

Comments on “Earphones in audiometry” [Zwislocki *et al.*, J. Acoust. Soc. Am. 83, 1688–1689 (1988)]

Mead C. Killion

Etymotic Research, 61 Martin Lane, Elk Grove Village, Illinois 60007

Edgar Villchur

Foundation for Hearing Aid Research, Woodstock, New York 12498

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The Zwislocki *et al.* [“Earphones in Audiometry,” J. Acoust. Soc. Am. 83, 1688–1689 (1988)] Letter to the Editor states that insert earphones have some unresolved technical problems, such as limited frequency response, limited dynamic range and power handling capability, intersubject variability, and hygiene safety. In evaluating circumaural earphones, Zwislocki *et al.* say that the lack of a standard coupler disqualifies them for audiometry. Since this letter carries the weight of a CHABA committee recommendation, these issues are commented on herein. Section I was written primarily by Mead Killion and Sec. II primarily by Edgar Villchur. For brevity throughout, the authors of the Zwislocki *et al.* letter will be referred to as “the authors.”

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I. INSERT PHONES

A. Frequency response

The frequency response of the currently recommended supraaural headphone (TDH-39) is not significantly different from that of the most common clinical audiometric insert earphone (ER-3A), as illustrated in Fig. 1. In fact, the Etymotic Research ER-3A was purposely designed to mimic the limited real-ear frequency response of the TDH-39 so that the two transducers could be used interchangeably. A limited frequency response is not intrinsic to insert earphones, as evidenced by the commercial availability of the two insert earphones whose frequency responses are shown in Fig. 2. Although the output of these latter two earphones is roughly 20 dB less than the TDH-39 below 5 kHz, they are

unsurpassed in frequency response accuracy and smoothness by any earphone known to the writers: supraaural, circumaural, or insert.

B. Dynamic range

The dynamic range of the ER-3A is actually *greater* than that of the TDH-39 in the MX-41/AR cushion at low frequencies. It is somewhat less than that of the TDH-39 at high frequencies, but that is not a limitation for conventional audiometry. Both earphones will operate linearly to output levels well below 0 dB SPL, so the lower end of the dynamic range can be taken as 0 dB in both cases. At high levels, the ER-3A will produce 110 dB HL output from 500–4000 Hz,

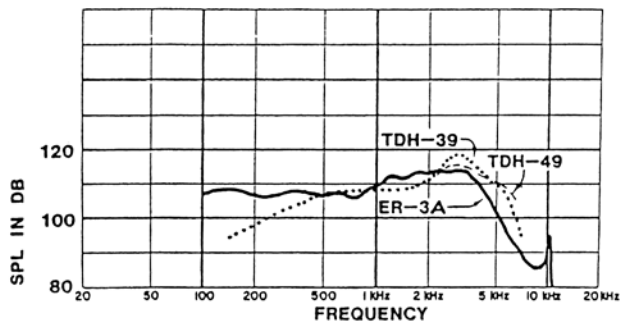


FIG. 1. Estimated typical eardrum pressure response for three 10-ohm earphones with 0.1-V (1 mW) drive.

the output limits of a conventional audiometer. The ER-3A will produce 95 dB HL at 125 Hz (significantly greater than will the TDH-39 at that frequency). Only at 6 kHz is the ER-3A output (90 dB HL) a limitation for conventional audiometry.

C. Intersubject variability

A comparison of intersubject variability for the TDH-39 and ER-3A earphones has been reported in four studies with a combined population of 113 subjects. These studies are summarized in the Wilber *et al.* (1988) article cited by the authors. At every audiometric frequency except 1 kHz, the standard deviation across subjects was lower for insert earphones than for supraaural headphones (see Fig. 3, from Wilber *et al.*, 1988). The *experimental* findings are that the "intersubject differences in ear-canal geometry and eardrum impedance and the difficulty of controlling the exact insertion depth," to which the authors refer, appear less important with a properly designed insert earphone than the variability introduced by the "air leakage" and "positioning of the earphone on the head of the listener" with a supraaural earphone.

