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Noise Control at the Ear by Hearing Protectors

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Case Report

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Abstract

The noise causes a masking effect that disturbs verbal communications. The noise limits the perception of acoustic signals of security with an increased probability of accidents at work. The noise increases the mental fatigue and decreases the efficiency of the work performance. The level of exposure to noise by hearing protectors can be estimated by the methods specified by two standards BS EN ISO 4869-2 and BS EN 458. In this paper we compare the methods using different hearing protectors [DOI:10.12866/J.PIVAA.2013.09.003][1]

Keywords: OSHA Regulations, BS EN ISO 4869, Noise Control, Hearing Protectors

1 Introduction

Valuable recommendations for the choice, utilization, care, and maintenance, and for the measurement of sound attenuation of hearing–protective devices have been laid down in international standards (cf. DIN EN 458, 1993; DIN EN 352-1, 1993; DIN ISO 4869-1, 1990).

Hearing protectors are the most popular and expensive countermeasure against occupational hearing loss, when the noise can not be controlled by relatively inexpensive and quick engineering measures [Beddoe, 1980]. It needs to analyse an important aspect [Behar and Mihai, 1984]. Use of conventional protectors may interfere with communication and with the perception of warning signals and other acoustic cues from the machinery [Fernandes, 2003] and [Goodfellow, 1994]. Therefore, one important aspect in the evaluation of these devices is their effect on communication [Hartmut et al., 1999]. Industrial workers must listen, discriminate between a variety of sounds,

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identify the location of sounds [Behar and Jackson, 1987]. Work can require the ability to understand the human voice (intelligibility) [Hashimoto et al., 1996].

For these reasons industrial workers can be hesitant to wear the protectors [Howell and Martin, 1975]. We recommend choosing hearing protectors not very protective [Smeatham and Wheeler, 1998]. This study estimates the attenuation of the protectors and the influence on speech perception in noise. We compare protectors with different attenuation characteristics by various methods. The results show the effect of attenuation characteristics on speech communications [Sutton and Robinson, 1981], [Taibo et al., 1977] and [Waugh, 1984].

2 Occupational noise exposure

OSHA Regulations (Standards–29 CFR) Occupational noise exposure–1926.52 suggests that protection against the effects of noise exposure shall be provided when the sound levels exceed those shown in Table 1. Sound levels are measured on the A–scale of a standard sound level meter at slow response. When employees are subjected to sound levels exceeding those listed in Table 1, feasible administrative or engineering controls shall be utilized. If such controls fail to reduce sound levels within the levels of the table, personal protective equipment as required to reduce sound levels within the levels of the Table 1. If the variations in noise level involve maxima at intervals of 1 second or less, it is to be considered continuous. In all cases where the sound levels exceed the values shown herein, a continuing, effective hearing conservation program shall be administered. When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. Exposure to different levels for various periods of time shall be computed according to the formula:

$$F\left(e\right)=\frac{T\left(1\right)}{L\left(1\right)}+\frac{T\left(2\right)}{L\left(2\right)}+\ldots+\frac{T\left(n\right)}{L\left(n\right)}\,, \tag{1}$$

where $F\left(e\right)$ = the equivalent noise exposure factor, T = the period of noise exposure at any essentially constant level and L = the duration of the permissible noise exposure at the constant level. If the value of $F\left(e\right)$ exceeds unity (1) the exposure exceeds permissible levels. Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.

Duration per day Hours	Sound level dBA slow response
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

Table 1: Permissible noise exposures

The level of exposure to noise by hearing protectors can be estimated by the methods specified by two standards BS EN ISO 4869–2 and BS EN 458.

The BS EN ISO 4869 estimates weighted sound pressure level on workers wearing attenuation devices in noisy environments. The BS EN ISO 4869 compares different hearing protectors; it checks the suitable conditions of hearing protectors; it identifies the device that satisfies the sound characteristics of the work environment.

