HEARING PROTECTOR FIT-TESTING: SPECTRUM UNCERTAINTY BUDGETS

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1 Introduction

While noise control at the source remains the objective for proper protection of workers against Noise-induced hearing loss (NIHL), hearing protection devices (HPD) are, for practical and economic reasons, often used as the first, if not the only, line of defense. In the field, however, the attenuations achieved by individual wearers of HPDs varies dramatically from these labeled laboratory values, for many reasons now well understood.

1.1 HPD fit-testing

To address the critical question of how much an individual users in the field are getting from their hearing protections devices (HPD), field attenuation estimation systems (FAES), colloquially referred to as "fit-testing system" have been developed over the years [1].

Because of the wide range of technologies used it was felt that a national standard would be required to ensure precision and accuracy of FAES measurement outcomes. The development of such a standard is in process under the auspices of the Acoustical Society of America (ASA) and the American National Standards Institute (ANSI), designated ASA/BSR S12.71-201x. The Working Group S12/WG 11, Hearing Protector Attenuation and Performance, has prepared an initial draft of a standard and is continuing to work to finalize this for balloting and approval [2].

1.2 Personal attenuation rating (PAR)

In its current draft format, ANSI S12.71 specifies minimum performance criteria for systems designed to estimate the real-ear attenuation provided by HPDs on individual users. The performance criteria are intended to ensure that FAES complying with the standard provide comparable test results to a reference laboratory procedure. Accuracy and precision are assessed by comparison of FAES data to those from the standard REAT procedure (ANSI, 2008) for the same fit of the device on an identical group of test subjects. This standard also specifies the procedures for the computation of the PAR, the personal attenuation rating. The PAR is an NRR like number, but since it is based on the data from one wearer who is the actual user of the device, instead of a group of 10-20 subjects, the between-subject standard deviation correction that is included in the NRR computation is not needed.

However, as with any single-number rating such as the NRR, the spectral variability must be accounted for. With the NRR this is accomplished using a constant 3-dB spectral safety factor, whereas the PAR accomplishes this with an explicit protection performance value that results from the variability in the computations using the 100 NIOSH noises. The PAR can be directly subtracted from A-weighted noise measurements instead of requiring the use of C weighted values as is recommended with application of the NRR. The computational details of the PAR are beyond the scope of this paper but can be found in [3] together with a comparison to other attenuation ratings and metrics.

2 Method

2.1 PAR spectrum uncertainty

PAR is expressed with its associate uncertainty that originate from three different sources: the measurement, fit and spectrum uncertainty components. The measurement uncertainty pertains to the intrinsic precision and accuracy of the FAES system in prediction the attenuation that would be measured using REAT for the same fit of the HPD under test. The fit variability pertains to the variability in the attenuation of the HPD from one fit to the next. The spectrum uncertainty arises when a fit-test system provides a single number such as a PAR that is to be applied to A-weighted sound level measurements of noises with unknown spectral content. Depending on the actual noise spectral content, there can be a variation between the attenuation predicted using an octave band calculation (usually on 7 octave-bands) applied to the actual octave-band noise data, versus that achieved with a PAR, which is analogous to the single number approach described in ANSI S12.68 [4]. The spectrum uncertainty can be easily obtained by computing the difference between the incident A-weighted sound levels and the A-weighted sound levels effective when the HPD is worn, over all the noise of NIOSH 100 database of industrial noise spectra [5].

2.2 Spectrum uncertainty budget

In the field, when a FAES is used, the calculation of the spectrum uncertainty has to be performed for every HPD attenuation estimation. This can be rather computationally intensive and it also requires that the FAES used do actually provide attenuation estimates at two or more octave-band frequencies.

It is therefore proposed in this study to "budget" for such spectrum uncertainty value, by computing for every type of HPD, a conservative -but representative- value of spectrum uncertainty. For this reason, attenuation values of representative HPD samples, measured in laboratory

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conditions and listed in the Hearing Protector Device Compendium Database.

