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Suitability of commercial systems for earplug individual fit testing

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A B S T R A C T

Hearing Protection Device (HPD) rated attenuation is measured using the Real Ear Attenuation at Threshold (REAT) method specified in Standard ISO 4869-1. This statistical method assumes optimal fitting and is applied under laboratory conditions to predict the hearing protector performance for an individual wearer. The rated attenuation is therefore generally higher than that measured in the field. A consequence is the emergence of commercially available systems, which offer the capability of individual fit testing of hearing protectors in the field to control the attenuation actually received by the wearer. The purpose of this paper is to assess the suitability of these systems. Three commercially available systems dedicated to earplugs were used under laboratory conditions to assess the performance of preformed, foam or custom-molded earplugs for at least 20 test subjects. Results were compared with REAT attenuations for the same group of subjects. Two of these systems ensure mean attenuations close to benchmark values and individual comparisons are acceptable for these systems, although discrepancies with respect to benchmark values can be wide. These systems can therefore be used to validate a choice of hearing protection as long as a large but acceptable safety margin is considered. They are also quick and easy to use, and can contribute to worker training and motivation.

1. Introduction

Hearing Protection Device (HPD) rated attenuation is measured using the Real Ear Attenuation at Threshold (REAT) method specified in Standard ISO 4869-1 [1]. This method assumes optimal fitting and computes statistically HPD performance, called Assumed Protection Value (APV), for a group of 16 subjects under laboratory conditions. Although the APV represents the attenuation achieved or exceeded by 84% of laboratory subjects (i.e. the average Insertion Loss (IL) of the HPD calculated for a group of 16 subjects minus one standard deviation), the attenuation actually provided by a HPD in real use is generally lower than the APV. Many scientific studies demonstrate this point and Berger et al. [2] has undertaken a comprehensive review of 22 of these studies. The outcome is inadequate protection of the user, who can either be under-protected, raising a risk of noise impairment, or over-protected, leading to communication problems and difficulties in recognizing warning signals. Some HPD manufacturers have therefore recently introduced fit-check systems, allowing individual assessment of hearing protector attenuation in the field. These systems implement different methods, of which there are three basic ones for individually assessing hearing protector attenuation: MIRE, subjective loudness matching and audiometry. The purpose of this paper is to assess the suitability of some of the commercial earplug individual fit testing systems available on the market. Three commercial systems, 3 M's EARfit, Howard Leight's VeriPRO and Cotral's CAPA, were selected for appraisal. Each of these three uses a different attenuation assessment method. The twofold aim of this testing survey was validation of these three commercial systems and comparison of each method's suitability.

The principle of Microphone In Real Ear (MIRE) is to determine the sound attenuation of an earplug from the difference in sound pressure level in the ear canal with an earplug (occluded ear) and without the earplug (open ear). Measurements are taken with two microphones: the first, inserted through the earplug into the ear canal (e.g. a probe tube microphone), measures the sound pressure at the eardrum and the second, positioned outside the ear, measures the incident acoustic field. The pressure difference between the two microphones provides the Noise Reduction (NR). To derive the Insertion Loss (IL – i.e. the sound attenuation of the earplug as measured by REAT), the NR must be corrected by the transfer function between the sound pressure level outside the ear and the sound pressure level in the open ear canal in order to account for the ear's effect on the sound field. This method was standardized in 2002 [3] and is widely used in electronic earmuff

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certification standards [4]. The correction transfer function (so-called HRTF in [3]) is measured or can be taken from the standard, which gives theoretical transfer functions. A drawback of this method is that it does not account for the bone conduction path. A correction has been proposed by Voix and Laville [5] and this has proved to be very accurate either for earmuff attenuation field measurements (see [6]) or for custom-molded earplug attenuation field measurements (see [7,8]). With regard to earplugs, another drawback is that measurement requires positioning a tube in the ear canal through the earplug. Some commercial measuring devices – i.e. probe tube microphones – are dedicated to this application. However, there is a risk of leakage caused by the probe-tube between the earplug and the ear canal walls or a risk that the probe-tube will be pinched by the earplug. MIRE is therefore a rather efficient method but is difficult to implement. However, it is the method retained by 3 M for the EARfit system, which is dedicated to 3 M foam or pre-formed earplugs. This system uses surrogate earplugs, similar to real ones but incorporating a by-pass tube linking a microphone to the ear canal. A loudspeaker generates the acoustic field for the tests. Instead of using theoretical corrections for converting the NR to the IL, the EARfit system is calibrated in the laboratory based on the real REAT value of the earplug. Calibration was performed using a group of 20 test subjects and for each earplug offered with the system. The resulting correction factor is simply the difference between the APV and the result given by the EARfit system. The latter system is therefore not universal and compliant with the standard, but it is the only one available on the market that applies the MIRE method for foam or preformed earplugs. It should be noted that PHONAK offers a similar system, SafetyMeter but this is exclusively dedicated to PHONAK custom-molded earplugs.

