

IN-EAR NOISE DOSIMETRY: FIELD METHOD USING EARMUFFS' NOISE REDUCTION

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1 Introduction

Precisely assessing the noise dose reaching the eardrum is key for proper hearing loss prevention program (HLPP). However, measuring this dose under hearing protection devices (HPD) is complex, especially for earmuffs, due to (1) their difficult instrumentation especially when considering the placement of the microphone under the HPD, (2) measurements artefacts - referred to as wearer's induced disturbances (WID) - that adds noise to the in-ear microphone (IEM) measurements [1] and (3) the necessity to precisely estimate individualized acoustic corrections. Such issues were addressed in previous studies that aimed either to remove WIDs [1] or to neglect their contribution on earplugs [2]. The proposed method designed for earmuffs will predict the noise dose at the eardrum based on continuous measurements of noise reduction (NR) through the earcup and measurement from the outer-ear microphones (OEM) only.

2 Method

The proposed approach aims to address the three aforementioned issues by relying on sound pressure measurements outside the earcanal to make the WIDs contributions negligible. Thus, it relies on the estimation of four acoustic transfer functions (TF) in order to determine an individualized insertion loss (IL) : the transfer function of the open ear (TFOE), the noise reduction NR^* , the external transfer function TF'_{ext} and the transfer function of the earcanal TF'_{canal} .

$$IL = 20 \log_{10} \left(\frac{p_t}{p'_t} \right) = L_{p_t} - L'_{p_t} \quad (1)$$

The necessary measurement locations are showed on Fig. 1 (top). The prime symbol ("'") indicates that the measurement is done with worn earmuffs. L_{p_0} is the sound pressure level (SPL) measured without the head being present. These TFs illustrate the link between the SPLs measured at the eardrum while the hearing protector is worn and the SPL L_{p_0} . It is illustrated in Fig. 1 (bottom) and can be written as follow :

$$IL = NR^* + TFOE + TF'_{canal} - TF'_{ext} \quad (2)$$

The proposed approach is detailed in the flowchart of Fig. 2. The *first step* consists in assessing three TFs for calibration purposes. First, the TFOE, specific to the wearer, needs to be assessed. On top of classical microphone in real ear (MIRE) method, several alternatives are possible

[3–5]. Second, the TF'_{canal} , which is wearer specific, depends mostly on the earcanal geometry [6]. This function can be estimated using finite element methods (FEM) that allow to evaluate easily several ear canal geometries and vary the microphone placement [7]. Third, the TF'_{ext} depends on the precise position of the OEM. The estimate of this function and its variability can be measured once for each specific model of HPD.

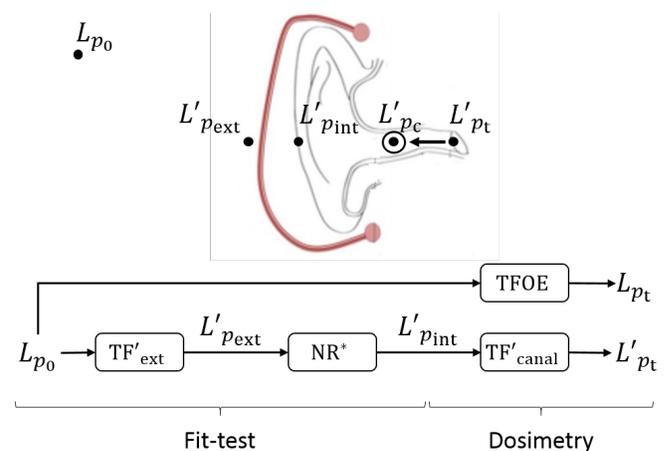


Figure 1 – Sound pressure level measurement locations of the proposed approach (top). The circled dot represents the alternate position used in the experimental validation. Transfer functions used to compute the effective sound pressure level at the eardrum L'_{p_t} as well as the insertion loss (bottom).

The *second step* consists in using the optimal microphone pair (see recommendation from [8]) to estimate the NR^* and define a baseline specific to the evaluated earmuff. This function serves as reference for real-time measurement of the attenuation. The calculated uncertainties are used to define two error factors : NR_{min} and Δ_{th} . The first factor is used in the *third step* to ensure that the attenuation is sufficient in all frequency bands. This step is also used to monitor the fit of the earmuff (fit-test) and warn the wearer if needed. The *fourth step* calculates the difference between the baseline and the measured attenuation. This difference is compared to the threshold Δ_{th} . When above this threshold it is necessary to assess whether this difference is due to WIDs contribution. If so, the method developed by [1] to remove such energetic contributions can be used. In the *fifth step*, when no WIDs are detected, the noise reduction estimate NR^* is updated. Finally, the precise noise dose under HPD can be calculated from the accumulated values of L'_{p_t} in the *sixth step*. The steps 3 to 6 are looped and allow for the continuous estimation and monitoring of the NR^* , while the estimation of L'_{p_t} enables the calculation of the noise dose under the earmuff.

