An evaluation of comfort afforded by Hearing Protection Devices

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ABSTRACT

This paper focused on the comfort afforded by 3 models of hearing protection devices. Devices were selected and, after being tested in a real occupational context, evaluated using a questionnaire regarding different comfort indexes. In this way, it was possible to compare the “performance” of the hearing protectors regarding the comfort indexes, and to determine which one, globally, has afforded the greatest comfort. Since that it is not likely that all the indexes contribute in the same way to the global comfort sensation, each worker was asked to score the importance of each index evaluated before. This enabled to order the indexes by the importance they have on the global comfort feeling. It is hopped that this study contributes to a greater efficacy of the hearing conservation programs implemented through the use of hearing protection.

Keywords

Hearing protection devices, Noise, Exposure, Comfort

INTRODUCTION

According to Hetu and Getty (1991), noise induced hearing loss is the most common permanent professional disease in industrialised countries, having the particularity of not being exclusive of one activity, but to be common to all of them.

Personal hearing protection, though the last measure that should be adopted to minimise the effects of noise exposure, is beyond any doubt the most spread in industrial context. In what concerns noise exposure, the low cost and easy implementation of Hearing Protection Devices (HPDs) turn it into the chosen measure to solve the noise problem in all kind of activities and in particular in industry.

For a hearing conservation program, implemented in any industry, to be successful it is necessary that workers use the HPDs during all exposure time. The removal of protection for 30 minutes, for instance, reduces the effective protection to approximately half of what could be achieved with its use during all exposure time

(Franks and Berger, 1998). So, it is crucial that hearing protection devices are comfortable, since this is a determinant factor for their use.

Comfort is a concept difficult to define, given its highly subjective character. According to Richards, quoted in Kuijt-Evers et al. (2004), comfort is a person's state, involving a subjective feeling of well being towards the environment or a situation. This well being should be understood as both physical and psychological. Having in account this definition one might consider that all mentioned reasons not to use/remove the hearing protectors (excluding the behavioural, such as the fact of not considering it important, or not being compulsory), are items that contribute to the global comfort feeling.

In the following paragraphs are presented the HPDs' characteristics and their relation with comfort, already mentioned in previous studies on this theme (Arezes, 2002; Hsu et al., 2004; Park and Casali, 1991):

- *Attenuation* – the attenuation afforded by HPDs is normally the analyzed characteristic when selecting these equipments. Legislation defines calculation methods to determine the attenuation that should be afforded by a HPD and the Portuguese standards establish their minimum attenuation level. But, if it is true that HPDs should perform its function effectively – protect the inner ear from noise exposure - one should not make the mistake of selecting a device with excessive attenuation. Traditionally HPDs have greater attenuation in the high frequency range than in low frequency. If we consider that the majority of sounds have both frequencies in their composition it is not difficult to understand that these are distorted by the use of HPDs. If we add to this the, potential, an excessive attenuation, we will surely have greater rejection from workers. This fact assumes more importance to individuals that already present hearing losses (Harrison, 1993). Therefore, it is important to find a balance between the attenuation that protects hearing and reduces discomfort, and that that blocks signals perception and verbal communication.
- *Weight* – Excessive weight of some devices, normally of earmuffs, is frequently mentioned by some users as an element of discomfort. Normally there is a direct relation between attenuation and weight, one increasing with the other, then again the importance of choosing a device with adequate attenuation.
- *Pressure* – In this item we must consider 3 distinct situations: the pressure exert by the band and foam of the earmuffs on the head, the one exerted in the inner ear by the earplugs and the one exerted on the ear by the semi-aural plugs (also called ear caps). The pressure of the band/foam of the earmuff is necessary for its effectiveness, although it should not be too excessive, which in turn, leading to a recurring situation that is the "spreading" of the band by users. The pressure exerted on the ear by semi-aural plugs leads to pain, which makes them only adequate to short duration uses. The earplugs are associated with some complaints of excessive pressure against the inner of the ear canal.
- *Texture* – The HPDs components' materials and consistence should be considered in their conception. The parts of the device that contact with skin should be soft and flexible, not cause irritation or allergies. This item represents for itself a comfort parameter, but is associated with others, such as the ability for heat dispersing and perspiration absorption, that are mentioned in the following points.
- *Heat dissipation ability* – The use of HPDs, especially earmuffs, difficult heat exchange in the covered area, leading to a localized temperature increasing. In hot environments, which are normally found in industry, this may causes discomfort, but if the room temperature in the working area is low this may be positive, as it will contribute to maintain the heat, thus enhancing comfort.
- *Perspiration absorption ability* – In hot environments, or in the case above mentioned, it is normal that perspiration occurs in the contact area between HPDs

