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Hearing Protection Devices' efficiency in high impulsive noise exposure

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ABSTRACT: Unlike occupational environments, noise exposure in recreational activities, such as the shooting of fireguns, it is not legally framework, as far as it is not carried out as an occupational task, or in the scope of a work contract. Moreover, this kind of exposure it not, generally, inspected or controlled, which implies that protection against noise exposure is an exclusive task of the users themselves. Therefore, in the great majority of the cases, their choice is the use of Hearing Protection Devices (HPD). The main aims of this work are the profile characterisation of shooting site users and, on other hand, to analyse the HPD's efficiency in real use conditions, namely when used in high impulsive noise exposure. For this purpose a questionnaire was developed, and applied, and a technique to assess HPD's real efficiency, similar to MIRE (Microphone In Real Ear), was also applied. From the obtained results, it was possible to verify that high impulsive noise exposure is very significant amongst shooting sites users, and that the HPD generally used is, in most cases, suitable for their protection, namely in what concerns the exposure to high impulsive noise.

1. INTRODUCTION

In Portugal, occupational noise exposure has been legally framed since 1992 by the transposition of the European Directive 86/188/CEE of 16th May, which occurs through the publication of the Decree-Law 72/92 and the Decree 9/92 [1][2], both from 28th April. This legislation establishes, among other issues, the action level and the threshold limit value for the daily noise exposure and defines the technical measures and organizational strategies as priority actions to minimize noise emission and its propagation. Accordingly, HPD should be considered as an ultimate solution, as far as to workers' protection concerns. Since then, HPD use, although considered as temporary, emerges as a very frequent solution in occupational settings.

According to Portuguese legislation, whenever the threshold limit value for daily noise exposure or the maximum peak level, 90 dB(A) and 140 dB respectively, are exceeded, HPD use should be compulsory. If exposure exceeds the action level for daily exposure (85 dB(A)) HPD should be available at workplaces but its use is optional.

High impulsive noise exposure is very frequent in occupational environments. However the increasing exposure from recreational, or leisure, activities has originated an increasing attention from researchers working in this domain [3]. Unlike occupational environment exposure, recreational noise exposure has no legal framework and consequently has no inspection or control entities, at least formally. Therefore, when it happens, the protection of exposed individuals is generally done by themselves. This means that noise protection is

frequently done through the use of HPD. However, the HPD should be adequately used in order to obtain maximum efficiency for noise attenuation in real conditions [4].
The exposure to continuous high sound pressure levels, generally found in occupational settings, and the respective effects have been widely studied [5]. Presently, and as result of many of these studies, it is consensually accepted the dimension of noise exposure effects, including the effects of the exposure to impulsive noise.
It is also consensual that the most severe hearing losses are originated by the exposure to high impulsive sound pressure levels [6]. Impulsive noise is a noise in which the sound pressure level has a very fast increase followed by a very fast decrease, which is generally called peak level and it is defined as the sound pressure level that has a duration less than 1 second and it repeats in a period greater than 1 second. The peak sound pressure levels could reach nearly 170 dB (peak). This level can exceed the threshold of pain and cause damage to the tympanic membrane.
The frequent use of fire guns originates exposures to high impulsive sound pressure levels and consequently a serious risk of hearing loss. Amongst the shooting site users, the most frequent users are military personnel, police agents and people with sport purposes. Although in Portugal it is not well known the total number of persons that have been exposed in such environments, as well as the consequences of such exposure, in some countries these data is well documented. In Finland, for example, people exposed to high impulsive sound pressure levels, either in occupational or non-occupational settings, constitute the great majority of compensation cases due to noise induced hearing loss [7].
Due to the lack of information about the use of HPD amongst the fire guns shooters, as well as the unknown real efficiency of such devices, this work intends to be an important contribution to the study and characterisation of the use of HPD in the mentioned environments. For this purpose several noise measurements were carried out and a HPD's real efficiency assessment technique, similar to MIRE (Microphone In Real Ear), was applied.
This study was developed in the Ergonomics Laboratory of University of Minho and has been carried out in several locations, namely:

- Indoor shooting site of Polícia Judiciária's Building (PJ) (Criminal Police) in Porto.
- Outdoor shooting sites of 25 m (closed type – figure 2) and 300m (open type) in Braga, both belonging to the Portuguese Army, Cavalry Regiment no. 6.
- Outdoor shooting site (open type) for sport shooting in Vizela.

