Noise risk assessment

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Abstract

The work-related risks assessment is a meticulous process that must take into account all the risks to health and safety in a company. The objective of this paper is to evaluate the risk deriving from exposure to noise for the workers of a company X chosen as a model for our purpose.
Exposure to high intensity noise and for long periods of time may cause a permanent increase in the hearing threshold, called bilateral perceptual hearing loss caused by changes in the neuro-sensory structures of the inner ear.
The evaluation process involved the preliminary analysis of the activities carried out by the employees, the identification of noise sources and homogeneous groups of potentially exposed workers, the measurement of noise emission levels and, following the acquisition of exposure to such sources, the calculation of personal exposure levels.
In accordance with the provisions of Legislative Decree 81/08, exposure levels have been calculated on a daily basis for those homogeneous groups that perform fairly routine activities, as in the case of personnel in the bodywork departments (knockers/fitters, painters), mechanical workshop department (mechanical and electromechanical) garage department (handling of vehicles, vehicle washing workers).
The homogeneous group of beater/assembler, mechanical/electromechanical groups has an exposure that exceeds the upper values of action [85 dB (A)] and exceeds the exposure limit value of 87 dB (A). The employer has the obligation to subject workers to health surveillance, to plan a program of corrective measures and to require workers to wear Hearing PPE. Considering the attenuation of the PPE in question the Lex, 8h falls below 87 dB (A).

KEY WORDS: noise, risk assessment, occupational disease, work.

Introduction

The work-related risks assessment is a meticulous process that must take into account all the risks to health and safety in a company. The objective of this paper is to evaluate the risk deriving from exposure to noise for the workers of a company X chosen as a model for our purpose.
The evaluation was performed according to the following methodological steps:

a) Analysis of the working reality and of the activities carried out
b) Identification of measurement stations and homogeneous risk groups
c) Performing phonometric surveys
d) Acquisition from the management of the time spent by the different homogeneous groups in the identified stations, for the calculation of the professional exposure level
e) Processing of acquired data, aimed to calculate personal exposure of workers, possibly taking into account the attenuation produced by PPE where required by law
f) Identification of the most critical situations and indication of any proposals for protective or improvement actions.

This assessment methodology complies with the requirements of the technical standard UNI 9432: 2008 "Acoustics - Determination of the level of personal exposure to noise in the work environment", which defines the sampling and measurement methods with relative uncertainty, the verification of effectiveness of PPE and the characteristics of the instrumentation used, with two-year calibration. For the purposes of the provisions of Article 193 c. 2 of Legislative Decree 81/08 (1), this work has as its primary objective to provide valid indications and correct references for the prevention of risks from exposure of workers to noise and for the planning of effective protection measures, as well as ensuring the fulfillment of legal obligations. Taking into account the attenuation provided by the earpieces worn by the workers, the dual purpose of this article is to assess compliance with the exposure limit values and to check the efficiency of the PPE supplied.

General information about noise

The human ear is sensitive to frequencies between 20 and 20,000 Hz, corresponding respectively to wavelengths of 17 m and 1.7 cm. Noise is a sound sensation considered unpleasant, annoying or intolerable. The audible sound sensation of the human ear is formed by an overpressure of the air. Sound pressure is measured in Pascal (N/m^2). For the purposes of noise risk assessment, the sound pressure P is expressed in Decibel (dB), which is equal to the 10 * logarithm of the ratio between that same value P and a reference value P0.
The sound pressure level Lp is equal to:

$$Lp = 10\,log\,(\frac{p^2}{p_0^2}) = 20\,log\,(\frac{p}{p_0})\,[db]$$

In which:
p = effective value of sound pressure
p0 = 20 μPa = reference sound pressure
In work environments the sound pressure changes constantly and for preventive purposes it is necessary to be able to evaluate its average value in a given time. This mean is called equivalent continuous sound level (Leq) and is equal to:

$$L_{eq} = 10\,LOG\left[\frac{1}{T}\int_0^T \left[\frac{p(t)}{p_0}\right]^2 dt\right]\ in\,[dB]$$

* In this document the logarithm 10 will be indicated for simplicity with the symbol "log".

The sound level thus obtained is equivalent to a hypothetical constant noise that, at the same time T, carries the same amount of sound energy. The human ear is differently sensitive to the different frequencies that make up a normal sound signal. The sensitivity of the human ear has been approximated and standardized over the years with different weighting curves (A, B, C, D) with different protectionist purposes. These standardized weighting curves are used for the phonometric measurements which are therefore expressed in terms of dB (x) with x which corresponds to the different weighing curves (A, B, C, D). Among these, those used in the assessment of workers' health risks as provided for by Legislative Decree 81/08, are the weighting filters A and C, whose weights applied for each octave band central frequency are reported in Table 1 and whose graphical representation is illustrated in Figure 1.

Table 1. Filter weights A and C.

