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HEARING PROTECTOR FIT TESTING AND THE NEW ANSI S12.71 STANDARD

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Individual hearing protection devices (HPD) are often the first line of defense against noise-induced hearing loss (NIHL) in the workplace. Unfortunately, the real-world attenuation offered by HPDs greatly differs from the laboratory ratings, for many reasons that are now well understood. Mostly, these are related to the proper fit of a given HPD by an individual user. To better assess this fit and predict the effective individual attenuation, Field Attenuation Estimation Systems (FAES) have been developed over the years and are now being used more and more frequently in Hearing Loss Prevention Programs (HLPP). Nevertheless, all FAES do not rely on the same measurement paradigms, nor do they imply the same hardware and, as with any measurement system, the intrinsic measurement uncertainty will differ from one FAES to another. The new ANSI S12.71 standard, which took a few years to complete, addresses this issue by specifying how such measurement uncertainty should be calculated and what the associated experimental validations are. This paper summarizes the main concepts developed within the ANSI S12.71 standard and will discuss the future of FAES and fit testing in an effort to stop the ongoing epidemic of NIHL.

1. Introduction

There are many types of hearing protection devices (HPD), as presented in Fig. 1, but there used to be essentially one procedure to measure their attenuation: the real-ear attenuation at threshold (REAT) method. This method for measuring the hearing protector attenuation achieved by groups of test subjects in a laboratory setting has been described in many standards over the years, the most recent embodiment of which is ANSI/ASA S12.6 [1]. Data from that method have been commonly used for rating and labeling the noise attenuation of hearing protection devices (HPDs). However, the laboratory method does not address a key question, namely, "What amount of protection can, or is, a given individual actually getting from his/her HPD?" To do so, manufacturers have developed a variety of Field Attenuation Estimation Systems (FAES), colloquially referred to as "fit-test systems" that can be used for measurements at the workplace. What has been lacking up to 2018 was a national standard that provides guidance on standardizing important performance aspects and data outputs from the various FAES in order to facilitate selection of systems, comparison of their performance and application of the test results.

