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**Noise**

**Session 1pNSa: Advanced Hearing Protection and Methods of Measurement II**

**1pNSa9. Estimation of noise exposure level for subjects wearing hearing protector devices**

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Industrial workers are exposed to noise levels that could damage their hearing. The FieldMIRE (FMIRE) method has been developed to quantify earplug and earmuff attenuations with two microphones located under and outside of the HPD. This technique has been designed to be used in the field, but doesn't give a direct access to the noise exposure level, that is, the noise level at the head location without the subject. In this article we present a combination of the FMIRE method with a proposed technique to estimate the sound pressure level without subject, in order to quantify both the ambient and protected noise exposure levels and deduce the effects on worker hearing. Several experiments have been conducted on four subjects with three types of earplugs and with five types of earmuffs. Firstly, the best location for the microphone outside of the HPD has been determined. Secondly, correction factors that need to be applied on the outside microphone measurement to estimate the sound pressure level without subject have been quantified. Finally the proposed technique has been validated with measurements taken in a simulated workplace.

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## INTRODUCTION

Hearing protection devices (HPD) attenuations are traditionally quantified in laboratory with subjective or objective measurements in a diffuse field according to ANSI S12.6 [1]. These laboratory measurements are most often not representative of reality in the field (see for example [2]). Moreover, sound field of various types are present in industrial workplaces [3]. The Field-MIRE (F-MIRE) technique, developed to quantify the HPD attenuation in laboratory or in the field [4] is more and more used with the increase popularity of individual fit testing and miniaturization of electronic components and microphones [4, 5, 6]. The technique uses two microphones to measure simultaneously the sound pressure level (SPL) under the HPD and outside of it. The outside microphone location is then of first importance not only to optimally quantify the attenuation of HPDs but also to get an estimate of the sound field experienced by a worker when used in industrial conditions. It is therefore necessary to understand well how this exterior microphone is affected by the sound field and by its location near the ear or near the protector.

In previous studies [7, 8], the present authors focused first on earmuffs. Experiments were first realized in laboratory in a diffuse field in a reverberant room and in a free field in an anechoic room. This study allowed to determine an "optimal" outside microphone location for earmuffs and to propose a correction factor function to apply to this SPL measurement allowing to obtain an estimate of the SPL without subject. These results were validated in a simulated workplace in the second paper [8]. Encouraging results were obtained. The estimated SPL results without subject were satisfactory within a  $\pm 2$  dB range.

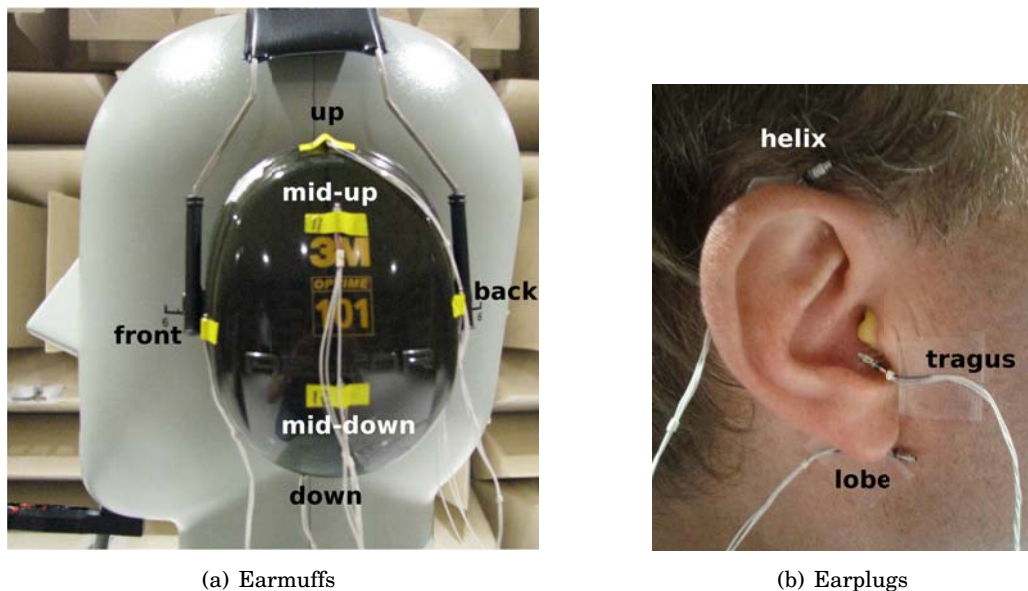
In the present paper, the same procedure was used on earplugs and results for both types of HPD are presented here. The first part presents the methodology. In a first set of experiments, one are interested in determining the optimal location for the outside microphone for hearing protection devices (HPD) for both earmuffs and earplugs. This series of tests allowed to propose simple scheme and approximation to estimate the sound pressure level without the subject from measurements made with the outside microphones positioned near the HPD. In a second set of experiments, a workplace was simulated and measurements were performed to verify if the approximation proposed in the first part gives satisfactory results when used in more realistic conditions. The second part present the results for earmuffs and earplugs.

