

THE OPPORTUNITIES AND CHALLENGES OF IN-EAR NOISE DOSIMETRY

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1 Introduction

Most industry employers are required to follow certain regulations when it comes to protecting their employees from Noise Induced Hearing Loss (NIHL). Although ideally, noise reduction measures should be directly applied to the damaging noise sources by reducing their acoustic emission below acceptable limits, these mitigations are often unrealizable for practical or economical reasons. Hearing Protection Devices (HPDs) then become the only option left to prevent the effects of noise overexposure. Yet despite a huge choice of HPDs, their performance is not guaranteed as it mostly depends on how well they are adapted to a particular worker's situation. A compliant HPD model should offer sufficient attenuation while leaving unaltered speech and communication signals, when possible. Overprotection should be avoided, as it may lead the worker to remove his HPD to better communicate and, thus, decrease its performance drastically [1]. To help in the selection process, it is therefore essential that each worker's individual noise exposure be precisely known when wearing a particular HPD model, which is rarely the case. In fact, noise exposure is generally computed from combined measurements of the unprotected noise levels and the attenuation of the HPDs, although the latter is subject to significant intra- and inter-subject variability [2]. After a short review of the existing methods for HPD attenuation measurement and individual noise exposure assessment, this paper will focus on the new emerging in-ear dosimetry approach. The benefits and opportunities of such method will be described together with its challenges with regard to hearing-loss prevention.

2 Review of existing methods

2.1 Measurement of HPD attenuation

HPDs are typically characterized by attenuation ratings that rely on measurements performed under well-controlled laboratory conditions. Those measurements can use subjective methods such as the real-attenuation-at-threshold (REAT) procedure, or objective techniques like the microphone-in-real-ear (MIRE) method. Unfortunately, these are known to fail at predicting the HPD performance in the real-world work environment [2], which encouraged the emergence of so-called Field Attenuation Estimation Systems (FAES) [3]. Considering various quality factors (speed, accuracy, repeatability and practicality), it is a modified MIRE method, termed field MIRE (F-MIRE) [4], that appears like the best current compromise to evaluate the in-field performance of HPDs.

Yet despite the progress achieved with field measurement technologies, some uncertainties remain as all of the above methods rest on timely measurements that generally fail to account for poor re-insertion, HPD removal or even potential loss of acoustic seal over time [3]. The real-world HPD attenuation is hence expected to deviate from these well-controlled measures, which was confirmed by findings looking at the effective daily protection as a function of time during work shifts [2]. Future research should also address the need for fully individualized attenuation data, which could be computed on the basis of an identification function for each particular subject's ear dimensions [4].

2.2 Measurement of Individual Noise Exposure

When the effective protected noise levels (those actually received at the subject's eardrum) cannot be measured directly, the tracking of individual noise exposure requires the knowledge of both the attenuation and the unprotected levels. The unprotected noise exposure varies based on environmental factors and can be measured effectively using personal dosimeters (body-worn derivatives of integrating sound level meters), although errors due to placement effects can be quite significant in a directional field [5]. But the main obstacle to individual noise exposure assessment arises from the difficulties in measuring the HPD attenuation. It is to circumvent this problem that later works have been focusing in measuring the effective (protected) noise exposure rather than the unprotected noise levels.

An in-ear dosimetry system, the QuietDose, was commercialized by Sperian Protection following their 2008 acquisition of doseBusters™ USA. This consists of a generic eartip adapter with an integrated miniature microphone that inserts into compatible eartips and connected to a dosimeter. When the HPD is being worn, the dosimeter measures the protected level and when removed, the microphone continues to measure the level of exposure (unprotected). Such device appears to take into account the performance of the protector as well as proper fit, but does not provide any insight as to why a particular worker is over his dose as it gives little information regarding the exposure level when the HPD is worn. Furthermore, the convenience of this system is hampered by the necessity of downloading the exposure data at the end of the day.

This lack of real-time data was then overcome by some of the authors of this paper with the development of a smart earplug with integrated in-ear dosimetry [6], which also benefits from a microphone doublet; one microphone measures the sound reaching the outer part of the HPD while the other is attached to a sound bore that travels through the earplug and monitors the protected noise levels.

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3 Aspects relating to In-Ear Noise Dosimetry

3.1 A promising avenue

Those recent technologies, along with the miniaturization of electronics during the last decade, are a clear step towards more intuitive approaches for assessing individual noise exposure. While previous methods aimed in the prediction of personal exposure based on misrepresentative HPDs ratings, in-ear noise dosimetry can ensure compliance with safety regulations through an ‘upstream’ control of the effective noise dose received by the employee.

Besides, the monitoring of the unprotected noise levels that comes with the latest instrumentation available [6], added to the protected noise levels, should permit to gather indications as to why a particular worker is overexposed (unusually noisy equipment, sound field spectral balance, HPD removal or poor fit, insufficient HPD attenuation, etc.) and help improving the effectiveness of HPDs.

3.2 Challenges with regard to NIHL prevention

NIHL has been studied as far as the 1700’s but remains challenging because of the extreme complexity of the human auditory system, and it is beyond the scope of the proposed research project to go through the biological factors that may drive phenomena like individual susceptibility. Nevertheless, we have identified three main elements of on-going research that are to be considered when using in-ear noise dosimetry to prevent NIHL by limiting the received noise dose of a given individual.

The first research element concerns the acoustical corrections due to the Transfer Function of the Open Ear (TFOE), as well as the Occluded Ear Canal Resonance and Probe tube Effect (OER). The TFOE represents the amplification of the sound pressure caused by the resonance in the open ear canal, which varies with the geometry of the human head, torso, pinna, and shape of ear canal as well as eardrum impedance. The OER is mostly dependent on the length of the probe tube through the HPD and the length of the residual part of ear canal between earplug and eardrum. These correction factors, which are both dependent on the user’s morphology, are essential for comparison with noise regulations since most noise criteria are expressed as free-field values. Estimates such as those measured on a head and torso simulator have already been used [6], but future instrumentation would benefit from individualized factors that can take the high variability of the mentioned ear characteristics into account. An analytic model was developed as part of this study that uses the geometry given by Stinson [7] to calculate individual correction factors based on ear dimensions. This showed encouraging results, but the search for a practical method to identify the main parameters used in this model remains a major challenge.

The second research element deals with the noise induced by the user himself, which was clearly identified by several authors as a dominant sound source in medium-level noise environment [2] [6]. This can be caused either by low-frequency noise generated by movements from the wearer or by his own voice that directly contributes to the recorded noise levels. An automatic detection method is currently

under investigation to discriminate such time events. This method could use some of the algorithms used as part of the development of a Voice Activity Detector that can operate in low signal-to-noise situations [8].

Finally, some researchers have raised questions about the potential influence of ear occlusion on noise susceptibility. According to Theis et al. [9], “human subject data is extremely important in developing and validating calibration factors for any type of noise dosimeter but particularly so for in-ear dosimetry”. This statement comes along with data supporting the idea that in-ear dosimetry overestimates the noise dose. To verify this finding, further studies will be undertaken involving loudness-balance tests performed on a group of human subjects.

4 Conclusions

Despite the great advantages that in-ear dosimetry systems can offer for hearing conservation, progress is to be made with regard to the acoustical corrections needed to relate noise measured in the occluded ear to risks of hearing loss.

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