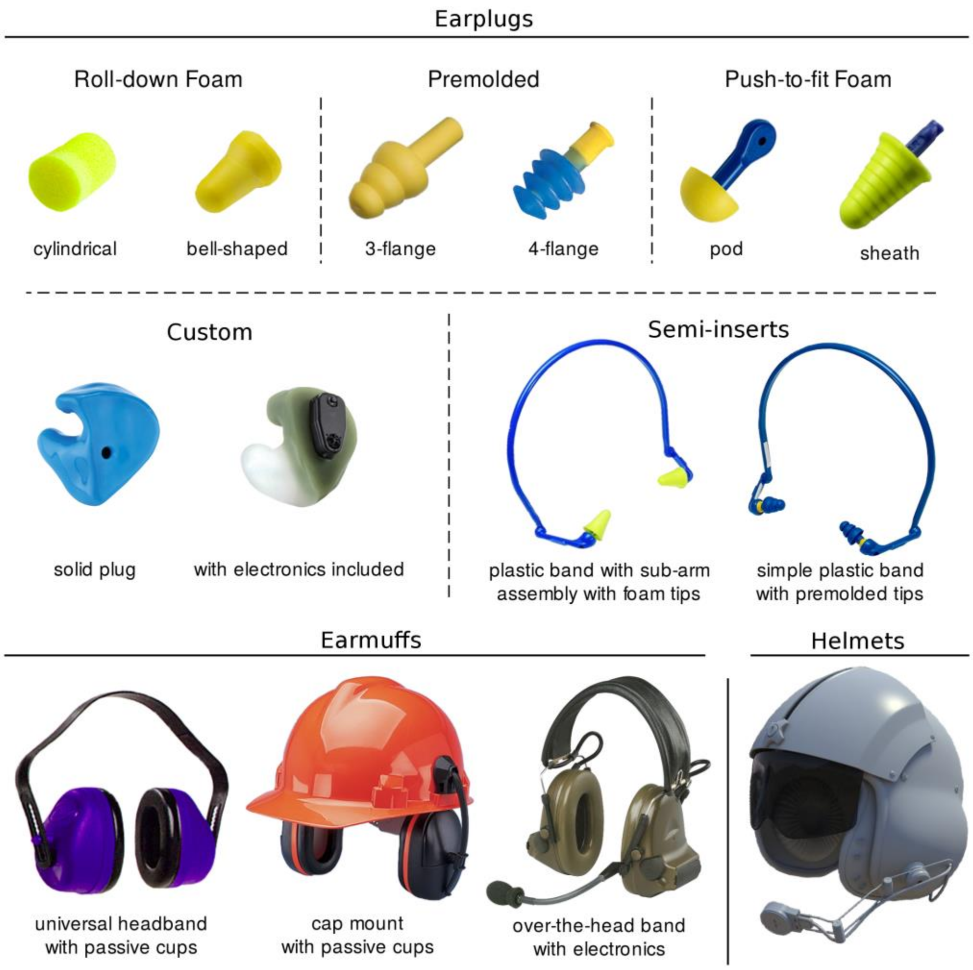

Figure 1: The various categories of HPDs (adapted from [2]).

2. Why NRR is "not really relevant"?

As summarised in [2], the apparent importance of HPD attenuation values received from REAT data of test subjects was substantially emphasised by the advent of the Noise Reduction Rating [3] and the accuracy and simplicity that it seemed to provide. As a result, manufacturers of hearing protectors highlighted the NRR and a battle of numbers ensued. The Occupational Safety and Health Administration (OSHA) enforced the position of the NNR by including it as the preferred method for assessing HPD adequacy for compliance into the Hearing Conservation Amendment [4]. In many instances, additional key parameters of performance were overlooked in favour of choosing the HPD with the highest NRR. This contributed to wearer dissatisfaction and consequent misuse, or even non-use, resulting in inadequate protection.

A further concern that arose regarding HPD attenuation was to answer a natural and seemingly straightforward question on how much noise reduction hearing protectors can really provide. Regrettably, this hasn't been easy [5], and the application of optimum-performance laboratory data has not provided a useful solution. Consequently, the NRR that is computed from such data is generally acknowledged to provide little effective guidance in the selection and specification of hearing protection [6]. In fact, it can be said with only slight exaggeration that perhaps the principal value in the NRR is that it indicates the product, which has been designed and tested for noise reduction [6].

3. HPD fit testing: an old new idea

Historically, the best of the laboratory procedures [6] were modified to reduce costs, improve portability and ruggedness, and were utilized under field conditions to estimate the amount of attenuation provided by HPDs in actual use [7]. The procedure that was first successfully applied to test both earplugs and earmuffs under field conditions was REAT conducted in a sound field produced in a smaller acoustical chamber than the one used in laboratory testing. For earplugs, earphones mounted inside large circumaural cups instead of loudspeakers in a chamber have also been used to measure earplug attenuation in a similar manner [8], and for earmuffs, the microphone-in-real-ear (MIRE) procedure was used with microphones mounted on the inside and outside of earmuffs [9]. These field -attenuation measurement procedures have been useful for research purposes and have revealed the significant difference in HPD attenuation obtained by users in the field versus test subjects in the laboratory. Based on the field measurement systems previously developed, mostly for research purposes, commercial systems have more recently been made available to answer the pressing question within the hearing conservation community, specifying the amount of protection that a wearer gets from his/her HPD [10]. It is worth while mentioning that the term fit testing, as it is used in this article, refers to the process of conducting a measurement in order to estimate the acoustic attenuation of a given HPD, as for example would be measured according to ANSI/ASA S12.6-2016.