## METHODS

### Location of the microphone outside of the HPD

The main objective was to investigate the variation of the sound field measured by a microphone positioned near a hearing protection device (earmuffs or earplugs) in order to better understand how to use this particular microphone for: i) noise exposure estimate; ii) F-MIRE attenuation measurements. In the case of earmuffs, a paper summarizing the main findings of a study conducted in a laboratory was presented by the authors in 2011 [7]. Tests were conducted in a diffuse field in a reverberant room and in a free field in a semi-anechoic room on 4 subjects with 5 different earmuffs (EAR 1000, Peltor Optime 95, Peltor Optime 98, Peltor Optime 101 and Peltor Optime 105). In free field conditions, twelve sound directions in the horizontal plane from  $-150^\circ$  to  $180^\circ$  with  $30^\circ$  steps were considered. Six miniature microphones were fixed on each earmuff as illustrated in figure 1(a). The measurements were realized on both ears simultaneously using a pink noise of about 85 dB overall SPL.

In the case of earplugs, similar tests were realized. Three subjects were tested with three different kinds of earplugs: 1 flush earplug (E-A-R Classic), 1 half conch earplug (Sonomax Eers earphones) and 1 full conch earplug (Sonomax SonoCustom). For each earplug, 3 different locations were considered for the outside microphone: 1 at the lobe, 1 at the tragus and 1 at the helix of the ear (see figure 1(b)). As in the case of the earmuffs, the measurements were realized in a diffuse field in a reverberant room and in a free field (12 different sound locations) in a semi-anechoic room with a pink noise.



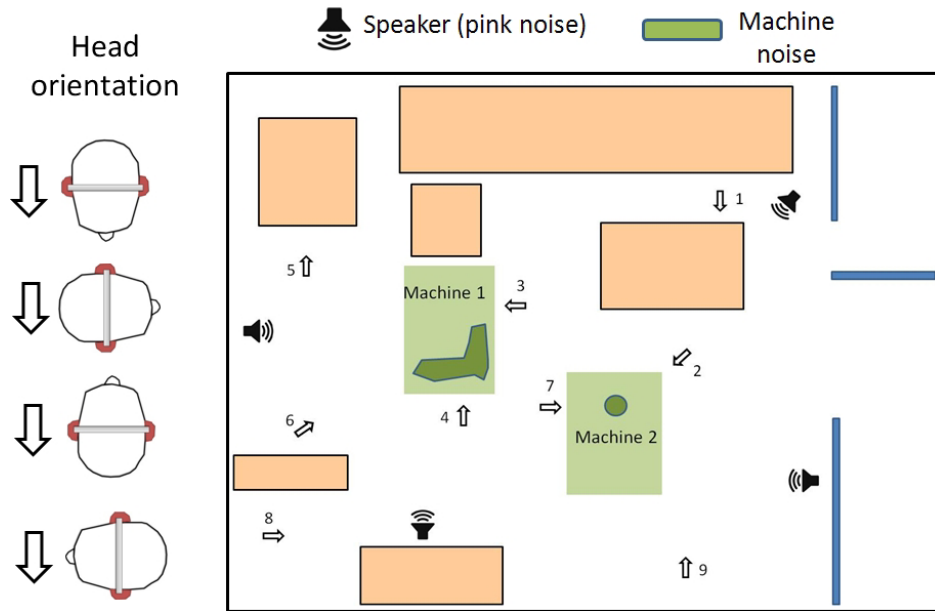
**FIGURE 1:** Different locations of outside microphones for earmuffs (a) and earplugs (b).

In order to study the variation of the sound field measured at the different locations of the outside microphone in both cases (earplugs and earmuffs), the transfer function between the sound pressure level at the microphone location and the sound pressure level at the center of the head without subject is considered and is noted  $TF_{ext}$  [dB] in the paper.

Values of the transfer function  $TF_{ext}$  were then utilized to establish approximations which can be used to estimate the SPL in the absence of the subject from microphones located on or just outside of HPDs. These approximation curves were derived separately for the earmuffs and the earplugs. Such results for the earmuffs were already presented in [8]. These approximation or correction factors are noted  $\Delta$  [dB] in the paper.