D. Hygiene

Hygiene could be a problem only if the disposable ER-3-14 foam eartips are used on more than one patient, which is specifically not recommended. Indeed, it could be argued that hygiene is much less of a problem with an insert ear-

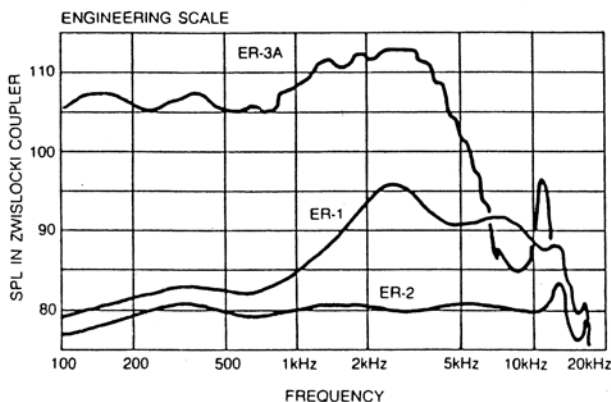


FIG. 2. Comparison of three insert earphones with 0.1-V drive.

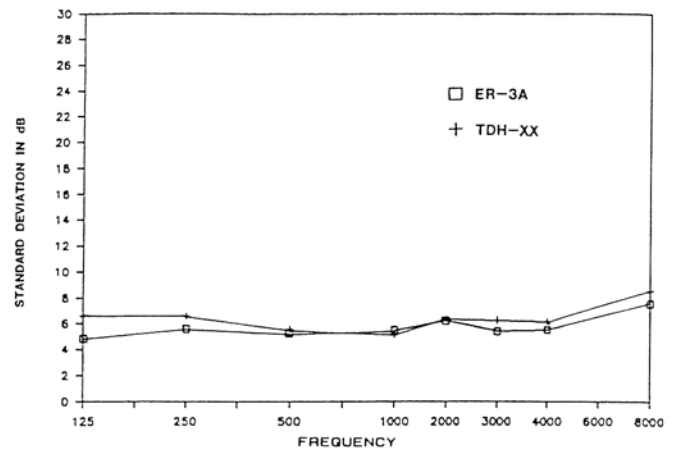


FIG. 3. Standard deviation of thresholds across subjects, averaged across four studies, for ER-3A and TDH-39 earphones [from Wilber *et al.* (1988), used with permission].

phone using disposable eartips than with a supraaural earphone having a foam cushion which is regularly transferred from ear to ear to ear without cleaning.

E. Additional advantages

In addition to these considerations relative to routine audiometry, there are circumstances in which the advantages of an insert earphone make it the earphone of choice. These are:

(1) Testing of patients with moderate-to-severe bilateral conductive loss, where the increased interaural attenuation of the insert earphone (see Fig. 4, from Killion *et al.*, 1985) provides an immediate and simple solution to the "masking dilemma."¹

(2) Testing of profoundly deaf patients with "left corner audiograms," where the response to the TDH-39 is often vibrotactile rather than auditory (Boothroyd and Cawkwell, 1970). The several-orders-of-magnitude reduction in direct vibration output that is possible with a properly designed insert earphone mounted away from the ear, combined with the increase in undistorted acoustic output possible at 125 Hz, makes the insert earphone the only choice in these cases.²

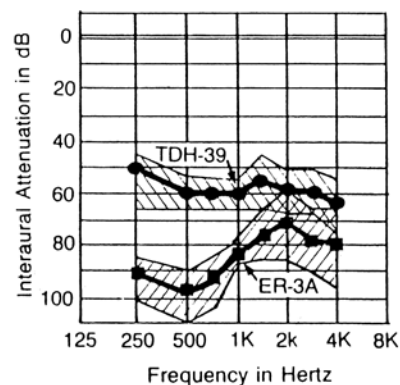


FIG. 4. Interaural attenuation (average and range) measured on six subjects with unilateral hearing loss for ER-3A and TDH-39 earphones [from Killion *et al.* (1985), used with permission].

(3) Testing of patients in locations (such as a hospital bed or nursing home) where a soundproof booth is not practical. The proper use of an insert earphone with slow-recovery-foam eartips can provide noise exclusion equivalent to a single-wall soundproof booth, an expectation supported by the data of Clemis *et al.* (1986), shown in Fig. 5, and by the data of Killion and Berger (1987), shown in Fig. 6. In most cases, testing to audiometric zero can be safely undertaken with a properly designed insert earphone whenever the SPL of the background noise is less than 45 dBA.

(4) Testing of patients whose earcanals collapse under the MX-41-/AR earcushion, producing false indications of high-frequency hearing loss during audiometric testing. This occurred with supraaural earphones in 4% of the roughly 1200 patients seen for audiometric testing reported by Hildyard and Valentine (1962). The problem is eliminated with insert earphones using properly inserted eartips, which hold the earcanal open rather than collapsing it.