with the skin. If the materials of what the HPD are made of do not have the ability to absorb the humidity, irritation may occur in the contact area.

- *Difficulty to perform tasks* – Another mentioned reason to justify not using HPDs is the difficulty to perform normally the routine tasks, in particular in some jobs that require the recognition of specific sounds (e.g. some worker from maintenance teams identify certain machines problems by "strange" sounds) and those that require dislocation in confined spaces, which do not allow the use of HPDs.
- *Difficulty to fit* – The easiness for the initial fit of HPDs also contributes to the frequency and duration of HPDs use. Devices that require complicate fitting procedures are more likely to be inadequately/less used, especially by workers that go from noisy places to quieter ones quite often, or stay in noisy environments for very short periods of time. Another interesting aspect is the fact that the subjects that have been trained to correctly fit their HPDs report bigger discomfort than the one that haven't, this being true only for earplugs. An explanation to this may be the deeper insertion on the ear canal, needed to obtain the desired attenuation that leads to greater discomfort (Park and Casali, 1991). The difficulty to fit may also come as a consequence of the simultaneous use of more than one personal protective equipment.
- *Intelligibility*- it means the ability to understand and differentiate different sounds in general, and the verbal communication (speech) in particular. This is one of the most indicated reasons for the non utilization of HPDs. The use of HPDs interferes with communication and with the hearing of acoustical warning sounds. In the absence of background noise, the use of HPDs deteriorates significantly the intelligibility, both through the attenuation afforded by the devices and the sound distortion associated with its use. However, in noisy environments, which are exactly the situations where they are most needed, the use of HPDs could improve intelligibility (Fernandes, 2003). The use of adequate HPDs will actually improve verbal communication and the perception of warning sounds.
- *Aesthetics* – HPDs' aesthetics it is also been pointed as a likely cause for the non use. This reason could be minimized if workers take part of training programs and if several HPDs models are made available for selection, allowing them to select those devices they like more.

METHOLOGY

In his particular study 3 different models of HPDs were selected. Those devices were used for a week period, by 5 workers in an industrial context, in particular in a textile company. All the 3 devices were tested simultaneously, which is the same to say that in the same week all the workers used the same devices.

Workers' selection was carried out considering the results of the noise exposure assessment that was carried out previously in their workplaces. Three of them have a daily exposure level higher than the threshold limit value at the time of the study (90 dB(A)), and two of them were exposed to a daily exposure level slightly higher than the action values (85 dB(A)). It was ensured that all the workers should carry out their tasks in similar noise exposed sites.

All the comfort indexes were selected after a literature review on this issue. Amongst all the previously mentioned indexes, only aesthetics was not included in the study. This decision was made considering that, even though this factor could be defined as influencing comfort, it seems that this not appear to influence the physical perception of comfort.

For the carried out field tests it were selected an earmuff and two earplugs, one moldable by the user and a pre-molded model. Additionally, it was also considered

different HPDs in terms of attenuation characteristics, since it was intended that all the devices presented different attenuation characteristics.