### Workplace Simulation

The correction factors  $\Delta$  were established in a laboratory environment using the procedure described in the previous section to measure  $TF_{ext}$  values. To verify if these factors can correctly estimate the SPL values without the head from microphone measurements taken at the ear of HPD in realistic work environments, an industrial workplace was simulated in a mechanical shop as depicted on figure 2. Two machines were running simultaneously and a background sound field was simulated with a pink noise delivered by four speakers located all around the room in such a way that near the machines, the noise contribution from the machines was predominant.



**FIGURE 2:** Overview of the room and speaker setup used for the workplace simulation.

Four subjects of different height were tested with two types of HPD: Peltor Optime 101 earmuff and E-A-R Classic foam earplug. The subjects were asked to stand still at 9 different locations in the room as illustrated on figure 2 with 4 different head orientations (front, right, back and left). A microphone was located on each HPD at locations determined using the  $TF_{ext}$  set of data obtained in the laboratory (see previous section).

One main goal was to apply the proposed correction factor  $\Delta$  to the microphone measurements made on each ear and then compare these estimates to the measurements done without subjects. To do so, all the  $TF_{ext}$  were calculated and the correction factors were applied to them. It was then verified if these "corrected"  $TF_{ext}$  would tend toward a target value of 0 dB with a given tolerance.

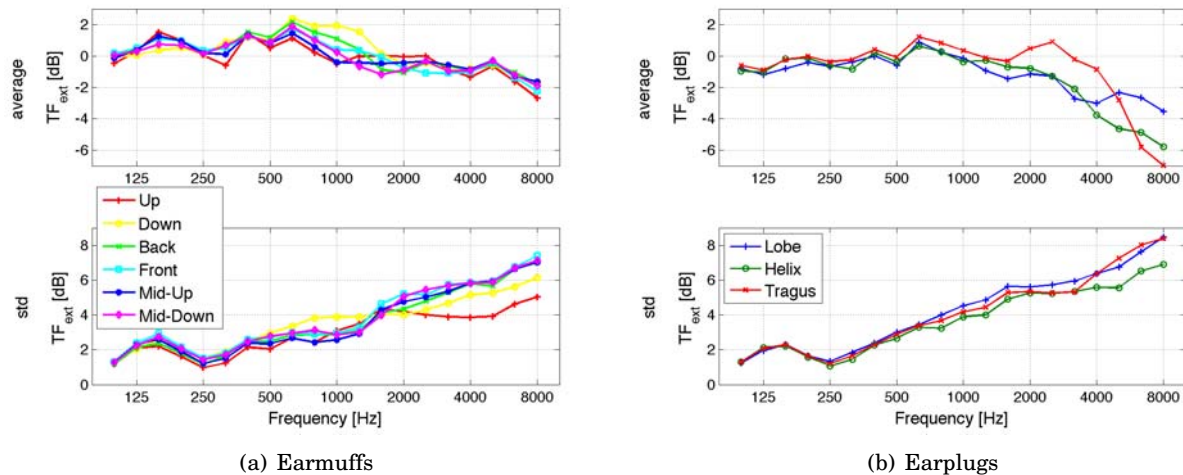
## RESULTS

### Selection of the Outside Microphone Location

The average and standard deviation of  $TF_{ext}$  [dB] in free field for each outside microphone location is presented in figure 3: (a) for earmuffs and (b) for earplugs.

According to figure 3(a), as presented in a previous work [7], the standard deviation of  $TF_{ext}$  for the "up" location of the outside microphone is significantly lower, in particular at high frequencies, than for the other locations. Therefore, this particular location was selected as it seems to be the most suitable to quantify the sound pressure level with less possible deviation.

In the case of earplugs (see figure 3(b)), the standard deviations of  $TF_{ext}$  obtained for each microphone location are mostly the same for the three tested locations. The "lobe" location was chosen for the exterior field measurements as the average  $TF_{ext}$  values are more regular as a function of frequencies. Additionally, the "lobe" location is more practical as it is easier to position the microphone for various types and shapes of earplugs (foam, push-ins, molded, etc.) than at the "tragus" position and does not potentially interfere with safety glasses and/or helmets as in the case of the "helix" position.



**FIGURE 3:** Average and standard deviation of  $TF_{ext}$  in free field for each outside microphone location in the case of earmuffs (a) and earplugs (b).