Considering the characteristics of hearing protectors and the sound levels of noise, we compare three different methods to choose the best hearing protector. The three methods are octave band method, high medium low frequency method and single number rating. The three methods consider the attenuation of noise in octave bands from 63 Hz to 8 Khz). The manufacturers of hearing protectors give information of the characteristics on the data sheets. The characteristics of hearing protectors are the average values with the relative standard deviations. The three methods evaluate the attenuation produced by hearing protectors according to statistical concepts. The difference of 3 Hz of sound pressure level does not affect the efficiency of the hearing protectors. The calculation procedure differs in the three methods.

Octave Band Method (OBM) evaluates the sound pressure levels in octave bands, measured in the workplace. OBM is the reference method, as it considers the actual spectral characteristics of the noise. If there are no levels for octave bands, HML and SNR are valid alternatives. The HML method considers A and C–weighted sound pressure levels. The SNR method considers the C–weighted sound pressure level. If the noises have high or low frequencies, we prefer to adopt OBM or HML.

At the beginning of measurements, workers need a complex dressing. During the test, the worker must turn the head to the right and left, lower and raise the head by itself. The subject must pronounce several times in a loud voice some vowels, open and close the mouth.

The instantaneous levels and average sound pressure levels can describe the noise. The level of exposure can be effected for constant, variable and impulsive level of noise.

Hearing protection with high attenuation restrict the verbal communication. The degree of protection can be assessed as follows:

- If the exposure level of exposure is greater than 90 $\mathrm{dB(A)}$, the hearing protection is low;
- If the exposure level is about $85 - 90$ $\mathrm{dB(A)}$, the hearing protection is acceptable;
- If the exposure level is about $75 - 80$ $\mathrm{dB(A)}$, the hearing protection is adequate;
- If the exposure level is less than 75 $\mathrm{dB(A)}$, the hearing protection is very protective.

3 Hearing Protection Equipment

There are types of hearing protection: disposable ear plugs, reusable ear plugs, banded ear plugs and ear muffs. Hearing protections mitigate the intensity of the sound energy transmitted to the auditory apparatus. The features of hearing protections are the following:

- decrease of sound energy;

- sound reduction in the medium–high frequency noise;
- bandwidth to the frequencies of the voice;
- comfortable for a wide range of ear sizes;
- hypo–allergenic material.

Disposable ear plugs present tapered shape to fit the ear canal comfortably. Ear plugs consist of soft foam that seal the ear comfortably. Ear plugs have smooth and resistant surfaces for hygiene. Ear plugs are comfortable for a wide range of ear sizes and they consist of hypo–allergenic material. Disposable ear plugs can be combined with ear muffs for additional protection.

Reusable ear plugs provides added aspects:

- finger grip design makes insertion easier;
- multi–flanged plugs fit securely into ear canal;
- soft, elastic material conforms to a wide range of ear sizes comfortably;
- ideal for dusty, dirty situations.

Reusable ear plugs can be washed and used many times.

Banded ear plug is a flexible band that makes fitting easy and maintains low pressure over a wide range of head sizes. Banded ear plugs are soft foam pads that close the ear canal opening without being inserted into the ear. Banded ear plugs are comfortable alternatives to ear muffs and ear plugs. Banded ear plugs can be worn with band under the chin or behind head. Banded ear plugs can be used many times.

Ear muffs guarantee different headband positions for versatility. If the headband is worn under the chin or behind the head; adjustable head strap secures ear muffs. Ear muffs consist of padded headband for comfort. Ear muffs have a soft, foam–filled cushions to fit comfortably and securely on the ear. Ear muffs have adjustable swivel cups that enhance comfort and fit. Ear muffs consists of sliding headband that allows easy adjustment to fit a wide range of head sizes.

Hard hat mounted ear muff provides the following aspects:

- durable, lightweight plastic ear;
- beveled cups for better fit under helmets cups;
- ear muffs conveniently flip up and lock when not in use;
- soft foam–filled cushions stay soft after extensive use;
- replacement cushions and inserts available contoured ear cushions to enhance fit;
- unique molded inserts provide large inner space for the ear.

4 Predicting Hearing Protector Effectiveness

To determine the reduction in noise level (at the ear), the performance of the protector is compared with the frequency characteristics of the noise in question. Protector manufacturers are required to provide standard information (BS ISO EN $4869–1 : 1995$) including mean and standard deviation attenuation values at each octave-band centre frequency from 125 Hz to 8 KHz (63 Hz is optional); assumed protection values at each centre frequency (the mean attenuation minus the standard deviation at each frequency).