At the end of each week of use, workers were requested to fulfill a questionnaire for evaluating each HPD. This evaluation included all the comfort criteria/indexes mentioned previously.

After all the HPDs were tested, it was requested the fulfillment of a second questionnaire regarding comfort evaluation. In this questionnaire, workers could establish a priority order in what concerns the comfort indexes. This hierarchization permits a determination of the relative weight of each index, from workers' the point of view.

As the initial fit of the devices might influence the perception of comfort (Park and Casali, 1991), workers involved in this study were enrolled in an initial training session for improving the way they fit their HPDs.

Figure 1 – HPDs used in the test: moldable earplug, pre-molded earplug and earmuff.

RESULTS ANALYSIS AND DISCUSSION

Questionnaire A – Evaluation of each HPD

After applying the questionnaire all the classifications were registered and the obtained results are summarized in table 3.1.

Table 1 – Mean and Limits of the obtained classifications (LL: Lower Limit and HL: Higher Limit) for a 95% confidence interval.

Index	HPD								
	Moldable			Pre-molded			Earmuff		
	Mean	LL	HL	Mean	LL	HL	Mean	LL	HL
Attenuation	3,0	2,1	3,9	2,8	2,2	3,8	2,6	1,9	3,3
Pressure	2,8	1,8	3,8	3,2	2,6	3,6	3,8	2,2	5,4
Weight	--[a]	--[a]	--[a]	1,2	0,6	1,8	3,4	2,0	4,8
Texture	1,8	1,2	2,4	2,8	1,8	3,8	3,2	2,2	4,2
Ability to dissipate heat	1,4	0,7	2,1	2,6	1,9	3,3	4,2	2,6	5,8
Ability to absorb perspiration	1,8	0,2	3,4	2,6	1,2	4,0	4,2	2,6	5,8
Difficulty to perform tasks	1,6	0,9	2,3	2,8	1,2	4,4	4,0	2,5	5,5
Fit difficulty	2,6	0,7	4,5	2,2	0,6	3,8	1,8	0	4,0
Intelligibility	2,4	1,7	3,1	2,0	1,1	2,9	2,6	1,2	4,0

[a] The value was omitted due to the fact that it was constant.

In order to analyze the results of the questionnaire A, a non-parametric test was applied, the Kruskal-Wallis test, in which the considered null hypothesis H_0 was that there are no significant differences in the classification mean value for the tested

HPDs. Through the application of this test we have obtained the results summarized in table 3.2.

Table 2 – Kruskal-Wallis test results.

Variable	Chi-Square	df	p
Attenuation	1.141818	2	0.565
Pressure	2.262626	2	0.323
Weight	11.70502	2	0.003
Texture	6.651429	2	0.036
Ability to dissipate heat	9.418182	2	0.009
Ability to absorb perspiration	6.397765	2	0.041
Difficulty to perform tasks	7.354217	2	0.025
Fit difficulty	0.969002	2	0.616
Intelligibility	1.373913	2	0.503

Considering a significant p level of 0.05, when p values obtained in the Kruskal-wallis test is less than 0.05 the H_0 is rejected. Accordingly, the comfort indexes related with weight, texture, ability to dissipate heat, ability to dissipate sweat and annoyance in task performance present statistical significant differences in what regards the mean classification for the three considered hearing protectors.

All the other indexes (attenuation, pressure, fit and intelligibility) do not suffer significant variations in the mean score for all the considered devices.

The hearing protector that was classified as being the most uncomfortable device was the moldable one. This device also presents the higher nominal attenuation (referred by manufacturer's catalogue). Earmuff was considered as the device with the most adequate attenuation.

These results can be interpreted in two different ways, namely:

- Attenuation afforded by moldable earplug was excessive, which might have lead to a greater discomfort reported by workers.
- Earmuff was classified as the best device because it affords a higher effective attenuation.

