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Comparison of REAT and insertion loss measurements using headphone audiometry

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ABSTRACT

Under the current standard, hearing protector performance is assessed using the REAT (Real-Ear Attenuation at Threshold) method. This method involves measuring hearing thresholds with and without hearing protection in free-field conditions. The insertion loss of the hearing protection corresponds to the difference between these thresholds. REAT requires a highly sound-isolated audiometry room with minimal background noise and a diffuse field to ensure that both ears receive identical sound exposure. This study aims to compare REAT results with those obtained through headphone audiometry. Unlike REAT, headphone audiometry measures thresholds separately for each ear, allowing the detection of minor asymmetry between ears. Furthermore, this technique requires only an isolated cabin rather than a free-field environment. This study measured the insertion loss of two different types of earplugs on 13 subjects: a foam earplug and a custom-molded earplug in hard acrylic. These values show some differences between the two methods, with small variations at high frequency for foam earplugs and slightly greater variation at low frequency for custom molded earplugs. In addition, the standard deviation is significantly higher, especially for custom-molded earplugs.

Keywords: Earplug performance, REAT, Headphone audiometry.

1. INTRODUCTION

Every day, we are exposed to continuous and/or impulsive noise that can damage our hearing. In Europe, legislation prescribes a maximum noise exposure level of 87 dB(A) for 8 hours with hearing protection [1]. The best-known solution is using individual Hearing Protection Devices (HPDs), as it is often complicated to reduce the noise level of the sound sources. Adequate protection requires accurate knowledge of the HPD's performances.

Currently, the European and American industries consider the REAT (Real-Ear Attenuation at Threshold) method as the reference for assessing the performance of hearing protectors worn by an individual [2-5]. The REAT method corresponds to a hearing threshold evaluation performed in a diffuse sound field, with and without an HPD. Although the ANSI/ASA S12.6 and ISO 4869 standards describe a detailed protocol to measure the attenuation provided by a given device, the described procedure is generally uneasy to implement on a large scale.

Key difficulties include:

- Acoustic environment: Requires a very well-insulated anechoic room with low background noise and a diffuse sound field so that the two ears perceive the same sound.
- Participant hearing symmetry: participants must have symmetrical hearing in both ears, as threshold is measured with both ears together.
- An additionnnal issue is that Brueck (2009) has shown that the actual attenuation performance of earplugs is often different from that claimed by the manufacturer [8], which limits the relevance of this subjective method.

Alternatively, an objective method is also described in the ANSI Standard [6]. This method is based on the estimation of the HPD insertion loss using a microphone inserted in

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the ear canal: it is the MIRE (Microphone In Real Ear) method. Installing a microphone in earplugs is difficult as it could damage them or create an acoustic leak. A study by Berger [7] showed that it is possible to use this method with earplugs specially designed for insertion of a microphone probe, but these earplugs can only be used to measure attenuation.

In this context, fit-test systems have been developed to measure the effectiveness of HPDs in situ. These systems have been used in the literature to measure the attenuation of earplugs [9,10].The aim of this study is to find a method for estimating the effectiveness of earplugs in the laboratory that is easier to implement than the REAT method and less intrusive than the MIRE method. We therefore propose to estimate insertion loss by measuring hearing thresholds with and without earplugs using headphone audiometry. Measuring threshold with headphones rather than in the open field has a number of advantages:

- the headphones isolate the subject, which simplifies the environmental conditions of the measurement,
- participants can present auditory asymmetry between the two ears as each ear is measured separately,
- there are two attenuation values for each subject (one for each ear).

2. MATERIAL AND METHOD

In this study, we performed a comparison between the results obtained with headphone audiometry and data provided by the earplug manufacturers, which were obtained by the approved laboratories using the REAT method.

2.1 Earplugs used

Two different earplugs have been evaluated (Figure 1) :

- A custom earplug in Crylit® manufactured by 3D printing, with a specific geometry for each ear tested,
- A classic foam earplug.

Figure 1. Photographs of the two earplugs used.

2.2 Headphone audiometry

The audiometer used was an Otometrics audiometer with TDH39 headphones. We used the Békésy method at fixed frequencies to measure hearing thresholds. With our equipment, we were able to measure the center frequency of octaves from 125 Hz to 8 kHz. The audiometer cannot measure frequencies below 125 Hz.

2.3 Participants

Thirteen voluntary subjects (nine males and four females) participated in the tests. Each participant has their custom earplug with the same filter from the same manufacturer.

2.4 Measurement protocol

Each participant sat in an audiometry booth in front of the audiometer. They each performed 4 audiometry, each time starting with the left ear:

- the first without an earplug;
- the second with the custom earplug;
- the third with the foam earplug;
- the fourth without the earplug.