2. METHODOLOGY

In this study, three different techniques were applied, namely:

- Sound pressure levels measurement and calculation of the personal daily exposure levels.
- Questionnaire administration.
- HPD real efficiency assessment, using a technique similar to MIRE.

As it is intended to analyse only exposure that may potentially originate health problems, namely hearing loss, only users having daily personal exposure greater than the action level defined in Portuguese legislation were considered. In order to characterize the sound pressure

levels of each type of guns used, it was also carried out a spectral analysis of the most significant guns. This characterisation can constitute an important basis for the HPD selection. Additionally, a questionnaire, regarding some aspects of the shooting practice and the use of HPD, was distributed by all the subjects' sample.
Lastly, the third part of the methodology consisted in evaluating the efficiency of some HPD, using a technique for real efficiency assessment. This technique consisted in a modified version of the MIRE technique. Using this technique, two different HPD were tested (a passive and an active one with external sound pressure level dependency).

2.1 Equipment
Both sound pressure levels and spectrum analysis were made using a sound level meter Bruel&Kjaer type 2260, 9 dosimeters Bruel&Kjaer type 4436 and 2 dosimeters Quest model Q-100. Additionally, with the aim of real conditions simulation in Laboratory, an artificial head and torso Bruel&Kjaer type 4128 were used. The artificial head is equipped with an artificial pinna Bruel&Kjaer type 4158.

2.2 Questionnaire development and application
The applied questionnaire is essentially divided in two sections: a first section, concerning the individual characterization and profile of shooting sites use and a second section, related to the noise exposure and the use of HPD.

2.3 MIRE technique
The principle of the MIRE application is the use of two miniaturized microphones. One placed in the outside part of the hearing protector and the other in the inside the HPD earcup. The difference between the two registered sound pressure levels is the attenuation afforded by the device. In the present study we have tested earmuffs in which the microphones were placed outside and inside the earcup (Figure 1).

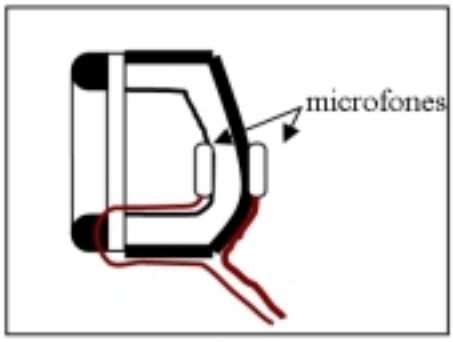

Figure 1 – *Schematic representation of the microphones position inside and outside the HPD.*

The inside microphone wire was introduced in the HPD underneath the sponge material of the earcup via a very small hole, which in turn was sealed with silicone in order to assure total tightness of the earcup. Both microphones were connected to two dosimeters.
In order to know with more detail the TFOE (Transfer Function of the Open Ear) concerning the maximum peak levels, a Laboratory validation of the technique was carried out. In this

test, maxLpeak obtained in both microphones (one near the ear canal and the other oriented for the exterior) were compared. The aim of such analysis is to determine the influence of the microphone position on the registered maxLpeak, despite the presence of the HPD.
Using an audiometric booth, it was tested the maxLpeak obtained in each position. A fire gun without bullets was used to simulate the high impulsive peak levels. TFOE was obtained by the mean difference between the two microphones. Lately, when testing the HPD efficiency, the obtained values were corrected with this difference.

3. RESULTS AND DISCUSSION

3.1 Measurement sites and weapons

Shooting practice is, as mentioned previously, essentially carried out by military forces, police agents and shooting athletes. Therefore, depending on the type of use, the shooting site, as well as the used weapon, can vary significantly.
As the main goal of this study is to characterize the exposure of these people to impulsive noise, the study sample was, whenever possible, constituted for subjects of each group users mentioned above.
The type of weapons depends basically on the users group. Military personnel, for example, use mainly automatic rifles. Police agents, such as those of the PJ, use a great diversity of weapons, as for example, automatic rifles, gun-machines, pistols, revolvers and hunting-guns. Users from sport purposes use mainly hunting-guns. It should be also referred that this last group of users the studied subjects are exclusively from the “moving plates” shooting competition.