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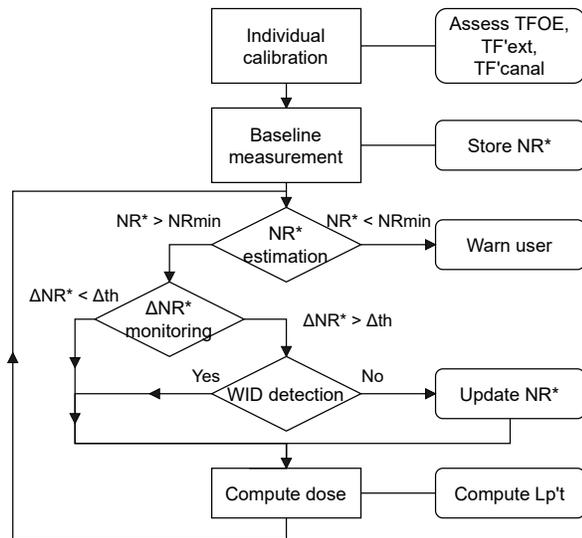


Figure 2 – Flowchart of the proposed approach, L'_{pt} from continuously updated values of NR^*

All SPLs measurements and TF assessment previously described were conducted on the Optime 98 earmuffs (3M, U.S.A.) on 23 participants, in both free-field and diffuse-field, and under three conditions [8].

3 Results

Fig. 3 shows the mean and standard deviations (STD) of the noise reduction NR^* for the optimal microphone pair (identified as the one giving the smallest STDs over all evaluated pairs in [8]).

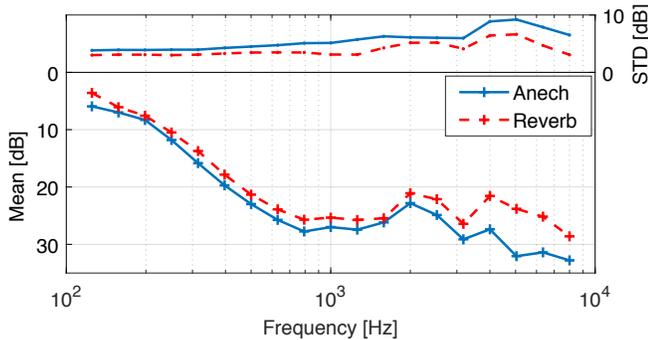


Figure 3 – Mean and standard deviation values of the NR^* measured on 23 human participants in diffuse-field (reverberant chamber in red) and in free-field under 24 incidences (anechoic chamber in blue)

Fig. 4 presents the insertion loss, IL^* , calculated based on the following equation 3 :

$$IL^* = NR^* + TFOE^* + TF'^*_{canal} - TF'_{ext} \quad (3)$$

The " " symbol used for IL^* , TF'^*_{canal} and $TFOE^*$ indicates that one of the required measurement is not located at the eardrum (see circled dot in Fig. 1). All TFs in equation 3 are computed based on the same dataset used for the fourth required TF plotted in Fig. 3.

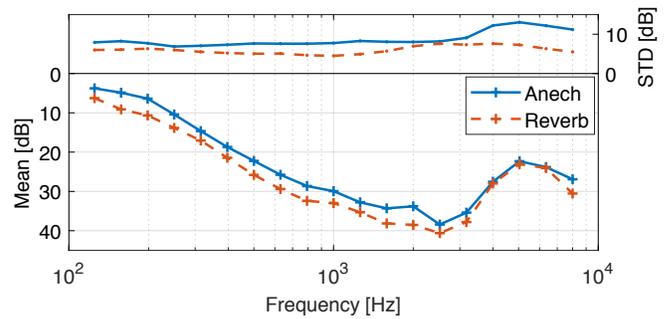


Figure 4 – Mean and standard deviation values of the IL^* computed from the four transfer functions based on equation 3 in both acoustic fields.

4 Discussion and conclusions

While the proposed method, relying on the assessment of the noise dose at the eardrum based on continuous microphone measurements outside the HPD has already been done for earplugs [2], the proposed adaptation for earmuffs was validated off line from experimental measurements conducted on 23 human subjects. The validation confirmed that on the one hand, NR^* measurements showed on Fig. 3 should enable the definition of the baseline (see Fig. 2) while the STDs will help in defining the NR_{min} and Δ_{th} factors. On the other hand, this validation showed that the indicator IL^* computed from equation 3 would give promising results with regards to estimating the noise dose at the eardrum under earmuffs, pending that some individual acoustic correction could be determined from FEM models.

Acknowledgments

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