New insert earphones for audiometry

By Mead C. Killion, PhD

This report describes two new insert earphones designed for use in subjective and objective audiometry. While not without limitations of their own, these new earphones are free from most of the limitations of traditional headphones.

Traditional supra-aural audiometric headphones have several limitations:

1) Little noise exclusion at low frequencies where background noises are often a problem, e.g., testing in schools or nursing homes;

2) Poor cross-head isolation so that a masking noise must often be used in the non-test ear;

3) A limited bandwidth (6 to 8 kHz), which makes reliable high-frequency audiometry difficult;

4) An inaccurate real-ear frequency response for speech, so that the spectrum of speech reproduced at the eardrum by the headphone is quite different from the spectrum that would have been produced at the eardrum by the same talker in a face-to-face situation; and

5) A headband force that makes the headphones uncomfortable to wear for a long period of time and produces collapsed canals in some older individuals, giving erroneous indications of high frequency loss. This headband force, however, is still insufficient in many cases to produce a seal, giving large test-retest variability at low frequencies.

With the advent of "objective" or ABR (auditory brainstem response) audiometry, an additional limitation became apparent:

6) The electromagnetic signal radiated from the headphone is sometimes picked up by the ABR electrodes causing an artifact in the averaged response.

A new approach

As Bekesy described in the 1940s, good noise exclusion and interaural attenuation can be provided with the use of an "insert earphone," which is a hearing aid receiver coupled with a plastic tube to the ear. Similarly, the electrical artifact problem in ABR measurements is sometimes circumvented by using a plastic tube to couple the sound to the ear so that a) the earphone's electromagnetic radiation is removed from the vicinity of the ABR electrodes, and b) the acoustic time delay gives the electromagnetic radiation time to die away before the acoustic signal, typically a click, reaches the eardrum.

The canal collapse problem and the discomfort problem can be solved by sealing the tube into the ear with a soft foam earplug such as the EAR™ plug. In this laboratory's experiments, it was concluded that a tube with an outer diameter of 2.2 mm (.085 inch) was about as large as could be used if the EAR™ plug was to be squeezed down to fit all ears.

The challenge, therefore, was to obtain a smooth, wideband frequency response at the end of a long, small diameter tube. Two developments made this possible: the Knowles ED-series wideband receiver and Carlson's twin-tube damping arrangement[1].

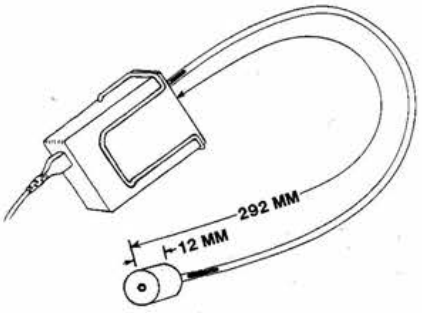

Fig. 1. Insert earphone with sound tube and EAR™ plug.

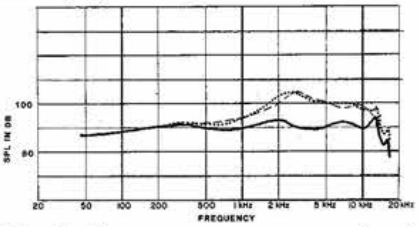

Fig. 2. Frequency responses: (.....) Zwislocki coupler response of ER-1 earphone with .316 volt drive; (-----) eardrum-pressure response of the average ear in 90 dB SPL diffuse sound field; (———) diffuse-field referenced response of ER-1 earphone with .316 volt drive.

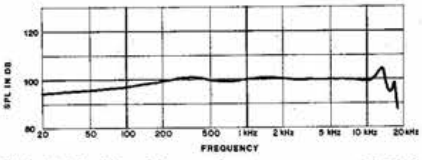

Fig. 3. Zwislocki coupler response of ER-2 earphone wtih 1.0 volt drive.

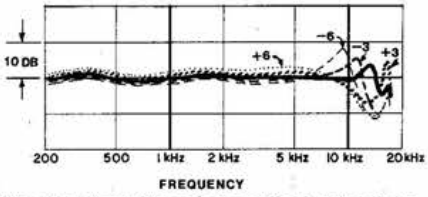

Fig. 4. Effect of eartip insertion on frequency response of insert earphones. Numbers on each curve indicate millimeters of deeper (+) or shallower (−) insertion than the nominal 12 mm.

Mechanical design—Fig. 1 shows the complete insert earphone. A rectangular case holds the receiver, two acoustic dampers, an electrical equalization network and Carlson's "resonance cancellation tube." The case is conveniently clipped onto a shirt collar or blouse, with the sound tube bringing the sound to the ear.

The replaceable sound tube has a length of 292 mm (11.5 inches) of #16 tubing (1.35 mm I.D.), measured from the wall of the case to the tip of the EAR™ plug. This length, in combination with the length inside the case, produces an acoustic time delay of 1.0 msec.

Frequency response—Two versions of the new insert earphones, designated the ER-1 and ER-2 Tubephones, have been designed. These differ only in their frequency response. For speech audiometry, where the goal is to produce the same frequency response at the eardrum for speech as would be produced in the live situation, the frequency response shown as the dotted curve in Fig. 2 has been provided.