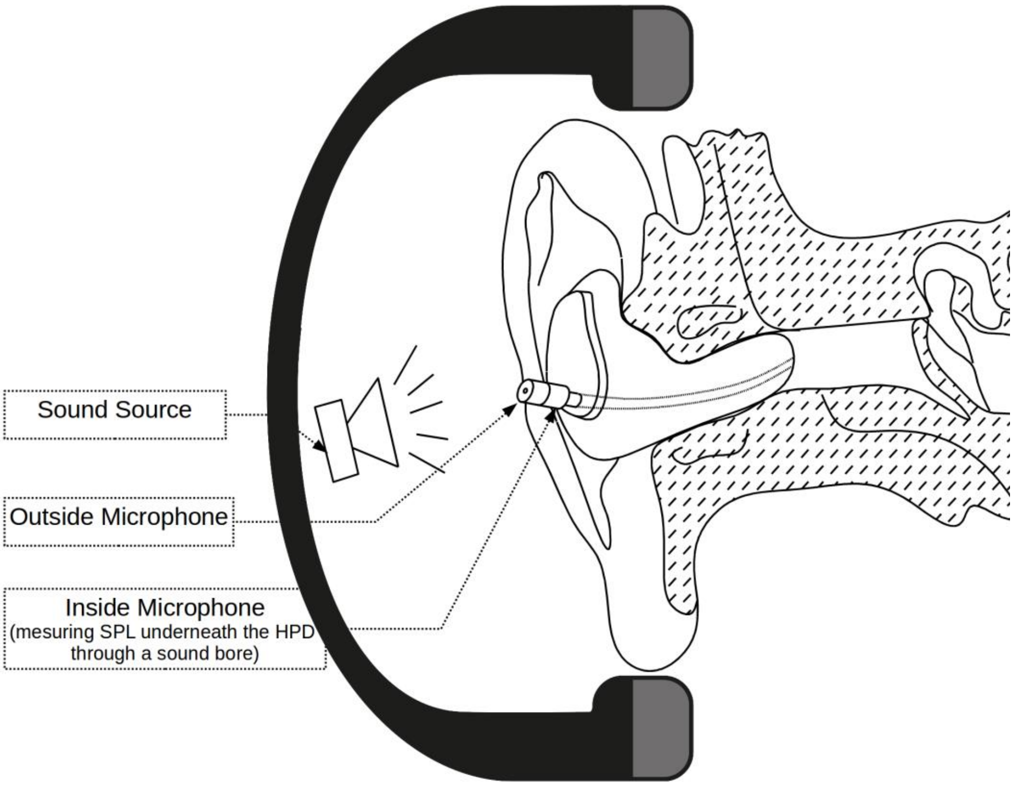

Figure 2: Illustration of an objective fit-test system using a microphone doublet under earphones to estimate the attenuation of a custom-molded earplug

4. The genesis of ANSI S12.71

The commercial offer of FAES has been rapidly increasing since the early 2000's and it could be foreseen that, because of the wide range of technologies used, a standard would be needed to ensure precision and accuracy of FAES measurement outcomes. In February 2008, a request to the Secretariat for Accredited Standards Committees S12 on Noise, through the Acoustical Society of America (ASA) was made by the author that a new standard be written to address that specific issue. The American National Standards Institute (ANSI) accepted the request and in March 2008 triggered a project initiation notification, assigning the Accredited Standards Committee S12 on Noise, in the development of a national standard, referenced ASA/BSR S12.71-2018 that can be used to systematize and compare the various FAES to facilitate selection of systems and application of the test results.

The Working Group S12/WG 11, Hearing Protector Attenuation and Performance, chaired by E.H. Berger assisted the Committee and met for the first time in February 2010 to discuss the first draft prepared by E.H. Berger and J.Voix and subsequently entitled "Performance criteria for systems designed to estimate the attenuation obtained by individual users of passive hearing protectors" [11]. Today's adopted standard is entitled "Performance criteria for systems that estimate the attenuation of passive hearing protectors for individual users" and is further described in the next section.

5. ANSI S12.71: What's in it for me?

The ANSI S12.71 standard specifies minimum performance criteria for systems intended to estimate the real-ear attenuation provided by HPDs on individual users. The performance criteria are intended to assure that FAES complying with this standard provide comparable test results to a reference laboratory procedure. Accuracy and precision are assessed by comparison of FAES data to those from the REAT standard laboratory procedure (ANSI, 2008) for the same fit of the device on an identical group of test subjects. This standard is intended to provide guidance to manufacturers of FAES in terms of the development of systems and specification of their performance in a standardized manner. A further goal is to assure that FAES provide data that are both useful for estimates of the attenuation obtained by individual users and are comparable between systems. The standard also determines the procedures for computation of a Personal Attenuation Rating (PAR) that provides a simple easy-to-apply single number that may be used for hearing protector assignment. As mentioned earlier, FAES-derived data do not replace the attenuation data from ANSI/ASA S12.6 or the insertion-loss data from ANSI/ASA S12.42 [12], nor are such data suitable for use as input data for ANSI/ASA S12.68 [13]. Furthermore, such FAES data are not appropriate for labeling the attenuation of HPDs.