(5) Hearing testing for hearings aid fittings, where the relationship between the audiometer dial reading and equivalent 2-cc coupler SPL's is tenuous at best when supraaural earphones (calibrated in a 6-cc coupler) are used. In contrast, to give a practical example, loudness discomfort readings can be converted *directly* to equivalent 2-cc coupler SPL specifications if an audiometer using an insert earphone that has been calibrated in a 2-cc coupler is employed (Hawkins, 1980; Cox, 1981). That calibration can now be performed with some assurance given the findings of the Wilber *et al.* (1988) study cited by the authors.

II. CIRCUMAURAL PHONES

Zwislocki *et al.* (1988) say the lack of a satisfactory commercially available coupler for circumaural earphones disqualifies that type of earphone for audiometry at present, although they think circumaural earphones "have several advantages (over supraaural earphones) that recommend them for standard use in audiometry." The authors say the main strength of the supraaural earphone—indeed the only feature other than interaural attenuation for which they do not report the circumaural earphone as superior or equal to

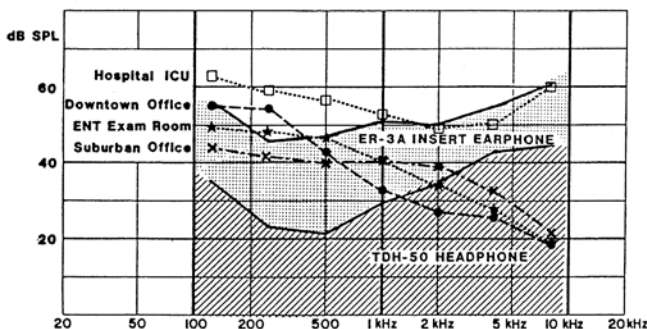


FIG. 5. Octave-band noise levels measured in four otologic nonideal testing sites, compared to allowable background noise levels for testing to audiometric zero with TDH-50 and ER-3A earphones [from Clemis *et al.* (1986), used with permission].

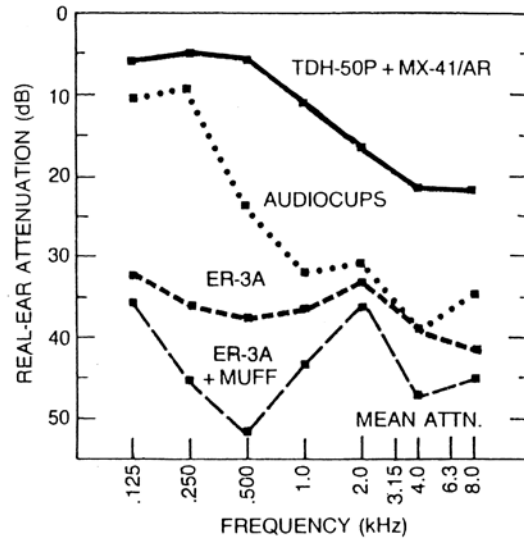


FIG. 6. External noise attenuation of four audiometric earphones measured in a diffuse noise field [from Killion and Berger (1987), used with permission].

the supraaural—is the availability of a standard coupler and method of calibration. We suggest that this conclusion needs to be put into perspective.

A. Calibration of supraaural earphones

The standard coupler measurement of a supraaural audiometer earphone, while repeatable with great accuracy, is itself not a very satisfactory calibration because it sacrifices validity for reliability. The NBS 9A coupler measures only the earphone mechanism; although the supraaural cushion is not removed during testing, it merely serves as an acoustic seal and is not otherwise a part of the coupler's acoustic circuit. Conditions of the cushion, such as elastic stiffness or mechanical Q, which affect the real-ear response and can change with time, have no influence on the coupler measurement. The validity of the calibration suffers because the effect of the cushion is bypassed.

The supraaural-earphone measurement has another weakness. The coupler response is converted to real-ear response by a transfer function, which is derived from an average of responses on different ears and with different cushion fits. Since there is a large variation in the real-ear response of the standard supraaural audiometer earphone, the transfer function yields a response curve that is likely to be significantly inaccurate for an individual subject and cushion fit.

B. Calibration of circumaural earphones

If the earphone mechanism of a circumaural audiometer earphone were removed from its mounting and measured separately (as was previously done for supraaural earphones with the 1A coupler), the validity of the measurement—which is to say, the degree to which the coupler measurement, after the application of an appropriate transfer function, represents real-ear response—would, in most cases, be greater for the circumaural earphone than for a supraaural earphone measured on a 9A coupler. This is

because of the reduced real-ear subject and cushion-fit variation in the response of a properly designed circumaural earphone.