### Correction Factors to Estimate the Sound Pressure Level Without Subject

As presented in a previous article [8], the correction factors depend strongly on the type of sound field (diffuse or free field). To characterize the sound field, simple assumptions were made using binaural recordings. The values of  $\Delta$  were computed for four different zones of noise source location: Zone 1- Source in the front/back of the head ( $-30^\circ < \theta < 30^\circ$  or  $-150^\circ < \theta < 150^\circ$ ); Zone 2- Ear/mic facing the source; Zone 3- Ear/mic in the shadow zone (source facing the opposite ear); Zone 4- diffuse field. For earmuffs and earplugs, the correction factors ( $\Delta$ ) were estimated from the average  $TF_{ext}$  obtained in each zone. It was found that the correction factors for Zone 4 (diffuse field) were very similar to those of Zone 1. Consequently, the same correction curves were used for these 2 zones and are noted "diffuse field" in the rest of the paper. Measurements were considered to be associated to the "diffuse field" zone when SPL differences between left and right ears would be below a certain threshold. Zone 2 (ear/mic facing the source) is noted "directly exposed" in the rest of the paper. Measurements were considered to be associated to the "directly exposed" zone when SPL differences between the exposed microphone and the one in the shadow would be above a certain threshold. On figure 4, the correction factors  $\Delta$  used to estimate the sound pressure level without subject are presented: (a) for earmuffs and (b) for earplugs.

### Validation with Measurements in a Simulated Workplace

The same procedure as the one described in [8] was used for the measurements in a simulated workplace. For each binaural measurement, the sound field type was first determined: "diffuse field" or "directly exposed". In the present paper, if the difference in overall sound pressure levels between both ears is smaller than a 2 dB threshold, the sound field was considered as diffuse while it was considered to be "directly exposed" above the 2 dB threshold. The correction factors presented in figure 4 were applied to the  $TF_{ext}$  to examine if the expected target value of 0 dB was attained. These results are presented in figure 5 for all measurements considered in the "directly exposed" zone.

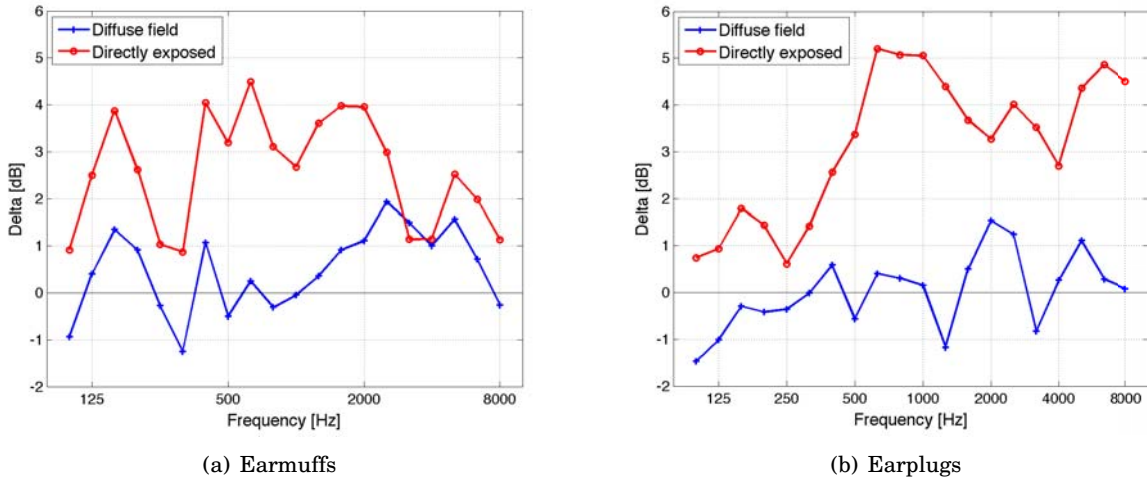


FIGURE 4: Correction factor Delta in the case of earmuffs (a) and earplugs (b).