F (Hz)	Curve A [dB]	Curve C [dB]
16	-56.7	-8.5
31,5	-39.4	-3.0
63	-26.2	-0.8
125	-16.1	-0.2
250	-8.6	0
500	-3.2	0
1000	0	0
2000	1.2	-0.2
4000	1.0	-0.8
8000	-1.1	-3.0
16000	-6.6	-8.5

The results of the measurements performed by applying these filters are then expressed in dB (A) and dB (C), respectively. A normal sound signal consists of a series of sounds at different frequencies. The characterization of the wave from the point of view of the component frequencies is called frequency analysis. In frequency analysis the whole spectrum of frequencies (from 20 to 20,000 Hz) is divided into bands of variable amplitude (commonly equal to an octave or a third of an octave) for each of which the corresponding sound pressure level is calculated. An analysis of this type is very useful for the identification of the characteristic frequencies of the phenomenon and, consequently, can be of great help in the choice of any mitigative interventions (sound-absorbing materials, protective shields, personal protection devices). With reference to the definitions reported by the UNI 9432: 2008 standard, it is possible to define the following types of noise:

- Constant noise; stationary noise: noise, with a duration greater than 1 s, with fluctuations between the maximum and the minimum of LAS <3 dB (A) during the observation period.
- Fluctuating noise; non-stationary noise: noise, with a duration greater than 1 s, with fluctuations between the maximum and the minimum of LAS> 3 dB (A) during the observation period.

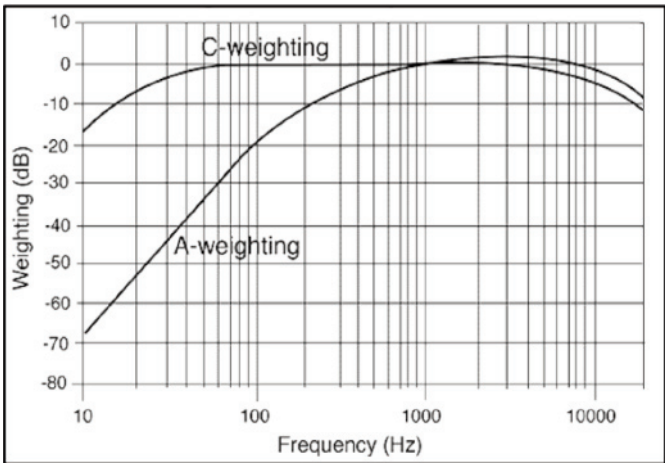

Figure 1. Weighting curves.

- Impulsive noise: noise characterized by steep growth and rapid decay of the sound level, having a duration of less than or equal to 1 s, and generally repeated at intervals.
- Cyclic noise: noise that always repeats with the same characteristics at equal time intervals and greater than the second.

Effects of noise

In terms of auditory effects, noise acts on the ear essentially through acoustic energy. Exposure to high intensity noise and for long periods of time may cause a permanent increase in the hearing threshold, called bilateral perceptual hearing loss caused by changes in the neuro-sensory structures of the inner ear. In Italy, noise-induced hearing loss is the most frequently reported occupational disease. According to INAIL data (2), the professional disease "Hearing loss and deafness from noise" represents the third cause of all cases of occupational diseases in Italy. Moreover, the noise with higher intensity can cause short-term effects also on the vestibular portion with vertigo, nausea, equilibrium disturbances usually reversible after the cessation of the sound stimulus. However, noise can also result in a masking effect that disturbs verbal communications and the perception of acoustic safety signals (with an increase in the probability of accidents at work), promotes the onset of mental fatigue, decreases the efficiency of work performance, causes learning disruption and interference on sleep and rest. In the last thirty years, several studies have demonstrated a correlation between exposure to noise and the development of alterations and/or pathologies in organs and apparatus, apart from the auditory one. Exposure to noise can induce biochemical, physiological, or psychosocial modifications that can remain either inside the range of biological normality or alter and compromise the psychophysical well-being of the individual depending on the extent of the functional alterations of organic systems and psychosocial functions; both the reversibility and duration of the alterations and the adaptation could be related to the recovery capabilitiy of the human organism and to the environmental condition. Among the factors that can influence the effects of noise we can find: intrinsic characteristics of the physical insult (pressure, sound intensity, emission frequency), extrinsic characteristics (duration of the exposure, way of emission, presence of impulsive components, masking effects), spectral characteristics (infrasounds, ultrasounds, time of recovery) genetic factors (susceptibility) and acquired factors of the human organism (acoustic isolation of the living houses and the social necessity for the industrial activities that generate noise). Other factors that influence the damage are the surprise effect, the semantic content and the identification of the noise source. It can be hypothesized that the extra-auditory effects of noise show themselves through a series of nervous circuits that use the autonomic nervous system and interfere on neuro-immune-endocrine parameters. The organs which are more studied are: cardiovascular, gastro-enteric and endocrine systems, nervous system and psychological effects, respiratory system, fetus and effects on reproductive system, immune system and genetic material (3).

Evaluation of noise professional exposure

The following are the criteria and methods for assessing the risks deriving from exposure to noise proposed by Legislative Decree 81/08 and by the recent UNI 9432: 2008 standard.

1. Definitions and parameters

The benchmarks in the risk assessment are:

• Equivalent continuous sound level (LAeq), expressed by the following:

$$L_{eq} = 10\,LOG\,\left[\frac{1}{T}\int_0^T \left[p\frac{(t)}{p0}\right]^2 dt\right]\,in\,[dB]$$

The equivalent level is the level, expressed in dB, of a hypothetical constant noise that, if substituted for the real noise for the same time interval T, would involve

the same total amount of sound energy produced by the acoustic phenomenon.