4.1 Octave Band Method

Octave Band Method is the most accurate prediction method, but requires the most detailed noise measurement and involves the most complicated method of calculating the $L_{A,eq}$ at the ear. The procedure is

- Measure the noise in octave band terms plus the overall $L_{A,eq}$ outside;
- Subtract the octave band assumed protection value for the ear protector;
- Add the A–weighting correction factors in each octave band;
- Convert this sum back to an overall $\mathrm{dB}\,(A)$ level–$L_{A,eq}$ inside;
- The protection in terms of $\mathrm{dB}\,(A)$ is the outside $L_{A,eq}$ minus the inside $L_{A,eq}$.

We apply the following relation

$$L'_{A,eq} = 10 \log \sum_{f=125}^{8000} 10^{0.1\left(L_{A,eq} - APV\right)} \ , \tag{2}$$

4.2 High Medium Low Frequency Method

High Medium Low Frequency Method is the preferred method in the absence of an octave–band spectrum. This method uses the values of high *H*, medium *M* and low *L* frequency to calculate the reduction of the noise level *(PNR)*. The weighted sound pressure level *A* effective $\left(L'_{A,eq}\right)$, measured on the ear equipped with the protection device, is obtained subtracting the weighted sound pressure level *A* $(L_{A,eq})$ and the value *PNR*. The *PNR* is subtracted from the L_{Aeq} to give the assumed level at the ear in $\mathrm{dB(A)}$ ·

$$L'_{A,eq} = L_{A,eq} - PNR \,. \tag{3}$$

The procedure measures the noise in functions of the $L_{A,eq}$ and the $L_{C,eq}$. The PNR, predicted noise level reduction, is calculated from one of two formulae:

- If $(L_{C,eq} - L_{A,eq})$ is less than or equal to 2 dB:

$$PNR = M - \frac{H - M}{4} \left(L_{C,eq} - L_{A,eq} - 2\right) \ , \tag{4}$$

- If $(L_{C,eq} - L_{A,eq})$ is more than 2 dB:

$$PNR = M - \frac{H - M}{8} \left(L_{C,eq} - L_{A,eq} - 2\right) \ , \tag{5}$$

4.3 Single Noise Rating

This method is used with a single measurement of the sound pressure level, in terms of $L_{C,eq}$. The SNR is subtracted from the $L_{A,eq}$ to give the assumed level at the ear in terms of the $L_{A,eq}$:

$$L'_{A,eq} = L_{C,eq} - SNR\,. \tag{6}$$

5 Experimental Analysis

The measuring equipment is calibrated at the beginning of the tests and it occurs at the end of the tests, with a acoustic calibrator class 1 according to *IEC 942*. We measure equivalent value of A–weighted sound pressure level $L_{A,eq}$, equivalent value of C–weighted sound pressure level $L_{C,eq}$, max value of A–weighted sound pressure level $L_{A,fast,max}$, max value of C–weighted sound pressure level $L_{C,fast,max}$, peak level L_{peak} and the analysis in frequency by octave (Tab.3) or third octave bands (Fig.1) of the noise. The microphone of the sound level meter, conforming to the rules *IEC 651* and *804* class *1*, is placed at ear height and 10 cm from the ear. Measurements correspond to the situation of the equivalent level of noise in the workplace. Measurements consider the working cycles of the machine and the operations performed by the worker. Table 2 shows the results of the measurements.

$L_{A,eq}$	$L_{C,eq}$	$L_{A,fast,max}$	$L_{C,fast,max}$	L_{peak}
95.8 dB (A)	95.7 dB (C)	98.6 dB (A)	98.5 dB (C)	112.3 dB (Lin)