Fig. 2 also shows the average, diffuse-field response of the normal ear, based on the data of Shaw,[7] Kuhn[5] and Killion and Monser.[3] The resonances of the normal external ear ("nature's own hearing aid") must be duplicated in the earphone response if accurate reproduc-

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Mead C. Killion, PhD, is president of Etymotic Research, Inc., Elk Grove Village, IL.

tion of pre-recorded material is desired.

The solid curve in Fig. 2 shows the difference between the earphone response and the normal ear response, and thus represents an estimate of the accuracy (fidelity) with which the ER-1 earphone reproduces typical pre-recorded material for the idealized "average listener."

For brainstem audiometry, the accurate reproduction at the eardrum of an electrical "click" stimulus is often of interest. Thus, the ER-2 earphone has been designed to provide the flat Zwislocki coupler frequency response shown in Fig. 3. When driven with a 100 microsec rectangular pulse, this earphone will produce a roughly rectangular pressure pulse at the eardrum, without excessive ringing, with linear (unchanged waveform) operation to 110 dB SPL peaks measured in the Zwislocki coupler.

Calibration

Any new audiometric earphone faces a calibration problem. Some years ago, however, this writer estimated the Minimum Audible Pressure (MAP) in terms of eardrum pressure,[2] based on available earphone and free field threshold data. While this estimate undoubtedly will require revision as new evidence becomes available, it provides an interim basis for insert earphone calibration in a Zwislocki coupler. (As reported by Sachs and Burkhard[6] and Kruger, et al[4] the Zwislocki coupler provides an excellent representation of the average ear up to 8 kHz.)

Table 1 gives the Zwislocki coupler and 2 cc coupler SPLs required for 70 dB HL earphone calibration, based on the earlier MAP estimate. The 2 cc coupler pressures have been derived from direct comparison of Zwislocki coupler and 2 cc coupler measurements on the new insert earphones. Above 250 Hz, the SPL differences are nearly identical to those reported earlier for hearing aid earphones.

Limitations

The new earphones are not without limitations: Their maximum undistorted output of 105 to 110 dB SPL (Zwislocki coupler) is equivalent to 95 dB HL in the 500 to 4000 Hz region, which is 5 dB less than required by ANSI S3.6-1969 for a wide range audiometer and 15 dB less than provided by most modern audiometers.

Frequency in Hz	Zwislocki coupler SPL	2 CC coupler SPL
125	100.0	97.5
250	89.0	86.0
500	82.0	78.5
750	79.5	76.0
1000	79.0	73.5
1500	80.0	72.5
2000	85.0	76.0
3000	85.5	75.5
4000	83.0	71.5
6000	83.0	68.5
8000	84.0	65.5
12000	88.0	-
16000	92.0	-

Table 1. Tentative 70 dB HL calibration values.

The electrical impedance of the new earphones varies from approximately 200 ohms at low frequencies to about 25 ohms at high frequencies (about 15 ohms at high frequencies for the flat-eardrum-pressure response version) as a result of the electrical equalization networks employed. The high electrical impedance of these earphones at low frequencies should not be a problem with most recent audiometer designs, but will cause attenuator error at high intensity settings in some older audiometers that use the headphone as part of the attenuator circuit.

Particular care must be taken in inserting the EAR™ plug so that the sound tube is not blocked by either the foam plug or a tortuous canal wall. Moreover, the insertion depth determines the frequency of a half-wave resonance boost that occurs at nominally 13 kHz for full (12 mm) plug insertion. Fig. 4 shows the effect of a 3 mm (1/8 inch) error in either direction, which could come about either because the edge of the plug was not placed flush with the ear canal entrance or because of an ear canal that was shorter or longer than average. Also shown in Fig. 4 is the effect of a 6 mm (1/4 inch) error, a less likely occurrence.

Where the earphone is to be used above 8 kHz for ototoxic drug monitoring, a custom earmold made at the beginning of the test series is suggested to reduce the test-retest variability to a minimum. XL-80 silicone impression material is suggested and will make an adequate "instant" earmold for most purposes. If a custom earmold using #13 or larger tubing already exists, a length of #16 extra-thin-wall Teflon tubing may be inserted through the #13 tubing and used as the sound tube.

A few individuals have large enough canals so that obtaining a good airtight seal is difficult (reducing the noise isolation and the low-frequency output of the earphone). For such cases, an adapter tip is provided to allow standard impedance-audiometry cuffs to be used instead of the EAR™ plugs. The writer has found the following check useful in questionable cases: set the audiometer to 60 HL at 4 kHz and listen near the plugged ear. Any audible sound indicates a leak. (At 4 kHz, the concha and pinna form a good horn coupling for sound leaking from the canal entrance, making any leak easy to hear.) □

The ER-1 and ER-2 are now a constant 10 ohms.

The ER-3 is available in either 10 or 50 ohms.

References

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The ER-3 will provide 110 dBHL between 500 and 4000 Hz.

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