- Peak acoustic pressure (ppeak): maximum value of the frequency weighted instantaneous acoustic pressure «C».
- Daily noise exposure level (LEX, 8h) [dB (A) referred to 20 μPa]: mean value, time-weighted, of noise exposure levels for a nominal working day of eight hours. It refers to all the noises at work, including impulsive noise. This quantity can be expressed with the formula:

$$L_{EX,8h} = L_{Aq.Te} + 10\,\frac{\log T_e}{T_0}$$

In which:

$$L_{Aq.Te} = 10\log\left\{\frac{1}{Te}\int_0^{Te}\left[\frac{p_A(t)}{p_0}\right]^2 dt\right\}$$

Te = daily duration of a worker's personal exposure to noise, including the daily quota of overtime work;
To = 8h = 28.800 s;
p0 = 20 μPa;
pA = weighted instantaneous acoustic pressure A, in Pascal.

- Weekly international noise exposure level ISO 1999: 1990 point 3.6, note 2. This parameter can be calculated from the individual daily exposure values according to the formula:

$$L_{EX,40h} = 10\log\left[\frac{1}{5}\sum_{k=1}^{m} 10^{0,1\,(L_{EX,8h})k}\right.$$

where (LEX, 8h) k represent LEX, 8h values for each of the m working days of the week considered.

Calculation of the error on a worker's daily personal exposure to noise

The uncertainties associated with the measurement of occupational noise exposure were determined in accordance with Appendix C of UNI EN ISO 9612-2011 (4).
The uncertainties associated with noise exposure measurements were calculated using the spreadsheet downloaded from the UNI website at the following address:
http://catalogo.uni.com/acustica/ISO9612_calculations.html

2. Reference limits

Legislative Decree 81/08 defines three levels of reference in terms of daily noise exposure and peak acoustic pressure, shown schematically in Table 2, for each of which provides for obligations on the part of the employer and workers.
The daily noise exposure level is used as a benchmark when the working time is divided into 5 days per week and the working conditions expose the workers to noise levels that do not undergo significant changes between the different working days.
If, due to the intrinsic characteristics of the work activity, the daily noise exposure varies significantly from one working day to the next, the daily noise exposure level can be replaced with the weekly exposure level, provided that:

a) the weekly noise exposure level, as demonstrated by a suitable control, does not exceed the exposure limit value of 87 dB (A).
b) appropriate measures are taken to minimize the risks associated with these activities.

Finally, if there is a variability in the weekly exposure level, the maximum weekly recurring level should be considered.
With regard to the use of personal protective equipment, Decree 81/08 art. 193, c. 2 establishes that the employer takes into account the attenuation produced by the personal hearing protection devices worn by the workers only for the purpose of evaluating their efficiency and compliance with the exposure limit value. In this regard, it is also clarified that the PPE in use are deemed adequate for the purposes of the provisions established by the same decree if, used correctly, guarantee a lower exposure level or at most equal to the lower value of action [80 dB (A)].

3. Risk assessment and prevention and protection measures

If, after assessing the level, type and duration of workers' noise exposure (including any exposure to impulsive noise), all effects on the health and safety of workers particularly sensitive to noise (minors and pregnant women), all effects on the health and safety of workers resulting from interactions between noise and ototoxic substances related to the activity carried out (as far as possible at a technical level) and between noise and vibrations, information on noise emission provided by manufacturers of the work equipment, the interaction between noise and warning signals, etc., the Employer believes that the lower values of action can be exceeded [LEX, 8h = 80 dB (A) and ppeak = 135 dB (C)], measures the noise levels to which workers are exposed and reports the results in the evaluation document.
Depending on the results of these measurement activ-

Table 2. References limits.

Reference value	Daily exposure level lex, 8h	Peak pressure ppeak
Exposure limit values	87 dB (A)	200 Pa (140 dB (C) referred to 20 μPa)
Higher values of action	85 dB (A)	140 Pa (137 dB (C) referred to 20 μPa)
Lower values of action	80 dB (A)	112 Pa (135 dB (C) referred to 20 μPa)

ities, different obligations may arise depending on the calculated daily exposure level (LEX, 8h) or the measured peak pressure (ppeak).
Regardless of the personal exposure values, in the workplace where workers may be exposed to a noise above the upper values of action [i.e. those with LAeq ≥85 dB (A)] appropriate signage must be installed (signaling Noisy zone and PPE obligation). These areas must also be delimited and, if technically possible and justified by the risk of exposure, access to them must be limited.

Personal daily noise exposure level ≥ 80 dB (A) or peak acoustic pressure ≥ 112 Pa [135 dB (C) referred to 20 μPa]
The employer ensures that the workers, or their representatives, are informed about:
- risks arising from hearing due to exposure to noise
- the measures taken in application of the rules envisaged
- the protection measures to which workers must comply
- the function of individual protection means
- the meaning and role of health control
- the results and significance of the risk assessment.

The employer makes personal protective equipment available to workers. Furthermore, it develops and implements a program of technical and organizational measures to reduce noise exposure.

Personal daily noise exposure level ≥ 85 dB (A) or peak acoustic pressure ≥ 140 Pa [137 dB (C) referred to 20 μPa]
The employer ensures that the workers, or their representatives, are informed about:
- risks arising from hearing due to exposure to noise
- the measures taken in application of the rules envisaged
- the protection measures to which workers must comply
- the function of individual protection means
- the meaning and role of health control
- the results and significance of the risk assessment.

The employer makes the personal protective equipment available to workers and supervises their effective use. Activate health surveillance. Furthermore, it develops and implements a program of technical and organizational measures to reduce noise exposure.