Table 2: Results of the measurements

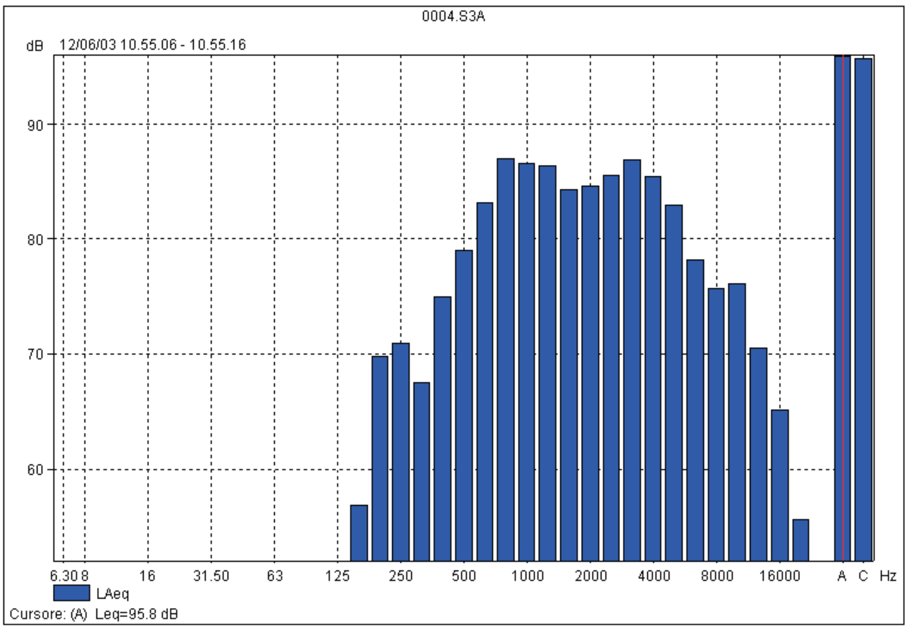

Figure 1: Frequency analysis by third octave bands

Attenuation data for hearing protection products are described in the Tables 4, 5 and 6, where REA is real ear attenuation, SD is standard deviation, APV = REA-SD is assumed protection value.

	Octave Bands							
Hz	125	250	500	1000	2000	4000	8000	16000
$L_{A,eq}$ dB (A)	56.8	70.4	85.1	91.4	89.6	90.1	81.6	71.7
$L_{Lin,eq}$ dB (Lin)	72.9	79.0	88.3	91.4	88.4	89.1	82.7	78.3

Table 3: Frequency analysis by octave bands

$SNR = 27$ and H–M–L = 31–24–16

	Octave Bands							
Hz	63	125	250	500	1000	2000	4000	8000
REA	13.7	11.2	19.1	25.7	29.2	32.0	36.8	39.0
SD	3.9	3.2	2.2	2.7	3.1	2.3	2.7	3.7
APV = REA-SD	9.8	8.0	16.9	23.0	26.1	29.7	34.1	35.3

Table 4: Attenuation data for ear muffs

- **Octave Band Method**. Attenuation data for ear muffs by octave band method
  - *Ear Muffs*. By Eq.(7) the protection provided by hearing protection is good because we get $75 \leq L'_{Aeq} \leq 80$ Hz (Tab.7).

$$L'_{Aeq} = 10 \cdot \log(10^{4.88} + 10^{5.35} + 10^{6.21} + 10^{6.53} + 10^{5.99} + 10^{5.6} + 10^{4.63} + 10^{7.17}) = 77.6 \text{ dB (A)} , \quad (7)$$

  - *Banded Ear Plugs*. From Eq.(8) banded ear plugs, placed behind the neck, is effective, because we obtain $75 \leq L'_{Aeq} \leq 80$ Hz (Tab.8).

$$L'_{Aeq} = 10 \cdot \log(10^{4.09} + 10^{5.73} + 10^{7.29} + 10^{6.28} + 10^{5.71} + 10^{4.96} + 10^{7.17}) = 78 \text{ dB (A)} , \quad (8)$$

- **HML**.
  - *Ear muffs*. Eq. (3) becomes

$$\begin{aligned} PNR =& 24 - \frac{31-24}{4}(-0.1-2) \approx 20 \text{ dB (A)} \\ &\Rightarrow L'_{Aeq} = 95.8 - 20 = 75.8 \text{ dB (A)} \end{aligned} \quad (9)$$