5.1 FAES measurement uncertainty

FAESs may be used to train an employee to better fit his/her HPD, and also to train the trainer in that process. However, users may also wish to apply FAES results together with an organization's noise‑exposure policies to estimate whether a worker is obtaining adequate protection from existing HPDs, or to assign HPDs based upon noise exposures. Though there currently exist some FAES that can estimate the attenuation provided by earmuffs, the usual focus of FAES is the measurement of earplug performance. This is not only because correct fit and insertion of most earplugs requires more skill and is more variable than for earmuffs, and therefore more in need of assessment, but also because for most FAES, personal attenuation can be more readily estimated for earplugs than for earmuffs. Earplug assessments can be accomplished, as illustrated in Fig. 2, by using a circumaurally-mounted transducer to present a test signal, which is of course not possible when earmuffs are to be tested.

Proper application of estimated noise attenuation requires a further consideration, namely, the specification of uncertainty. Measurement uncertainty may differ between the various systems. For the end user to properly apply the FAES data, an explicit statement of the uncertainty must be provided. Good measurement practice (where a measurement is understood to consist of the measurement itself, its margin of error, and the confidence level - that is, the probability that the measurand is within the margin of error), dictates the provision of such uncertainty estimates. Uncertainty values are needed, not only for proper application of the FAES data, but also to facilitate a comparison of the precision and accuracy of differing FAES.

There are three presumed-independent principal sources of uncertainty to be considered in the computation of PAR from measured FAES data [14].

• Measurement uncertainty, sometimes called prediction uncertainty, pertains to the difference between the FAES prediction of attenuation and the value that would be measured for the same fit of the HPD by an accepted “gold standard,” such as REAT per ANSI/ASA S12.6. Since REAT values contain their own uncertainty, a correction to the computation is included to account for this.

• Fit uncertainty pertains to the variability in the fit of the HPD from one application to the next. It is substantially affected by the experimenter or user’s skill, depending on whether experimenter or user fit is being assessed, and also by the fitting characteristics of the HPD that is being evaluated.

• Spectral uncertainty arises from using a PAR designed for subtraction from A-weighted sound level measurements in noises with different spectral content. There will be a variation between the protection predicted when using an octave-band calculation versus that achieved with a single-number approach (see ANSI/ASA S12.68).

The ANSI S12.71 standard specifies the method of computation of the three principal sources of uncertainty and how to integrate that into the calculation of PAR. For systems that employ a surrogate HPD (an HPD modified to support the FAES instruments), an additional source of potential error may be introduced by the use of a surrogate. This is addressed in the standard too.

For those systems that do not provide a PAR, but rather a pass/fail indication for use in a specified noise environment, this standard specifies suitable statistics that shall be reported to provide guidance on the uncertainty associated with the pass/fail determination.

5.2 Personal Attenuation Rating (PAR)

FAES generally provide data in terms of a single-number personal attenuation rating (PAR). A PAR is computed for one or more fits of the HPD by an individual in a manner similar to the computation of the manufacturers’ labeled attenuation values that are derived from laboratory test data for groups of subjects. Examples of labeled values are the NRR as required by the U.S. Environmental Protection Agency as of 1979 and the Noise Reduction Statistic for use with A-weighting (NRS_A) as specified in ANSI/ASA S12.68. Although the various FAES have the same purpose and produce attenuation values that are presented in similar ways to one another, the underlying technologies, used to estimate attenuation and compute PARs, can differ dramatically. It can range from psychophysical tests to objective microphone measurements (as illustrated in Fig. 2), and from systems that calculate PAR in a manner analogous to the NRS_A as defined in ANSI/ASA S12.68, to others that simply indicate a pass/fail answer based on achieving a minimum required attenuation value. The various types of FAES are described and categorized in the ANSI S12.71 standard. While the term “personal attenuation rating” may have been used in the past by some authors to describe individual attenuation ratings achieved by various computational methods, the PAR standardized within ANSI S12.71 inherits its computational details from NRS_A [15]. The subtle differences in the PAR and NRS_A computations stem from the fact that the PAR is based on the data from one subject while the NRS_A is based on group data from multiple subjects. One unique feature of the NRS_A, as compared to the well-known NRR and most other single number ratings, is that it is presented as two numbers, an 80th and 20th percentile value, which define a range of performance to be expected for a given individual. Those values are intended for subtraction from A-weighted noise measurements instead of requiring the use of C-weighted values. Some FAES can provide PAR_{80} and PAR_{20} values, and also compute an averaged PAR, referred to as PAR_{50}, that can all be directly subtracted from A-weighted sound levels to estimate protected noise levels or exposures.