Personal daily noise exposure level ≥ 87 dB (A) or peak acoustic pressure ≥ 200 Pa [140 dB (C) referred to 20 μPa)
This level of exposure must never be exceeded. In workplaces which may involve personal daily exposure of more than 87 dB (A), the employer:
- takes immediate measures to bring the exposure below the exposure limit values
- identify the causes of excessive exposure
- modifies the prevention and protection measures to prevent the situation from happening again.

The verification of compliance with the exposure limits must be carried out taking into account the attenuation produced by the PPE; however, there remains the obligation to implement the technical or organizational measures (health surveillance, information and training, etc.) foreseen for the reduction of noise exposure.

4. Evaluation of hudget protection devices
Appendix D of the UNI 9432: 2008 standard contains procedures and evaluation of hearing PPE according to what is reported in the following paragraphs.

Calculation of optimal attenuation and equivalent sound level resulting from the use of PPE
To assess the extent of the optimal attenuation provided by the ear protectors, Appendix A of the UNI EN 458: 2005 allows the use of four calculation methods, which take into account the data acquired during the measurement and on the attenuation characteristics of the PPE declared by the manufacturer.
The optimal attenuation provided by the ear protection devices is measured in the laboratory according to a test procedure illustrated in UNI EN 24869-1. On the basis of these data different attenuation descriptors are calculated, with the methods indicated in the UNI EN ISO 4869-2.
The information on the characteristics of attenuation of the PPE, mandatory for the placing on the market of each PPE, are expressed in 3 ways:
- APVf: is the presumed optimal attenuation and is expressed with a series of values in dB, and is representative of the PPE sound attenuation in the octave band frequency spectrum ranging from 125Hz to 8kHz (sometimes it is also included the frequency of 63Hz); in case both the mean attenuation values and the presumed values are expressed (expressed as the difference between the optimal average attenuation and the standard deviation), the presumed protection values must be used for the calculations.
- H, M, L: is expressed with 3 values, in dB, the sound attenuation of the PPE for the high (H), medium (M) and low (L) frequencies; the manufacturer derives H, M, L from APVf values.
- SNR: the simplified noise attenuation (Simplified Noise Reduction) of the PPE is expressed with a single value, in dB; SNR is also obtained from the values in the octave band.

The methods considered (and the relevant reference standards) are:
1. the OBM method (Octave-band Method) or by octave bands (UNI EN 458: 2005 standard)
2. the HML method (UNI EN 458: 2005 standard)
3. the SNR method (UNI EN 458: 2005 standard)
4. the HML control method (UNI EN 458: 2005 standard).

The measured data necessary for the application of the various methods can be:

- noise levels per octave band
- the equivalent level of weighted noise according to curve A
- the equivalent level of weighted noise according to curve C.

Regardless of the method adopted, for each of the situations or measurement stations for which to calculate the attenuation produced by PPE, starting from the measured data relative to the weighted equivalent level according to curve A (LAeq), the actual level at the ear is calculated The Aeq.

The following is a description of the different methods applicable for the assessment of attenuation produced by Hearing Protection Devices.

It should be noted that the UNI 9432: 2008 standard (point D.1.1 of Appendix D) recommends avoiding the HML control method, being based on subjective input values (noise class), which may lead to a result "undetermined". For this reason, below, we have chosen to neglect its description.

A. The OBM method

To apply this method it is necessary to know the octave band noise levels measured in the workplace and the octave band attenuation data APVf of the considered ear protector.

The value of L'Aeq is obtained from the following formula:

$$L_{Aeq} = 10\ log \sum f\ [10^{(L_f + A_f - APV_f)}]$$

In which:

- f and the octave band central frequency of the spectrum between 125 and 8000Hz
- Lf and the noise level in dB in the octave band f
- Af and the frequency weighting of the A curve in dB in the octave band f (Table 1)
- APVf and the presumed protection value of the auricular protector in dB in the octave band f.

B. The HML method

To apply the HML method it is necessary to know the equivalent noise level values at the weighted workplace according to the curves A and C, LAeq and LCeq and the three attenuation values H, M and L of the considered ear protector.

The value of L'Aeq is obtained from the following formula:

$$L'_{Aeq} = L_{Aeq} - PNR$$

in which PNR (planned noise level reduction) is calculated using one of the following formulas, depending on the difference between LCeq and LAeq, then rounding to the nearest whole number:

$$\text{PNR} = M - \frac{H-M}{4}\left(L_{Ceq} - L_{Aeq} - 2\right)[dB]\ per\ L_{Ceq} - L_{Aeq} \leq 2\ dB$$

$$\text{PNR} = M - \frac{M-L}{8}\left(L_{Ceq} - L_{Aeq} - 2\right)[dB]\ per\ L_{Ceq} - L_{Aeq} > 2\ dB$$

C. The SNR method

For the application of this method it is necessary to know the weighted equivalent level C (LCeq) measured at the workplace and the SNR value declared by the manufacturer of the PPE.

The value of L'Aeq is therefore obtained from the following simple relation:

$$L'_{Aeq} = L_{Ceq} - SNR$$

Evaluation of PPE with reference to the obligations established by the legislation in force

Once the equivalent continuous sound level is determined for a worker who carries out a specific activity using a specific ear protection device, the first objective is to evaluate the adequacy of the supplied PPE or to verify if that specific device in that specific location is able or less to ensure compliance with the lower limit value of action.