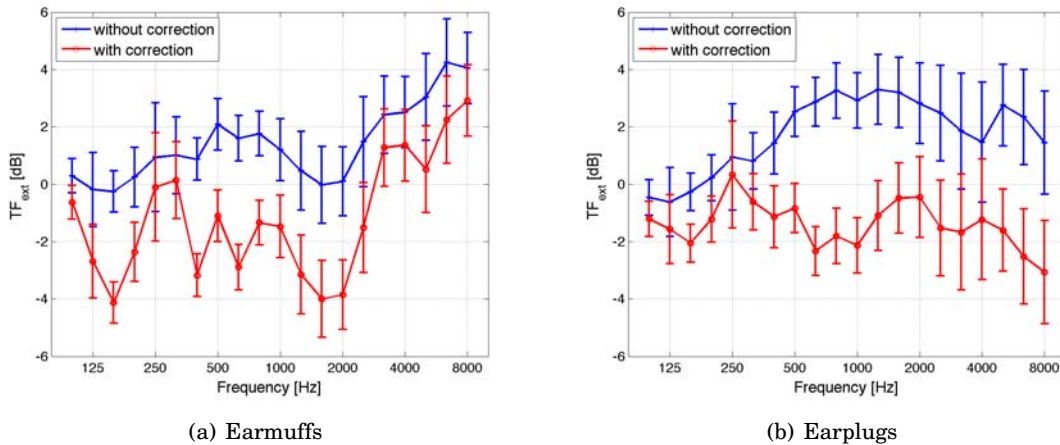


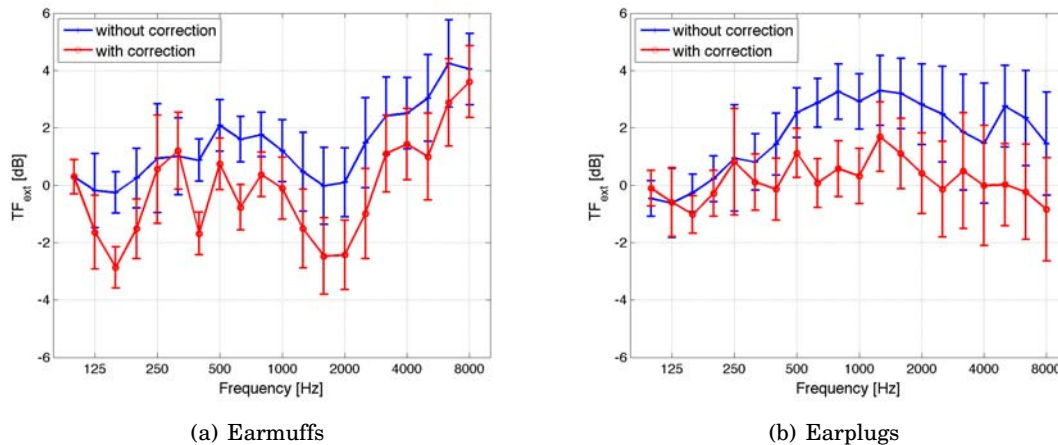
FIGURE 5:  $TF_{ext}$  with and without correction in "directly exposed" cases for earmuffs (a) and earplugs (b).

Despite the fact that corrections factors lowered the  $TF_{ext}$  values to acceptable values, the corrected  $TF_{ext}$  were below the 0 dB target, ranging around -2 dB for earmuffs and -1 dB for earplugs. This is most probably due to the fact that the correction factors were derived from ideal, laboratory diffuse or free-field conditions. Moreover, the free-field factors were derived from sources in the horizontal plane only. In more realistic settings, as in the one where the simulation were conducted, a mixed 3D sound field (neither perfectly diffuse nor perfectly directional of free-field) would exist, created by various sources at different locations and different levels of reverberation. Therefore, one could consider the proposed simple approximation to give quite adequate results, at least within a satisfactory 2 dB range.

In an attempt to improve the last set of results, a simple additional approximation can be made. A balancing scheme which consists of using both corrections factors ("diffuse field" and "directly exposed") simultaneously with different weighting to mimic the fact that both components (diffuse and direct fields) are present is proposed. Figure 6 shows the results when a 50/50 scheme is used. The  $TF_{ext}$  and the corrected  $TF_{ext}$  with  $.5 \Delta_{diffuse} + .5 \Delta_{directly\ exposed}$  correction are shown for



earmuffs (a) and earplugs (b) in the case of, again, the "directly exposed" zone. With this new simple correction, the corrected  $TF_{ext}$  is now closer to the expected 0 dB target line for both the earmuffs and earplugs. Investigations are under way to develop a more robust and precise balancing scheme.



**FIGURE 6:**  $TF_{ext}$  with and without correction in "directly exposed" cases for earmuffs (a) and earplugs (b).

## CONCLUSIONS

This paper presented the main results obtained with two sets of experiments aiming at studying the effect of microphone location and sound field characteristics for the exterior microphone used in the F-MIRE context. The first set of data allowed to propose an optimal location which reduces the variability. Both earmuffs and earplugs were studied. Additionally, correction factors used to approximate the sound pressure level without subject from measurements taken near earmuffs or earplugs in the cases of diffuse field and free-field were proposed. These correction factors were then used in the second set of experiments to validate the procedure using a simulated workplace. Despite the simplicity of the proposed approach, the presented results showed to be very encouraging. The SPL without subject was under-estimated from about 2 dB for earmuffs and 1 dB for earplugs. In order to improve the results, a better and more precise identification of the sound field would allow to develop a more optimal balancing scheme and is under investigation.

## ACKNOWLEDGMENTS

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