the best estimate of the entrance-to-eardrum

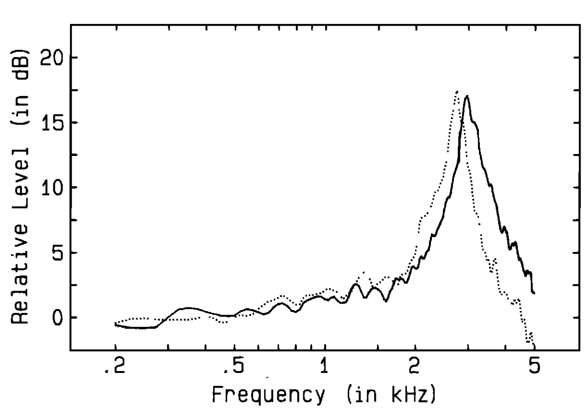

FIG. 4. Ear-canal-entrance-to-eardrum transformations measured on one subject with ear unoccluded (solid line), and with ear occluded by a supra-aural earphone (dotted line). Each transformation shows the difference between sound-pressure level at the eardrum and sound-pressure level at the ear canal entrance.

transformation of the earphone-occluded ear, the average peak shift data (seven subjects) were combined with the average entrance-to-eardrum transformation, given by Shaw (1974, Fig. 2), for the unoccluded ear (based on data for 13–19 subjects). This indirect derivation was chosen, in preference to using the four-subject occluded-ear transformation directly measured in this study, because the indirect procedure resulted in a transformation that is based on data from a larger number of subjects and is thus more likely to characterize the general population. The resulting values (the unoccluded-ear transformation shifted downward by 10%) are given numerically in column 2 of Table I.

It is appropriate to question whether different entrance-to-eardrum transformations ought to be applied for male and female individuals. Most of the data on sound-pressure distribution in the ear canal have been obtained on male ears. Djupesland and Zwislocki (1972) studied four male and three female ears: they reported the female ear canals to be almost 2 mm shorter than the male ear canals, on the average. However, Burkhard and Sachs (1975) studied a larger sample (12 males, 12 females) and, in two different estimates, inferred a mean difference in ear canal length of 0.4 and 0.7 mm, respectively, between males and females. Since individual variability in ear canal length is considerable, as reported by Burkhard and Sachs (1975), this small difference in average length seems insignificant. It has been assumed, therefore, that the same entrance-to-eardrum transformation may be used for both males and females.

III. COUPLER-TO-EARDRUM TRANSFORMATION

Table I gives the derivation of the 6-cc coupler-to-eardrum transformation that resulted from the measurements described above. Column 1 gives the coupler-to-ear-canal-entrance transformation values. Column 2 gives the entrance-to-eardrum transformation values. Column 3 gives the sum of these two transformations. When the values in column 3 are added to SPLs referenced to an NBS-9A

TABLE I. NBS-9A coupler-to-eardrum transformation (dB) for TDH-39 and TDH-49 earphones. Column 1 gives values for the coupler-to-ear-canal-entrance transformation. Column 2 gives values for the ear-canal-entrance-to-eardrum transformation [derived from Shaw (1974), transposed downwards in frequency by 10%]. Column 3 gives the complete transformation which is the sum of columns 1 and 2.

Freq. (kHz)	(1)	(2)	(3)
0.20	− 11.7	0.3	− 11.4
0.25	− 8.1	0.3	− 7.8
0.31	− 4.7	0.4	− 4.3
0.40	− 0.7	0.5	− 0.2
0.50	1.0	0.6	1.6
0.63	1.5	0.6	2.1
0.80	1.4	1.0	2.4
1.00	1.2	1.6	2.8
1.25	0.6	2.1	2.7
1.60	0.9	3.1	4.0
2.00	1.3	5.0	6.3
2.50	− 0.4	7.5	7.1
3.15	− 3.4	10.0	6.6
4.00	− 3.8	8.9	5.1
5.00	− 5.3	4.7	− 0.6
6.30	1.3	1.7	3.0

TABLE II. Intersubject standard deviations (dB) of NBS-9A coupler-to-eardrum transformation given in Table I. Column 1 gives standard deviation values from the present study for NBS-9A coupler-to-ear-canal-entrance transformation (average values for both earphones). Column 2 gives standard deviation values taken from Weiner and Ross (1946) for ear-canal-entrance-to-eardrum transformation. Column 3 gives the standard deviations obtained by combining columns 1 and 2.