The second method, subjective loudness matching, involves asking the HPD user to balance the loudness between his/her two ears for three distinct situations: without the earplug, with only one earplug fitted and with two earplugs fitted. The sound attenuation of each earplug is then calculated from the difference between the corresponding situations with and without the earplug. A headphone is used to generate the sound. This method was first presented in 2005 [9]. Test results have been fairly convincing, but have involved only one HPD. Howard Leight implements this method in its VeriPRO fit testing. An independent test using this system, reported in [10], was performed by E. Kotarbinska on 10 different earplugs. Although expressed in average values (SNR, NRR and NRRsf), comparisons reveal that the REAT is grossly underestimated. However, VeriPRO is widely distributed and has therefore been included in the tests.

The last method, audiometry, is similar to the REAT method. Audiogram is recorded with and without the earplug. This method requires a quiet environment since it relies on hearing threshold detection. A headphone is used to generate the sound, which can either be a pure tone or a broadband noise to accelerate the process. This technique is the most commonly used in HPD fit checking and many studies are associated with it (e.g. Casali and Park [11], Edwards et al. [12] or more recently Huttunen et al. [13]). The latter research papers confirm that the audiometry method correlates closely with the REAT method. Its main drawback is the time required to perform a measurement, which is twice that required to perform an audiometric test. There are several audiometry-based fit-check systems: Michael & Associates' Fit Check System, Workplace Integra's IntegraFIT and the NIOSH HPD Well-Fit. This method can obviously also be applied with a conventional audiometer in a quiet environment. Cotral's CAPA was the system chosen for the present test due to its proximity to our laboratories and its novel measurement acceleration process: CAPA simply works with rising sound intensities, rather than determining hearing threshold based on oscillations (Bekesy audiometric method). The sound is emitted three times at each frequency with a decrease in sound gradient and an increase in starting level. Each step improves the accuracy of sound threshold determination. The resulting threshold is higher than the absolute hearing threshold, but this process accelerates the test. A headphone is used to generate the sound, which is a pure tone. The threshold is first measured with un-occluded ears, then with both ears occluded. HPD attenuation is deduced from the difference in thresholds.

2. Equipment and methods

The test benches were those used for HPD certification standards. INRS was a Notified Body until 2006. These benches were fitted with data acquisition boards (DATA TRANSLATION and NATIONAL INSTRUMENT) controlled by internally developed software under MATLAB or LABVIEW. BRUEL KJAER free-field sensors for measuring sound fields and SONOMAX SONOPASS probes for measuring inside the subject's auditory canal were used for applying the MIRE method.

The test protocol was based on HPD certification standards because there is no standard or even recommendation for fit-check methods validation. As a first step, the attenuation benchmark was measured using the REAT method [1]. To confirm the results, an additional test was conducted using the MIRE method described in ISO 11904-1 [3]. MIRE testing was performed in a large reverberant chamber (205 m^3) to ensure an acoustic diffuse field. The HRTF (see Section 1) was measured individually for each ear and subject based on ISO 11904-1 Section 10.2. MIRE and REAT tests were conducted on the same group of subjects for each HPD. The subject group was composed of 20 persons, including 11 women and 9 men aged between 18 and 24 years, with perfectly normal hearing characteristics (Table 1). To evaluate the benchmark validity, we considered the discrepancy between the two quantities at mid-range frequencies (500 Hz, 1 and 2 kHz), where results provided by the MIRE and REAT methods are considered comparable.

We then compared the data obtained with a fit-check system (Table 2) for the same group of subjects and for the same HPDs with the benchmark to evaluate the fit-check system and related method. Average attenuation values for the group of test subjects were initially compared to assess the trueness of the system. Individual comparisons were then made for each subject to evaluate the fit-check method precision. In these individual comparisons, the Personal Attenuation Rating (PAR) or the Personal Single Number Attenuation (PSNA) given by the fit-check system was compared with a "pseudo Single Number Rating" ("pseudo SNR"). The "pseudo SNR" was calculated in the same way as a normal SNR (defined in [1]), using the subject individual octave band attenuations obtained with REAT as inputs, but ignoring the standard deviation (null standard deviation). The PAR calculation is different for each system: the calculation methods applied to the EARfit and VeriPRO systems can be found in [10] – Appendix A. The VeriPRO PAR calculation is similar to the Noise Reduction Rating (NRR) except that calculations are performed for a narrower bandwidth and no corrections for between subject variability and −3 dB de-rating are applied. For the EARfit system, the PAR is computed like the Noise Reduction Statistic (NRS), with the exception that the between-subject variability is replaced by the sum of the variances of the MIRE uncertainty and the within-subject refitting uncertainty. CAPA calculates another global quantity, the PSNA, in

Table 1
Subjects mean hearing thresholds and associated standard deviation.

Frequency (Hz)	125	250	500	1 k	2 k	4 k	8 k
Hearing threshold (dB(HL))	−2	−1	0	−1	1	2	−9
Standard deviation (dB)	4.9	4.2	3.5	3.8	3.8	3.1	5.8