The last test was used to check whether the participants were still focused. The measurements were validated if the difference between the first and last measurements did not exceed 5 dB for each frequency tested. The test lasted no longer than 20 minutes.

2.5 Estimated acoustic quantities

We determined the average attenuation per central octave frequency for each earplug between 125 Hz and 8 kHz over the 26 measurements (13 participants times 2 ears). For each frequency, the Assumed Protection Value (APV) was calculated. This APV corresponds to the mean value minus one standard deviation.

To calculate the SNR (Single Number Rating as described in ISO 4869-2 [5]) and the H, M, and L values, the earplug's attenuation at 63 Hz had to be estimated. It is proposed that the attenuation at 63 Hz be taken as the attenuation at 125 Hz minus 1 dB. The standard deviation is the same as at 125 Hz.

3. RESULTS

Figure 2 shows the average insertion loss values obtained for the 26 ears for the two types of earplug. These values are compared with the data provided by the earplug manufacturers. There was little difference except for the results at 125 Hz for the custom earplugs.

Figure 3 shows the APVs for the two types of earplugs. For the foam earplugs, there was a good correlation between our results and those provided by the manufacturer.

On the other hand, for the custom earplugs, where the standard deviation was significant, the APVs were lower than the manufacturer's data, especially at low frequencies. This discrepancy, caused by a very high standard deviation at low frequencies, cannot be explained at present.

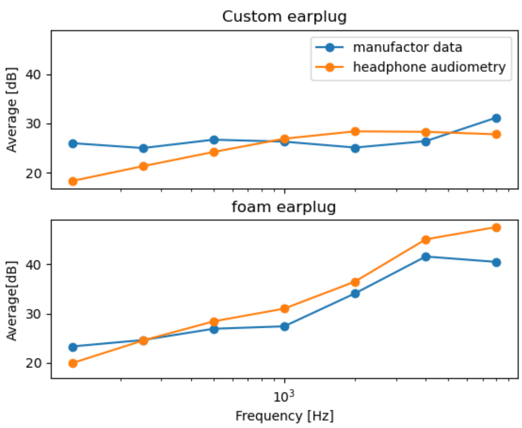

Figure 2. Average insertion loss for the two earplug.

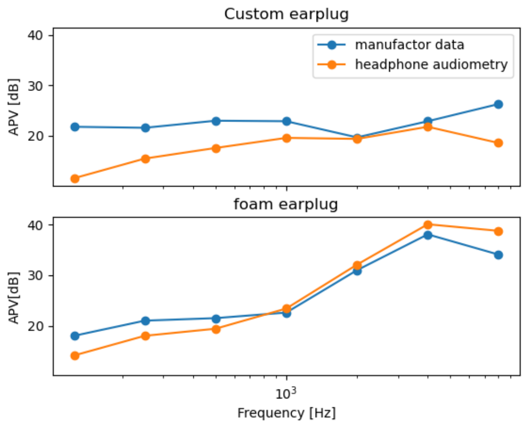

Figure 3. APV for the two earplugs.

Table 1 gives the two earplugs' SNR, H, M, and L values. As with the APV measurements for the foam earplug, the values for the custom earplugs are equivalent but slightly lower.

Table 1. SNR, H, M and L values for each earplug in dB.

	Custom earplug			
	SNR	H	M	L
Manufacturers data	27,7	30	24	22
Headphone audiometry	27	31	23	19
	Foam earplugs			
	SNR	H	M	L
Manufacturers data	23	21	22	22
Headphone audiometry	21	20	19	17

4. DISCUSSION

A method of assessing HPD that is simpler to implement than the REAT and MIRE methods was investigated. This approach consists of determining hearing thresholds with and without hearing protection using headphone audiometry.
In this preliminary assessment, the method gave promising results for foam earplugs, showing good agreement with the manufacturer's data. However, for custom earplugs, the method gave lower insertion loss and APV estimates than the manufacturer's data, especially at low frequencies.

One hypothesis to explain this difference could be that the static pressure exerted by the helmet on the auricle slightly affects the positioning of the protector, possibly reducing its performance. Indeed, the performance of custom earplugs can be more easily affected by deformation of the hearing canal than that of foam earplugs.

5. CONCLUSION & PESPECTIVE

Headphone audiometry method gives results that are consistent with the manufacturer's REAT measurements for foam earplugs. Nevertheless, this method warrants further study to verify whether the observations made with custom earplugs are valid. Given the difficulty of implementing this method, it could be used to verify whether or not the performance of earplugs is stable during prolonged wear. Indeed, Gong et al (2023) [10] reported a very slight loss after two hours of use. This new method could therefore be extended to assess changes in the performance of protectors over time, without the biases of conventional methods.

6. ACKNOWLEDGMENTS

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