The exact method used for the offline computation has been presented in [6] and is reused in the present study, for roll-down foam, pre-molded, formable, semi-inserts and earmuffs, as well as two other categories of hearing protectors: the custom molded earplugs and the push-to-fit earplugs. Consequently some FAES system with limited signal processing resources or with a measurement method that does not provide at least two octave-band attenuation values, may not have the ability to compute the spectrum uncertainty associated with the PAR of the HPD under test.

3 Results

These cumulative distributions of spectrum uncertainty are computed using Matlab (Mathworks, Natick, MA, USA) scientific programming software for a total of 353 HPDs: the 33 semi-insert, the 42 pre-molded earplugs, the 66 foam earplugs, and the 245 earmuffs present in the NIOSH Hearing Protector Device Compendium Database (while the total number of records from the NIOSH database was actually 386, due to tests reported for multiple position there were 340 distinct products), together with 7 custom-molded earplugs and 6 push-to-fit earplugs added by the author from the most recent online version of the NIOSH HPD Compendium. These distributions are plotted in Fig.1, on a range of 0 to 5 dB. Descriptive statistics have also been obtained on the different values of spectrum uncertainty computed for the various types of HPDs and are presented in Table 1.

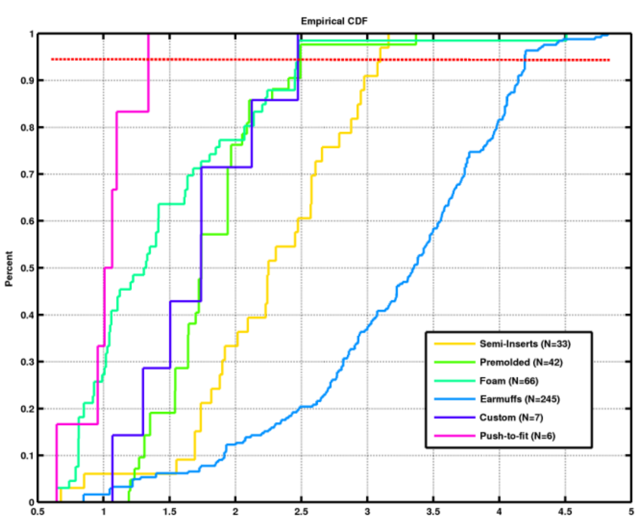

Figure 1: Empirical cumulative distribution function of the spectrum uncertainty computed for each of the six types of HPDs.

It can been seen from Fig. 1 that the spectrum uncertainty value for 353 HPDs representative of current product on the market is ranging from 0.4 dB to 4.8 dB. This upper value seems to be sometimes driven by only a few product samples within one type of HPDs. It is therefore proposed to express the spectrum uncertainty budget, i.e. by using the 95th percentile value of the cumulative empirical distributions plotted in Fig. 1. From the empirical distribution values, the 95th percentile value of the spectrum uncertainty, represented by a red horizontal line in Fig.1., is respectively of 3.09 dB, 2.49 dB, 2.48 dB, 4.19 dB, 2.47 dB, and 1.34 dB for semi-inserts, pre-molded earplugs, roll-down foam earplugs, earmuffs, custom molded earplugs and push-to-fit earplugs.

Table 1: Number of observations and empirical distribution parameter estimates for the spectrum uncertainty data of the different HPD types.

HPD Type	Semi-Inserts	Pre-molded	Foam	Earmuffs	Custom	Push-to-Fit
N	33	42	66	245	7	6
min	0.68	1.19	0.65	0.85	1.07	0.65
max	3.16	3.37	4.51	4.82	2.47	1.34
mean	2.26	1.82	1.45	3.18	1.71	1.02
median	2.25	1.74	1.32	3.35	1.74	1.04
std deviation	0.61	0.43	0.68	0.87	0.48	0.23
90th percentile	3.00	2.43	2.45	4.14	2.40	1.32
95th percentile	3.09	2.49	2.48	4.19	2.47	1.34

4 Conclusions

The study included a detailed spectrum uncertainty budget for the various categories of earplugs (roll-down foam, pre-molded, formable, custom molded, push-to-fit, etc.), semi-inserts and earmuffs. These values have been expressed at the 95th percentile for a direct use in the upcoming ANSI S12.71 standard and will be useful for FAES that cannot perform the computationally intensive octave-band calculation of PAR spectrum uncertainty.

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