To do this, the level of protection of the PPE is determined to check its adequacy as indicated in Table 4, extracted from UNI EN 458: 1995.

It is important to point out that in the specific case of the autopark, the PPE supplied is worn only by the workshop staff, while for the freight workers the protection must be guaranteed at the environmental level, through the constructive characteristics of the vehicles and not individual through a PPE that could in some way hinder the normal course of driving of the vehicle itself, as well as being prohibited by the highway code for drivers.

An ear protection device is considered acoustically suitable to obtain a "good" or "acceptable" protection, that is a continuous sound level equivalent to the worn device, L'Aeq, Te, as indicated in Table 3.

If the Aeq, Te> 80 dB (A), the attenuation provided by the ear protection device is insufficient and the device itself must be replaced by another device with greater attenuation capacity.

Values of L'Aeq, Te <65 dB (A) can however be considered acceptable upon verification of the absence of contraindications related to listening to acoustic warning signals, alarms or feelings of isolation manifested by the worker.

The adequacy of the ear protection device is also subject to the condition of L peak, C ≤135 dB (C) for all work activities.

Given the exposure levels measured in the field, the second objective of the present survey is to verify compliance with the exposure limit values [LEX, 8h = 87 dB (A) and L Peak, C = 140 dB (C)]. To do this it is necessary to consider that, in any case, the adoption of the ear protection devices must ensure that these exposure limit values are not exceeded.

If the assessment criteria referred to in the previous points are respected (verification of the adequacy of the ear PPE), the exposure limit values are always respected. In the special cases in which the criteria defined in the previous points cannot be respected, the calculation of the exposure levels must be carried out

Table 3. Estimate of the level of protection provided by the ear protection device according to the continuous sound level equivalent to the device worn.

Equivalent continuous sound level calculated taking into account the ear protection device The Aeq, Te dB (A)	Protection level
Greater than 80 dB	Insufficient
From 75 to 80 dB	Acceptable
From 70 to 75 dB	Good
From 65 to 70 dB	Acceptable
Less than 65 dB	Too high

(LEX, 8h) taking into account the attenuation of the ear protection devices, solely for the purpose of comparison with the exposure limit values.
If LEX, 8h> 87 dB (A), the attenuation provided by the ear protection device is not sufficient to meet the limit value established by the legislation in force and a series of immediate initiatives will have to be envisaged to remove the causes that determine this exposure.
The comparison of the peak sound level with the respective exposure limit value is made by direct comparison between the highest L peak, C and the limit value of 140 dB (C).
In the event that even in one circumstance the condition L Peak, C <140 dB (C) is not respected, the attenuation provided by the ear protection device is not sufficient to respect the limit value established by the legislation in force and it is necessary to provide a series of immediate initiatives aimed at removing the causes that determine this situation.

Evaluation of effectiveness
In the context of noise risk assessment it is necessary to verify the effectiveness of the ear protection devices.
This analysis includes an assessment of the entire management system for the use and maintenance of hearing protection devices which includes:

- Control of the hearing function of workers, based on the data reported in the anonymous and collective health report prepared by the Occupational Physician; in case of worsening, the Employer, together with the Occupational Physician, will have to verify the connection with the exhibition conditions.
- The verification of the effectiveness and efficiency of the control system of the use and maintenance of the ear protection devices that guarantees:
  - the perfect state and full efficiency
  - training in the use of workers and their correct use
  - the regular and systematic identification of risk situations
  - correct custody, maintenance and prompt replacement in case of need.

Evaluation of real actuation produced by audit protective equipment

The calculation methods previously described (OBM, HML, SNR, HML control) are all based on the attenuation data provided by the manufacturers of the ear protection devices. These data are estimated by detecting the hearing threshold of a group of subjects exposed to standard signals from loudspeakers, worn and unworn PPE.
The laboratory conditions according to which these tests are carried out, defined in detail by the ISO 4869-1: 1990 standard, refer to the ideal situation of use of PPE and very often are different from the real conditions of use in the workplace.
There are numerous elements that indicate that the attenuation measured in the laboratory is a strong overestimation of the attenuation obtainable in real work environments, for a number of reasons, the main of which concern:

- the size of the devices, sometimes inadequate to the physical characteristics of the workers (typically for the preformed ear protection devices)
- deterioration of the materials that constitute the ear protection device, linked to aging or inadequate preservation of the device itself
- the presence of long hair, beard, glasses, earrings, caps, etc. which make a good soundproofing of the headphones problematic
- the approximate placement or insertion of the ear protection device, which does not comply with the criteria established by the manufacturer
- displacement of the ear protection device from the original site (e.g. inserts moving out of the ear canal due to mandibular movements or headphones moving for head movements)
- lack of workers' knowledge of IP dressing and maintenance procedures
- type of noise at the workplace, which may be different from the simulated one in the standard tests
- discomfort produced by the PPE, which causes the worker to move the device
- the joint use of other non-hearing PPE (e.g. helmets, glasses).

Remember that some of the behaviors mentioned above are not in conformity with the provisions of current legislation. To take into account the loss of attenuation due to the elements listed above, the attenuation values obtained with the calculation methods seen above are multiplied by the β coefficients reported in Table 4.

Table 4. Values of the multiplicative coefficient β.