Freq. (kHz)	(1)	(2)	(3)
0.25	3.1	0.5	3.2
0.50	2.1	0.5	2.1
0.80	1.2	0.5	1.3
1.00	1.1	0.7	1.4
1.60	1.2	1.5	1.9
2.00	2.3	2.0	3.1
2.50	3.1	2.5	4.0
3.00	2.4	3.7	4.5
4.00	4.5	3.5	5.7
5.00	5.0	4.0	6.4
6.30	2.4	5.5	6.0

coupler, the result will estimate the corresponding SPLs produced at an average listener's eardrum.

In addition to deriving a transformation to estimate eardrum levels from supra-aural earphone test results, we wanted to determine the accuracy of eardrum-level predictions made with this transformation. Consequently, the intersubject variability of the coupler-to-eardrum transformation was determined in the following way. First, standard deviations of coupler-to-ear-canal-entrance transformations from the present study were determined at several frequencies for both earphones. The average values are shown in Table II, column 1. Second, standard deviations of ear-canal-entrance-to-eardrum transformations were obtained from the report of Weiner and Ross (1946, Fig. 7). These values are shown in Table II, column 2. Finally, it was assumed that the factors affecting these two transformations are independent. Hence, combined standard deviations could be determined by summing the variances of the two distributions. The resulting standard deviations are given in Table II, column 3.

The standard deviations of the coupler-to-eardrum transformation (Table II, column 3) reveal that predictions of eardrum SPL on the basis of the corresponding SPL in a 6-cc coupler is moderately accurate when applied on a individual basis. For 95% of individuals, the eardrum level predicted using this transformation will be within about 6 dB of the actual eardrum level, from 250–2000 Hz. At higher frequencies, however, the accuracy deteriorates. In the 4.0- to 6.3-kHz range, predictions will be within about 12 dB of actual level for 95% of individuals and within about 6 dB of actual level for 68% of individuals. Furthermore, this may be an optimistic picture of the overall variability associated with the coupler-to-eardrum transformation. If the factors affecting variability in the coupler-to-ear canal entrance transformation are not independent of those operating in the entrance-to-eardrum transformation, the effect would be to increase the overall variability seen in Table II, column 3.

IV. CONCLUSION

The NBS-9A coupler-to-eardrum transformation described above was derived for application in a hearing aid prescription procedure (Cox, 1985). Once desired eardrum SPLs are known, the 2-cc coupler levels necessary to produce these eardrum levels in an average ear may be determined by the use of a further transformation (Sachs and Burkhard, 1972).

In addition, this NBS-9A coupler-to-eardrum transformation may be of use in any application in which investigators are attempting to maintain orthotelephonic conditions while delivering stimuli via TDH-49 or TDH-39 earphones in MX-41/AR cushions.

Burkhard, M. D., and Sachs, R. M. (1975). "Anthropometric manikin for acoustic research," J. Acoust. Soc. Am. 58, 214–222.

Cox, R. M. (1985). "ULCL-based prescriptions for in-the-ear hearing aids," Hearing Instrum. 36 (4), 12–14.

Djupesland, G., and Zwislocki, J. J. (1972). "Sound pressure distribution in the outer ear," Scand. Audiology 1, 197–203.

Erber, N. P. (1968). "Variables that influence sound pressures generated in the ear canal by an audiometric earphone," J. Acoust. Soc. Am. 44, 555–562.

Lawton, B. W. (1979). "A survey of the sound field within the occluded ear canal," Proc. Inst. Acoust., November.

Sachs, R. M., and Burkhard, M. D. (1972). "Earphone pressure response in ears and couplers," Paper presented at the 83rd Meeting of the Acoustical Society of America.

Shaw, E. A. G. (1966a). "Ear canal pressure generated by circumaural and supra-aural earphones," J. Acoust. Soc. Am. 39, 471–479.

Shaw, E. A. G. (1966b). "Ear canal pressure generated by a free sound field," J. Acoust. Soc. Am. 39, 465–470.

Shaw, E. A. G. (1974). "Transformation of sound pressure level from the free field to the eardrum in the horizontal plane," J. Acoust. Soc. Am. 56, 1848–1861.

Stinson, M. R., Shaw, E. A. G., and Lawton, B. W. (1982). "Estimation of acoustical energy reflectance at the eardrum from measurements of pressure distribution in the human ear canal," J. Acoust. Soc. Am. 72, 766–773.

Studebaker, G. A. (1974). "Sound levels measured in three positions in ear canals occluded by an earmold," Paper presented at the National Convention of the American Speech-Language-Hearing Assoc., Las Vegas, Nevada.

Villchur, E. (1969). "Free field calibration of earphones," J. Acoust. Soc. Am. 46, 1527–1534.

Weiner, F. M., and Ross, D. A. (1946). "The pressure distribution in the auditory canal in a progressive sound field," J. Acoust. Soc. Am. 18, 401–408.