3.2 Noise Levels

From the carried out noise measurements, it was verified that the observed values were significantly high, in particular in what concerns peak levels.
Regarding personal daily exposure levels, it was found that these levels are not so critical due to the short period of exposure and its relative low frequency.
From these results it is clear that the effective risk of hearing loss development is associated with the high peak levels observed and not with the continuous noise exposure.
From the noise assessment we can summarise some results which are presented in the following tables (1 and 2).

Table 1 – *Variance range of the maximum peak level according to the site and weapon type.*

Site	Weapon type	Range MaxLpeak [dB]
Outdoor shooting site (open type)	Automatic rifle	130.6-146.3
Indoor shooting site	Pistol, revolver, gun-machine and rifle	145.8-148.5
Outdoor shooting site (closed type)	Pistol, revolver, gun-machine and rifle	123.9-143.9

Table 2 – *Main frequencies of the shooting sites noise spectrums.*

Site	Weapon type	Main frequencies (Hz)
Outdoor shooting site (open type)	Automatic rifle	500-2000
Indoor shooting site	Pistol	1000-2000
	Revolver	1000-4000
	Gun-machine	1000-4000
	Rifle	500-8000
Outdoor shooting site (closed type)	Pistol	1000-2000
	Revolver	2000
	Gun-machine	2000-4000
	Rifle	500-8000

3.3 Questionnaire results

From the questionnaire application, some data regarding the demographic profile of the users were obtained, as well as about the HPD use profile. From these data, it is possible to verify that almost all users have lower age, with a sample mean age of 32.8 (sd=11.2) years. Users from army are the youngest, with a mean age of 20.9 (sd=3.0) years and the oldest group of users are the people from Police, with a mean age of 39.8 (sd=7.5) years..

In general, the users are typically male, with a higher percentage of females in the sample from the PJ (12.5%). Concerning background education, there is a significant difference between all the considered groups. Individuals from military personnel and sport shooting have, generally, lower background level (more than 70% have a education background level less than the 4^{th} grade) and people from criminal police present a higher background level (more than 95% have a education level higher than the 9^{th} grade). To describe the type of exposure and the profile of HPD use, some results are presented in tables 3 and 4.

Table 3 – *Sample characterisation according to the frequency of shooting practice (in %).*

Frequency	Sports	Army	Police	Total
Annual	-	78.0	5.4	28.5
Semestrial	19.2	12.2	69.6	39.8
Each 4 months	-	-	12.5	5.7
Quarterly	-	-	5.4	2.4
Monthly	34.6	9.8	3.6	12.2
Weekly	42.3	-	-	8.9
Daily	3.8	-	3.6	2.4

Table 4 – *Sample characterisation according to the shooting practice duration (in %).*

Practice duration	Sport	Army	Police	Total
<1h	73.1	78.0	33.9	56.9
1-2h	26.9	7.3	58.9	35.0
2-4h	-	12.2	3.6	5.7
>4h	-	2.4	3.6	2.4

Despite the fact that the great majority of users present a low frequency in shooting practice, in some cases (sports and criminal police) the percentage of users with a weekly or more

frequency is significant. Only army users are sporadic users of the shooting sites, 78% of them using these sites only once a year. This yearly utilization is almost restricted to the initial training undertaken by all military personnel.
On other hand, data referring the duration of use were also analysed (table 4). Therefore, it is possible to observe that, despite the higher frequency practice of sport users, as mentioned previously, the duration of the practice is generally lower than that one of the other groups, namely PJ agents, which present the highest mean duration of shooting practice.
From the overall results, we can observe that the practice duration is generally short, i.e., near 92% of the practice duration is less than 2 hours. This fact does not minimize significantly the noise exposure risk assuming that hearing loss development from impulsive noise exposure is not a function, or at least directly, of the practice duration but it depends on the maximum peak level of the exposure.
Concerning the HPD use profile of the sample users, we verify that almost all (93%) sample subjects use, or refer to use, HPD when shooting. Nevertheless, it must be referred that some of these users declare to use HPD only when shooting and, in some cases, they remove their HPD when they are no longer shooting but remaining in the shooting sites. Besides, even a small percentage, 7% of users referring not to use HPD, is exposed to high peak levels, sometimes greater than 140 dB, which can potentially induce important hearing losses. Finally, and concerning the selected type of HPD, it was verified that more than one half of the users (57%) refers to use earmuffs.
A point that must be highlighted is the significant percentage of users (23%) that refer to use active HPD (devices incorporating electronics). This result could be surprising considering the lack of information about this type of devices and their high prices. However, a closer look to the questionnaire answers makes possible to verify that this percentage refers exclusively to the PJ agents. In the PJ indoor shooting site, there are available some active devices which are regularly used by all the agents who do their shooting practice there.