PPE for hearing	β
Headphones	0,75
Expandable inserts	0,5
Preformed inserts	0,3

The above factors are indicated by the NIOSH (National Institute of Occupational Safety and Health), in order to be multiplied by the NRR index and are based on a series of experimental data: the NRR index is similar to the SNR index (subject to some methodological differences in its determination and the use of a coverage factor fc = 2).
Values of β greater than those indicated in Table 5 (but obviously always less than 1) are possible in the event that the Employer guarantees compliance with the following rules:

- training of workers very accurate and repeated frequently
- strict control of the correct use of the supplied ear protection devices
- preparation and implementation of specific procedures regarding the conservation of ear protection devices and their replacement, in order to guarantee the original efficiency during the period of use.

For the purposes of the present survey, for the processing of the data collected in the field, it was decided to make an assessment of the attenuation ensured by the PPE used by the workers using the "HML" calculation method and using for the estimation of the actual attenuation. of the same PPE the correction coefficients above, that is a factor β equal to 0.75 to the headphones and equal to 0.5 for the earplugs (the real attenuation and so estimated equal to 75% and 50% respectively of the optimal provided by the manufacturer of the PPE).

Survey of sound levels

1. Measuring instruments
The phonometric measurements were performed using Larson & Davis 824 integrator sound level meters, complying with the requirements of the IEC 651 group 1 and IEC 804 group 1 standards.
If the sound level varies it must be able to follow the variations but, if these are too fast, it may be impossible to measure them. To overcome this problem, the tool allows to carry out measurements using different time constants:

- FAST (fast), used when you want to follow the fluctuations that are not too fast
- SLOW (slow), which allows to dampen noise fluctuations
- IMPULSE, used in the case of the presence of so-called impulsive noise (i.e. short-term sound); in fact, in order to evaluate the noise of this type of sound, it is necessary to take into account the fact that the softer sound is shorter and the ear is perceived. For this reason the constant IMPULSE implies the use of an electric circuit whose sensitivity decreases with the duration of the sound
- PEACK, used to verify the instantaneous sound pressure level.

In compliance with the UNI 9432: 2008 standard, at the beginning and at the end of the measurement series, an acoustic calibration of the entire measurement chain was carried out using the appropriate CEL 284/2 calibrator.
Finally, the certificates of calibration of the instrumentation used for the realization of the present survey must be attached.

2. Measurement methods
As regards the measurement methods, reference is made to the provisions of the UNI 9432: 2008 standard.
In particular, the measurements were carried out by positioning the measuring microphone in the middle of

Table 5. Activities carried out by the employees.

Workers	Operations performed	Departments involved
Editors/Beaters	Typing, assembly and disassembly of bodywork parts	Bodywork
Varnishers	Stuccoing and painting of vehicles	Bodywork
Mechanical and electromechanical	Ordinary and extraordinary maintenance operations of passenger cars	Repair shop - Mechanical Department
Workers handling vehicles	Logistic management and maneuvering of s parked vehicle	Garage
Washing workers	Manual and automated washing of vehicles	Garage

the area generally occupied by the worker's head, directing it towards the noise sources, and in such a way as not to alter the normal conditions of exposure present in the workplace.
In cases where the presence of the worker was essential for maintaining the usual reference exposure situation, the microphone was placed at about 0.1 m from the operator's ear and oriented in the same direction in which the worker addresses the look, during the execution of its activity, or, if this was not possible, the microphone has been positioned and oriented so as to better represent the real exposure to noise.
The duration of each measure was defined according to the location investigated and the type of noise measured. Generally in the presence of constant or cyclic noise the duration of the measurement is sufficient to obtain the stabilization of the instrument, and in any case superior to 1 minute. In the case of measures related to fluctuating (non-stationary) noise or to work or control paths, the duration of the measure coincided with the duration of the work cycle (or operation) or of the path itself.

Evaluation of risks

For a proper assessment of the risk of occupational exposure to noise it is necessary:
- carry out a proper analysis of the work environments subject to monitoring by describing the activities carried out
- identify the significant sound sources
- carry out a study of the different activities carried out by personnel for their classification in Homogeneous Exposure Groups
- acquire the time required to carry out activities in the various workplaces.

Below are the criteria for carrying out the specific investigation, the characteristics of the PPE used and how the data were processed and the levels of occupational exposure assessed.

1. Description of activities

The activities carried out within the site are related, with regard to the types of risk identified, to the following:
- mechanical maintenance of motor vehicles (mechanical and electromechanical workshop);
- activities of beating and assembling/dismantling vehicle parts
- vehicle painting activity
- vehicle handling activities inside the garage
- manual and automated washing of vehicles.

The Table 5 summarizes the operations performed by the persons in charge.

2. Identification of noise sources

Inside the workshop there are three different departments:
- Bobywork department where beating and painting operations are carried out
- Mechanical department and repair shop where mechanical and electromechanical repairs of vehicles are carried out
- Garage in which the vehicles are moved and washed.

Each department is equipped with different equipment and machinery depending on the operations that are performed by individual workers.

3. Identifying the homogeneid risk groups

Based on the analysis of noise sources and the information provided by management on the activities carried out and the areas frequented by the various operators, it was possible to identify the homogeneous groups of workers, or those who are "homogeneously" exposed to health risks and safety arising from exposure to noise.
The Table 6 shows the homogeneous groups for which it is reasonable to assume a level of exposure to noise higher than the lower limit of action [equal to 80 dB (A)].
Occupational exposure relative to all homogeneous groups not present in the previous table, which do not perform "noisy" activities or do not attend acoustically critical positions, is to be considered inferior to lower values of action.