The first hypothesis is supported by the fact that workers who participated in this study have been involved in a training program for improving their devices' fit. The main reason for the second hypothesis is related with the fact that earmuffs were those devices presenting fewer differences between real and nominal attenuation, together with the result obtained on the index "intelligibility", in which earmuff was considered to be the device that creates a higher communication difficulty.

The most uncomfortable device, regarding the item pressure, was the earmuff, by opposition to the moldable earplug that was considered to be the most comfortable regarding this particular index.

In the questionnaire, a reference to the distinction that should be made when a specific device was evaluated regarding the item "pressure" was included. When earmuff was evaluated, workers should evaluate the pressure exerted by the headband, whilst in earplugs workers should evaluate the pressure exerted by the device at the ear canal. The obtained results are in accordance with those found in the literature review.

In the item "weight", earplugs have obtained mean scores very low, and at a significant distance from the earmuff that was considered to be the most uncomfortable device.

The highest mean score in the item “texture” was obtained in the earmuff, while the moldable earplug was considered the softest device.

The worst device in what concerns the ability to disseminate heat was the earmuff and the best was the moldable earplug. At this point it is important to refer that all the subjects that have participated in this study worked in hot environments and, consequently, the inability to dissipate heat was an important factor that could contribute for the devices reported discomfort.

Earmuff was the devices that has obtained the highest mean score in the item “ability to absorb sweat” and the moldable earplug the one that has obtained the lowest classification. This result, as well as the one regarding the ability to dissipate heat, is originated by the fact that the devices are positioned above all the auricular area, which will create a difficulty for heat dissipation.

The highest score on the item “annoyance in task performance” was observed in the earmuff, followed by the pre-molded earplug and by the moldable earplug, which was considered the device that implies a lowest annoyance reported by users. Workers have also reported the discomfort by the earmuff volume, which did not allow them to place their head in some exiguous places.

The easiest fit was attributed to the earmuff and the most difficult fit attributed to the moldable earplug, which initial fit implied to mold the earplug, introducing it on the ear canal and holding it during 10 seconds.

The device with the highest mean score in the item “intelligibility” was the earmuff, by opposition to the pre-molded earplug. If we analyze the obtained values together with those related with the devices’ attenuation, it seems that the device with a more adequate attenuation profile was also the same that presents a highest attenuation perceived by workers.

In order to summarize these results, the following table presents the best and worst results for each item.

Table 3 – Synthesis of the comparative analysis between different tested devices.

Variable	HPD	
	Best	Worst
Attenuation	Earmuff	Moldable Plug
Pressure	Moldable Plug	Earmuff
Weight	Moldable Plug	Earmuff
Texture	Moldable Plug	Earmuff
Ability to dissipate heat	Moldable Plug	Earmuff
Ability to absorb perspiration	Moldable Plug	Earmuff
Difficulty to perform tasks	Moldable Plug	Earmuff
Fit difficulty	Earmuff	Moldable Plug
Intelligibility	PP	Earmuff

According to these results it was verified that moldable earplug is the one that presents better scores in a larger number of the evaluated comfort indexes (pressure, weight, texture, ability to dissipate heat, ability to absorb perspiration and difficulty to perform tasks), and the one that was also considered as the worst devices in what regards attenuation and fit difficulty.

Earmuff comes out in the opposite side, i.e., it obtains the worst score exactly on the same indexes where moldable earplug was considered the best, plus the intelligibility index. Besides, it was scored as the best device on the same indexes that were

considered worst for the moldable earplug. The pre-molded earplug was considered to be the best in the intelligibility index.

Questionnaire B – Evaluation of the comfort indexes

Questionnaire B intends to infer which indexes of comfort, amongst those considered in this particular study, were the most relevant for the HPDs users comfort perception. In this questionnaire the used scale was defined as an Likert's type optional scale with 5 options, ranging from "Not important at all" (with a 1 point score) to "Very important" (with a 5 points score).