3.4 HPD real efficiency

As mentioned previously, HPD real efficiency was analysed using a technique similar to MIRE, which is the acronym for Microphone In Real Ear. From the carried out tests we have obtained real attenuation values for peak levels, which are summarized in table 5. More than knowing the absolute attenuation afforded by HPD, it is very important to know if the devices are suitable for reducing peak levels to acceptable values, i.e., below the action level of 140 dB.
Additionally, it is also important to compare the obtained results with those provided by HPD manufacturers, also called nominal attenuation. At this respect, the present hearing devices related standards do not foresee any method for estimation the effective (with the use of HPD) peak levels. Recently, it was subject to discussion, a European standard project [8] which contained a practical method for effective peak level estimation when using a specific device. Considering the method mentioned above, the peak levels nominal attenuation of the tested HPD are 26 dB (Active) and 32 (Passive). Despite this value, the carried out tests show that real attenuation obtained in the use of this devices is significantly lower, depending on the weapon type (table 6) and site. Generally, Active devices present lower sound attenuation but a minor difference between the nominal

(catalogues) and real (obtained by MIRE) attenuation. In both cases (table 5 and 6) active devices also present less variability in the obtained results.
In average, the obtained attenuation values are comprised between 6.1 and 32.4 dB. It is also possible to verify that, in absolute terms, the limit for the maximum peak level (140 dB) is not exceeded in any of the carried out measurements with this specific HPD.

Table 5 –*Real attenuation (mean and standard-deviation) of the two types of HPD tested.*

	Active HPD		Passive HPD	
Weapon Type	m	sd	m	sd
Automatic rifle	18,6	9,5	10,6	2,2
Hunting-gun	11,3	9,0	17,4	13,0
Pistol	19,4	3,3	23,5	8,3
Gun-machine	17,9	6,1	20,2	11,8
Revolver	14,0	2,4	19,6	13,9

Table 6 – *Difference (mean and standard-deviation) between nominal attenuation and real attenuation values of the two types of HPD tested.*

Weapon Type	Active HPD		Passive HPD	
	m	sd	m	sd
Automatic rifle	7,4	9,5	21,4	2,2
Hunting-gun	14,7	9,0	14,6	13,0
Pistol	6,6	3,3	8,5	8,3
Gun-machine	8,1	6,1	11,8	11,8
Revolver	12,0	2,4	12,4	13,9

4. CONCLUSIONS

Although this study is not yet complete, the obtained results allow to verify that users of shooting sites, in particular those who do it more frequently, are exposed to significant high sound pressure levels.
Due to the high sound pressure levels registered in these sites, it is possible to conclude that there is a significant risk of hearing loss development amongst the frequent users of fire guns. This risk is even more critical if we consider the fact that the exposure in such places correspond to an exposure to peak levels higher than 140 dB, which implies, per se, a high risk of noise induced hearing loss development.
On other hand, it is also possible to verify that users' protection relies, almost exclusively, on the HPD use. From the obtained results, almost all users (93%) admit to use regularly HPD and only a residual percentage (7%) of users refer not to use HPD and, consequently, is directly exposed to the sound pressure levels at the shooting sites.
From the obtained results, it possible to draw the following conclusions:

- There is a high number of users of shooting sites, namely, military personnel, shooting athletes and police agents. Amongst them, a great percentage does it in an occupational context (military personnel and police agents).

- There is a high risk of hearing loss development derived from the shooting practice in the analysed sites.
- MIRE technique, or the modified one used in this study is very versatile and it allows to verify the efficiency of HPD in real use situations
- It is necessary, and urgent, that regular users and the working staff of the shooting sites be aware of the risk of such activity in order to be conveniently protected.

Finally, we hope that this work may contribute to a higher consciousness of the hearing loss development risk associated with the frequent shooting practice, and promote the use of HPD amongst the frequent users. Technically, we hope that this work may be an important contribution to the understanding of HPD attenuation in real conditions, in particular, when considering exposure to high sound peak levels environments.

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