4. Acquisition of permanent times

Through the management it was possible to acquire information to determine the effective duration of the operations and consequently calculate the time spent on the noise of the various tasks.
As far as the operators working on board the ambulances are concerned, they perform their duties on the

Table 6. Homogeneous groups with possible exposure higher than the lower values of action [80 dB (A)].

Department	Job
Bodywork	Beaters
	Editors
	Varnishers
Mechanical workshop	Mechanical and electromechanical workers
Garage	Workers handling the vehicles
	Washing workers

wave of the emergency, finding themselves in very different work situations; an analysis based on the study of individual cases would have been of little use, as well as difficult.
As far as the workshop workers are concerned, the time taken to use the equipment was provided by internal contacts.

5. Criteria for the execution of the survey

From the in-depth analysis of the activities carried out, an operational measurement program has been defined, identifying the significant equipment and/or machinery from the point of view of noise exposure.
In particular, as regards the measurement and the identification of the noise value generated by the equipment and/or machinery, the following is emphasized:

1. the measurement was carried out during the regular operation of the operations
2. measurements were made both with a single working tool and with the use of all the equipment.

Instead, to evaluate the dose of energy to which the workers are exposed, information on the times of the activities in the various workstations was obtained.
It was decided to identify more working days like a week of work so as to calculate in addition to the Lex, 8h daily, even the LEX, w weekly.
All the data collected for the various workstations or workplaces were then processed analytically in order to obtain LEX, 8h or weekly LEX daily exposure levels, w.

6. Characteristics of PPE used

The Table 7 shows the characteristics (brand, model, attenuation) of the PPE supplied to the workshop workers.
For the verification of the adequacy of the PPE at all the measurement stations, the calculation of the LAeq was carried out using the HML calculation method. This value of the equivalent continuous sound level, which takes into account the real attenuation of the PPE, was then compared with the lower value of action [80dB (A)]. From this comparison it is possible to draw up a list of all workstations for which the PPE in use are adequate and those for which the attenuation provided by them and, on the contrary, insufficient.
For the evaluation of the attenuation produced by the PPE in use, it was decided to apply in the calculation the only device supplied, the Bilsom Loton headphones, to homogeneous groups whose level of daily exposure to noise without PPE was higher than the exposure limit value, applying a correction factor of 0.75.

7. Data processing and evaluation of professional exposure levels

The calculation of personal exposure was made through a database that allows to obtain the values of LEX, 8h associated with each homogeneous risk group, starting from the results of the instrumental measurements and the definition of the time spent by the operators in the various positions.
The measurements are grouped by department and for each station and reported the equivalent sound level with weighting scale A [LA, eq in dB (A)], the peak sound pressure value [ppeak in dB (C)] and any measurement notes.
They are then reported the measurements made that showed a value of LA, eq higher than 80 dB (A), divided into three classes:

1. workstations with 80 dB (A) <LA, eq ≤ 85 dB (A)
2. workstations with 85 dB (A) <LA, eq ≤ 87 dB (A)
3. workstations with LA, eq> 87 dB (A).

In this regard it is recalled that, as provided for by art. 192, c. 3 of Legislative Decree 81/08 (1), the areas with LA, eq> 85 dB (A) or with ppeak> 137 dB (C), must be indicated by an appropriate sign (noisy area signaling and PPE obligation). These areas must be delimited and access to them must be limited (where this is technically possible and justified by the risk of exposure).
For the assessment of the adequacy of the PPE supplied to the workers, we proceed by comparing the lower values of action established by the Legislative Decree 81/08 with the values of LA, eq calculated taking into account the attenuation ensured by the earpieces in use for all those positions at which the measured values of LA, eq were higher than the aforementioned limits. This verification is also made with reference to the peak sound level and the corresponding lower value of action.
As already mentioned in the previous paragraphs, for the assessment of the personal exposure to noise of the various homogeneous groups identified it was necessary to acquire the time spent in the various workstations or positions. The analytical processing of these data allowed to obtain the values of LEX, 8h.
For each homogeneous group are listed the stations attended, sorted by department and for each of them are reported:

Table 7. Characteristics of attenuation of PPE.

PPE brand	Attenuation characteristics in dB										
	SNR	H	M	L	APV_1						
					125	250	500	1000	2000	4000	8000
Bilsom Loton Cap	28,00	35,00	25,00	17,00	9,90	13,20	21,70	31,10	28,90	33,20	24,70

1. time spent
2. the measured value of LA, eq
3. the percentage incidence that the stay in the individual stations has on the overall level of daily sound exposure (LEX, 8h) of the individual operator
4. any notes relating to the measure
5. LEX daily exposure level, 8h calculated; for all those homogeneous groups for which this should be higher than the exposure limit value [87 dB (A)], we proceed to calculate the LEX, 8h starting from the LA, eq which take into account the attenuation produced by the PPE of the hearing, evaluated for all those positions for which the LA, and q were higher than the upper action value [85 dB (A)]
6. the LEX weekly exposure level, w calculated for all homogeneous groups performing work activities with daily noise exposure that varies significantly from one day to another.

The staff can also be divided into groups depending on the value of LEX, 8h.