PARs are based on measurements at a single point in time and provide a more direct estimate of the protection that a given individual is expected to receive from her or his HPD than does average data from a group of laboratory subjects. The beauty of the PAR is that it requires no field derating. Unlike a laboratory-derived number based on a group of test subjects evaluated under ideal conditions, the only corrections that are applicable to PARs are statistical corrections to account for the uncertainty of the measurement data and noise spectral variation. However, PARs are still not based upon in-situ measurements for actual wearers and the exposures they experience during their work shifts. Thus, PARs reflect what a wearer can achieve and has been shown to achieve, not necessarily what he/she truly achieves on a day-to-day basis.

5.3 FAES vs REAT: What are the differences?

The ANSI S12.71 standard describes and categorizes the types of FAES. Regardless of type, a key performance metric will be comparison of attenuation data estimated via the FAES to the REAT values resulting from ANSI/ASA S12.6. The FAES results may differ from REAT. This is to be assessed and reported in an uncertainty statement. Four additional issues that impact the various types of systems are listed below.

- The ambient noise in the test environment must be low enough to avoid masking psychophysical test signals or contaminating the results from objective systems.
- For systems employing a surrogate HPD, the fitting and usability of the modified HPD must be considered in order to limit its effect on the wearer's ability to fit the surrogate, as compared to the unmodified HPD.
- For systems requiring a psychophysical response, the hearing ability of those being tested must be sufficient to assure that they can hear the signals after attenuation by the HPD under test.
- The rapidity with which the test can be accomplished is also a factor to be considered since this will affect practical application of the FAES and also the ability to address and potentially ameliorate the problem of fit uncertainty by taking repeat measurements on repeated fits. Objective systems may provide more rapid data acquisition.

6. And now?

The positive impact of fit testing in the efforts to reduce noise-induced hearing loss in the workplace is now widely documented in a variety of industries and across different territories [16]–[19]. For these reasons, the use of fit testing is now becoming increasingly accepted in HLPPs such as by many of the award-winning hearing loss prevention programs which have been recognized with the NIOSH/NHCA Safe-in-Sound award [20]. Furthermore, the OSHA‑NHCA‑NIOSH Alliance has identified individual fit testing as an emerging trend and best practice [21]. Other regulatory initiatives are currently underway around the globe as countries are considering including fit testing as best practice in hearing protection use standards and guidance documents. Currently, individual fit testing is incorporated within the standards on hearing conservation and the selection of HPDs in the U.S., Canada, and Europe (ANSI/ASSE A10.46, 2013; CSA Z94.2, 2014; CSA Z1007 2016; EN 458, 2015). Furthermore the U. S. military has recognized the importance of fit testing by including recommendations to fit test when feasible (Mil Standard 1474E Section 4.2.1.1, DoD, 2015) and in the case of the Army, when STSs are detected (Department of the Army, Pamphlet 40–501, 2015). In addition, several countries, including Germany, are planning or have already included fit testing in upcoming revisions to existing standards and requirements.

Individual fit testing of hearing protection represents HLPP best practice in the early 21st century, and is a valuable step toward the goal of preventing occupational noise-induced hearing loss. It is therefore excellent news that the ANSI S12.71 got adopted in United States in 2018, as it definitely helps refine and frame the use of individual fit testing in an effort to stop the ongoing epidemic of NIHL.

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