Results obtained (table 4) show that all the comfort indexes have obtained mean scores greater than 2.5 points (middle score on the used scale), which means that all of them were considered to be relevant for the comfort perception. The following table shows the mean and the 95% confidence interval for all the evaluated indexes.

Table 4 – Relevancy score of the comfort indexes and the corresponding 95% confidence interval

Index	Mean	Confidence interval
Attenuation	3.6	±0.894
Pressure	4.0	±0.000
Weight	4.2	±0.837
Texture	3.0	±0.000
Ability to dissipate heat	4.0	±0.707
Ability to absorb perspiration	3.8	±0.447
Difficulty to perform tasks	2.8	±1.304
Fit difficulty	4.0	±0.707
Intelligibility	3.6	±0.548

Attenuation, which is frequently the most used criterion in the HPDs selection, was considered to be the 6th, in the ranking of importance, by the users.

Ability to dissipate heat and, consequently, the ability to absorb perspiration have obtained higher scores (3rd and 5th place, respectively) because the thermal environment in which the HPDs were tested was somehow critical due to the high temperatures. If this study was carried out in a cold environment this priority order would, certainly, be different.

CONCLUSIONS

After the described study some conclusions were drawn and it can be divided into two different groups, namely:

a) HPDS comfort

(i). The indexes weight, texture, ability to dissipate heat, ability to absorb perspiration and difficulty to perform tasks were dependent of the type of HPD considered. All the remaining indexes (attenuation, pressure, fit difficulty and intelligibility) did not present statistical significant differences;

(ii). The HPD classified as being the best device in a large number of indexes was the moldable earplug. This device have also obtained the worst score in the attenuation and fit difficulty indexes;

(iii). The HPD classified as the worst in a high number of comfort indexes was the earmuff. However, this device has also obtained the highest score in the attenuation and fit difficulty indexes;

(iv). It seems that HPDs users have considered that the device with a more adequate attenuation is also the device that presents a more adequate effective attenuation. Although the higher nominal attenuation (reported by manufacturers) was registred in the moldable earplug, the difficulty to fit this device led to an inadequate fit and, consequently, to a worse attenuation.

b) Relative importance of HPD comfort indexes

(i). All the studied comfort indexes were considered to be relevant for the global comfort perception;

(ii). From the considered comfort indexes, it seems that weight is the most important index and the difficulty to perform tasks the less important.

Finally, it is important to refer that the small size of the use sample may have a significant effect in the obtained results. Therefore, the extrapolation of these results for other contexts should be done with caution, in particular in what regards the reliability of the presented results.

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REFERENCES

Arezes, PM; Miguel, AS, 2002. Hearing protectors acceptability in noisy environments, The Annals of Occupational Hygiene, 46, pp. 531-536.

Fernandes, J. C., 2003. Effects of hearing protector devices on speech intelligibility, Applied Acoustics, 64, pp. 581-590.

Franks, J.R., Berger, E. H., 1998. Hearing protection-personal protection-overview, Encyclopedia of Occupational Health and Safety, pp. 31.11-31.15.

Harrison, C., 1993.Hearing Protection attenuation. Is more really better?. OH&S Canada.

Hetu, R. and Getty, L., 1991. Development of a rehabilitation program for people affected with occupational hearing loss: A new paradigm, Audiology, 30, pp. 305–316.

Hsu, Y.; Huang, C.; Yo, C.; Chen, C.; Lien, C., 2004. Comfort evaluation of hearing protection, International Journal of Industrial Ergonomics, 33, pp. 543-551.

Kuijt-Evers, L. F. M.; Groenesteijn, L.; Looze, M. P.; Vink, P., 2004. Identifying factors of comfort in using hand tools, Applied Ergonomics, 35, pp. 453-458.

Park, M.; Casali, J. G., 1991. An empirical study of comfort afforded by various hearing protection devices: Laboratory versus field results, Applied Acoustics, 34, pp. 151-179.