We are not proposing that a method of calibrating circumaural earphones be adopted that, like the current supraaural calibration, bypasses the effect of the coupling device between the earphone and the ear. We are rather saying that the current standard method of calibrating a supraaural audiometer earphone is not a good reason for staying with this earphone; users are only beguiled by the stability of the 9A coupler measurement.

Although the need for a circumaural earphone has been reduced by the existence of a commercially available insert audiometer earphone, we believe that there remain applications for which the circumaural earphone is useful. The lack of a standard circumaural earphone and the lack of a standard circumaural coupler feed on each other. Manufacturers are loath to produce a circumaural earphone for which there is no accepted method of measurement, and there isn't much motivation to design and produce a circumaural coupler when there is no circumaural audiometer earphone in use. The circle needs to be broken.

III. FINAL REMARKS

To our knowledge, there have been only two serious attempts to design a new audiometric earphone in the last 20 years: Villchur's (1970) and Killion's (1984). The performance data recorded in the literature on both Villchur's circumaural and Killion's insert earphone ought to speak for itself. Inductive reasoning from the data, rather than Aristotelian deductive reasoning from principles, ought to prevail. In light of the above information, we believe the recommen-

dation of the CHABA committee—in effect that we continue the use of a World War II Air Force headphone for audiometry—ought to be reconsidered.

¹Because the vibration output of the TDH-39 is only about 50 dB below its air conduction output, testing a patient with a 60-dB bilateral conductive loss using TDH-39 earphones amounts to testing with two bone vibrators. Under those circumstances, neither ear can be stimulated or masked in isolation. This creates the classic dilemma, which cannot be circumvented as long as a supraaural earphone is used for testing.

²A vibrotactile response can still occur when the patient feels a "mechanical shock" as his eardrum distends. In the insert earphone experiments reported by Killion *et al.* (1985), this occurred at 105–110 HL at 500 Hz, a value which would extrapolate to roughly 90 dB HL at 125 Hz, some 20 dB better than the vibrotactile threshold for the TDH-39 at that frequency.

Boothroyd, A., and Cawkwell, S. (1970). "Vibrotactile thresholds in pure tone audiometry," *Acta Oto-Laryngol.* **69**, 381–387.

Clemis, J. D., Ballard, W. J., and Killion, M. C. (1986). "Clinical use of an insert earphone," *Ann. Otol. Rhinol. Laryngol.* **95**(5), 520–524.

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Hawkins, D. (1980). "Loudness discomfort levels: A clinical procedure for hearing aid evaluations," *J. Speech Hear. Disorders* **45**, 3–16.

Hildyard, V. H., and Valentine, M. A. (1962). "Collapse of the ear canal during audiometry," *Arch. Otolaryngol.* **75**, 422–423.

Killion, M. C. (1984). "New insert earphones for audiometry," *Hear. Instrum.* **35**(7), 46–47.

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Killion, M. C., and Berger, E. H. (1987). "Noise attenuating earphone for audiometric testing," *J. Acoust. Soc. Am. Suppl.* **1** **81**, S5.

Villchur, E. (1970). "Audiometer-earphone mounting to improve inter-subject and cushion-fit reliability," *J. Acoust. Soc. Am.* **48**, 1387–1396.

Wilber, L. A., Kruger, B., and Killion, M. C. (1988). "Reference thresholds for the ER-3A insert earphone," *J. Acoust. Soc. Am.* **83**, 669–676.

Zwislocki, J., Kruger, B., Miller, J. D., Niemoeller, A. F., Shaw, E. A., and Studebaker, G. (1988). "Earphones in Audiometry," *J. Acoust. Soc. Am.* **83**, 1688–1689.

Reply to "Comments on 'Earphones in audiometry'" [M. C. Killion and E. Villchur, *J. Acoust. Soc. Am.* **85**, 1775–1778 (1989)]^{a)}

Jozef J. Zwislocki

Institute for Sensory Research, Syracuse University, Syracuse, New York 13244

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This is a reply to the Letter to the Editor of Killion and Villchur [*J. Acoust. Soc. Am.* **85**, 1775–1778 (1989)] in which these authors take issue with a report of CHABA WG 91 [Zwislocki *et al.*, *J. Acoust. Soc. Am.* **83**, 1688–1689 (1988)] on "Earphones in audiometry." The conclusion of WG 91, that the use of supraaural earphones should not be discontinued in favor of either circumaural or insert earphones, is further justified.