    Ear muffs are considered a good ear protector.
  - *Banded ear plugs*. Eq. (3) becomes

$$\begin{aligned} PNR =& 17 - \frac{25-17}{4}(-0.1-2) \approx 13 \text{ dB (A)} \\ &\Rightarrow L'_{Aeq} = 95.8 - 13 = 82.8 \text{ dB (A)} . \end{aligned} \quad (10)$$

    Banded ear plugs, placed behind the neck, result acceptable.
- **SNR**

$SNR = 23$ and H–M–L = 27–19–17

	Octave Bands							
Hz	63	125	250	500	1000	2000	4000	8000
REA	21.0	20.2	19.8	19.1	23.2	33.4	41.0	40, 7
SD	4.1	4.4	4.2	4.3	3.7	4.5	2.9	5.4
APV = REA-SD	16.9	15.8	15.5	14.8	19.5	29.0	38.1	35.2

Table 5: Attenuation data for banded ear plugs with band under the chin

$SNR = 21$ and H–M–L = 25–17–15

	Octave Bands							
Hz	63	125	250	500	1000	2000	4000	8000
REA	20.1	19.3	17.6	17.7	21.4	30.7	36.7	38.1
SD	4.4	3.4	4.5	5.5	4.1	4.0	3.7	6.1
APV = REA-SD	15.7	15.9	13.1	12.2	17.3	26.8	33.0	32.0

Table 6: Attenuation data for banded ear plugs with band behind head

- *Ear Muffs*. We calculate L'_{Aeq} by the weighted equivalent level *C*:

$$L'_{Aeq} = L_{Ceq} - SNR = 95.7 - 27 = 68.7 \text{ dB (A)} , \tag{11}$$

  Ear muffs is very protective.

- *Banded Ear Plugs*. We calculate L'_{Aeq} by the weighted equivalent level *C*:

$$L'_{Aeq} = L_{Ceq} - SNR = 95.7 - 21 = 74.7 \text{ dB (A)} , \tag{12}$$

  Banded ear plugs are advisable.

In the investigation proposed the same protector can be sometimes appropriate and sometimes inappropriate. In fact, if the method of evaluation is simplified, numerical approximations weigh greater extent.

6 Conclusions

The methods OBM, HML and SNR allow us to evaluate the influence of hearing protector devices on speech intelligibility. Protectors can hinder the understanding of speech, they increase the

	Octave Bands							
Hz	125	250	500	1000	2000	4000	8000	16000
$L_{A,eq}$	56.8	70.4	85.1	91.4	89.6	90.1	81.6	71.7
APV	8.0	16.9	23.0	26.1	29.7	34.1	35.3	0.0
$L_{A,eq}$ - APV	48.8	53.5	62.1	65.3	59.9	56.0	46.3	71.7

Table 7: Attenuation data for ear muffs by octave band method

	Octave Bands							
Hz	125	250	500	1000	2000	4000	8000	16000
$L_{A,eq}$	56.8	70.4	85.1	91.4	89.6	90.1	81.6	71.7
APV	15.9	13.1	12.2	17.3	26.8	33.0	32.0	0.0
$L_{A,eq}$ - APV	40.9	57.3	72.9	74.1	62.8	57.1	49.6	71.7

Table 8: Attenuation data for banded ear plugs by octave band method

difficulties involved in hearing to hear emergency alarms. It needs to choose, in a noisy environment, protectors that can improve verbal intelligibility, and the market offers devices that facilitate their users' spoken communication.

The choice of method to be adopted as standard depends on what degree of uncertainty can be accepted. The octave–band procedure is of course more accurate, but it is time-consuming to calculate the effective protection this way for a range of protectors. We believe that OBM is the most rigorous method to be preferred. APV are provided in the frequency range $15 - 800$ Hz. The HML method expresses the sound attenuation of hearing protectors for the high (H), medium (M) and low (L) frequencies. Predicted noise reduction (PNR) is calculated using the values provided by the manufacturer. The method SNR is very simple but does not take into account the component 16000 dB (A).

Considering that the most important purpose of hearing protectors is to prevent workers from noise. The reduction cannot be a countermeasure against the problems of speech communication. Consequently, industrial workers should be encouraged to wear the hearing protectors with satisfactory attenuation.

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