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The authors of the comments (Killion and Villchur, 1989) take issue with the recommendation of CHABA Working Group 91 (WG 91) that the currently accepted

supraaural earphones should continue to be used and not be replaced, for the time being, with circumaural or insert earphones (Zwislocki *et al.*, 1988).

The Working Group welcomes the comments for several reasons. They give us the opportunity for some additional clarifications. The authors of the comments are experts in the field and have contributed to it by developing a cir-

^{a)} This reply is made with the consent of the majority of the members of Working Group 91 of the Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) of the National Research Council.

cumaural earphone and an insert earphone, the latter being commercially available. Their comments must be considered as authoritative and valuable. Their evaluation of the three types of earphones in question departs from ours in emphasis rather than substance. We found during our deliberations that not enough developmental work has been done on audiometric earphones and their calibration devices and hope that the comments, together with our short report and this reply, will attract more attention to this aspect of hearing testing.

Our decision not to recommend circumaural or insert earphones as replacements for supraaural earphones was not dictated by satisfaction with the latter, but rather by the perceived lack of technological readiness with respect to the former. The situation has been described quite accurately by one of the authors of the comments, who has stated: "The lack of a standard circumaural earphone and the lack of a standard circumaural coupler feed on each other."

The situation has improved with respect to insert earphones because of their recent commercial availability and the availability of a standard calibration device for them. With an extension, the device can also be used for calibration of supraaural earphones so that the outputs of both types can be compared directly. However, the extension has not been standardized, and we felt that the experience with insert earphones is not yet sufficient to recommend them as a replacement for the supraaural ones. They appear to be superior to the latter in some respects, but inferior in others.

We refer the reader to our original report, "Earphones in audiometry" (Zwislocki *et al.*, 1988) for a more comprehensive evaluation of insert earphones. Here, we limit ourselves to the points of divergence with the comments. It is true that the earphone ER-3A, the only commercially available insert earphone with sufficient sensitivity and dynamic range for audiometric applications, has a better low-frequency response than the TDH-49 supraaural earphone. However, this advantage is more than offset by a diminished sensitivity above 4 kHz, where the most severe hearing losses tend to occur. The diminished sensitivity is accompanied by a decreased dynamic range. According to Wilber *et al.* (1988), the intersubject variability of ER-3A is about the same as that of TDH earphones—no particular advantage for the insert earphones here. In addition, mean thresholds measured with ER-3A by several groups spanned a range of nearly 20 dB at 125 Hz and almost that much at 8 kHz.

We do not agree with the comments on the subject of hygiene, toward which we take a somewhat broader view. The fact that insert earphones have to be inserted into the ear canal is perhaps their main disadvantage. The ear canal is extremely sensitive to pain, particularly in its deep parts, and to infection. It is because of the danger of infection that the ear tips of insert earphones have to be changed after every application. This is not at all necessary for the cushions of supraaural or circumaural earphones. Furthermore, earwax can be pushed by the tip of an insert earphone toward the eardrum and cause all sorts of complications. Removal of earwax is not always easy and not without some risk. If not removed, it can obstruct the narrow opening of the insert earphone and lead to an apparent hearing loss. This effect parallels the effect of a closed ear canal due to the pressure exerted by a supraaural earphone.

Circumaural earphones have the advantage over insert earphones in that they do not have to be inserted into the ear canal. In all other respects they appear to be either essentially equal or inferior. The decision as to which type is more acceptable will probably require extensive field tests. Possibly, future developments will make it possible to use all three types of earphones interchangeably and to choose the most suitable one for a given situation. This is currently possible for the ER-3A and the TDH earphones (Wilber *et al.*, 1988).

The recommendation of WG 91 not to discontinue using supraaural earphones is just that. It is not aimed at stifling progress in the development of other types of audiometric earphones or at their exclusion from audiometry. On the contrary, the feeling of WG 91 has been that more work needs to be done on suitable earphones and on their calibration devices to overcome the well-known shortcomings of the supraaural earphones in current use.

Killion, M. C., and Willchur, E. (1989). "Comments on 'Earphones in audiometry,'" *J. Acoust. Soc. Am.* **85**, 1775-1778.

Wilber, L. A., Kruger, B., and Killion, M. C. (1988). "Reference thresholds for the ER-3A insert earphone," *J. Acoust. Soc. Am.* **83**, 669-676.

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