This subdivision by level of exposure of the professional figures investigated follows the following criteria:

1. exposure below the lower levels of action
2. exposure between lower levels of action and higher levels of action
3. higher exposure to higher levels of action.

For all the professional figures present in the examined site and not explicitly mentioned in the aforementioned evaluation, on the basis of the measurements carried out in the areas frequented, daily exposure levels of less than 80 dB (A) are assumed.

Analysis and conclusions

The following paragraphs analyze in detail the situation of the single positions and homogeneous groups in order to identify any adjustment measures that the Employer must adopt.

1. Analysis of the stations

With regard to the mechanics workshop and the bodywork department (beaters, assemblers, painters, mechanics), they use equipment that exceeds the value of 85 dbA (e.g. beater, grinding wheel, pneumatic gun, drill, etc.).

For these, and in general for all those characterized by an LA, eq> 85 dB (A), in addition to the use of suitable personal protection devices and the application of adequate signage, it is advisable to limit the operators' residence time as much as possible in the areas in question.

2. Analysis of the adequacy of ppe

As regards the verification of the adequacy of the PPE used at the workshop, the only type provided to the workers is the Bilsom Loton cap, used by the workers employed in the Workshops.

In light of the study conducted, it is noted that the equivalent sound levels are significantly attenuated for most stations where the values measured in the field were higher than 80 dB (A), while for some equipment used in the mechanical workshop and in the department bodywork (such as for example the pneumatic hammer or in the case of simultaneous use by several operators, the grinding wheel, the siren, and the pneumatic gun, etc.) the PPE appears to be "unsuitable" even if slightly above the lower value of action. These positions must be inserted first in the company protection and prevention program, delimiting them with appropriate signs from adjacent areas, providing the workers concerned with a PPE with greater abatement capacity and considering the possibility that, as an alternative to personal protection, where it is not possible with it to guarantee the reduction of the noise threshold below the limit value of action, we must intervene directly on the source or limiting the exposure time to the same.

3. Analysis of individual exposure

The analysis of the exposure of workers to noise, carried out using the methods previously described and using data on the time spent by workers in the various positions provided by the management, highlighted the following situation:

1. The homogeneous group of the Varnishers, employed in handling the vehicles and employed in the washing of the vehicles presents an exposure value higher than the lower value of action, i.e. at 80 dB (A). Therefore the employer has the obligation to plan a program of mitigation measures, make available to Hearing PPE workers and to provide suitable information and training of workers in relation to the risks arising from exposure to noise.
2. The homogeneous group of Beaters/Mounters, Mechanical/Electromechanical has an exposure that exceeds the upper values of action [85 dB (A)] and exceeds the exposure limit value of 87 dB (A). The employer has the obligation to subject workers to health surveillance, to plan a program of corrective measures and to require workers to wear Hearing PPE. Considering the attenuation of the PPE in question the Lex, 8h falls below 87 dB (A).

Please note that for the tasks whose Lex, 8h was higher than the exposure limit value, the evaluation of the Lex, 8h occurred by evaluating the LA, eq for all those positions where the LA, eq were higher than 85 dB (A), in compliance with the obligation for the Employer to require that the hearing protectors provided are worn by the workers.

4. Indications for the intervention program

With reference to the provisions of art. 192 c. 2, if following the evaluation it results that the lower values of action are exceeded, the employer must develop and apply a program of technical and organizational measures aimed at reducing the exposure to noise, considering in particular:

a) the adoption of other working methods that imply less exposure to noise
b) the choice of suitable work equipment, taking into account the work to be carried out, which emit the least possible noise
c) the design of the structure of places and workplaces
d) adequate information and training on the correct use of work equipment so as to minimize their exposure to noise
e) the adoption of technical measures for containment:
   - noise transmitted by air, such as shielding, casings or coverings made of sound-absorbing materials;
   - structural noise, such as damping or insulation systems;
f) appropriate maintenance programs for work equipment, the workplace and workplace systems;
g) noise reduction through better organization of work by limiting the duration and intensity of exposure and adopting appropriate working hours, with sufficient rest periods.

The results of the intervention program must be documented in compliance with art. 28, of Legislative Decree 81/08.

In the particular case of the Company X, in compliance with the obligations arising from the exceeding of the higher levels of action, for the homogeneous groups exposed, in addition to the preparation of health surveillance, as part of the program of technical and organizational measures referred to above, we recommend to evaluate the possibility of reducing the time spent in the noisiest positions.

In any case it is considered essential that workers wear the PPE made available to them, if they are to carry out activities or to attend locations with an equivalent level of noise measured (LA, eq) above 85 dB (A).

It is useful to remember that, as foreseen by the Legislative Decree 81/08, the use of the PPE of the hearing requires a specific training aimed to learn the correct use of the PPE in order to minimize the cases in which the improper use of the PPE effect of sound pressure attenuation.

Conclusions

The evaluation process involved the preliminary analysis of the activities carried out by the employees, the identification of noise sources and homogeneous groups of potentially exposed workers, the measurement of noise emission levels and, following the acquisition of exposure to such sources, the calculation of personal exposure levels.

In accordance with the provisions of Legislative Decree 81/08, exposure levels have been calculated on a daily basis for those homogeneous groups that perform fairly routine activities, as in the case of personnel in the bodywork departments (knockers/fitters, painters), mechanical workshop department (mechanical and electromechanical) garage department (handling of vehicles, vehicle washing workers).

The results of the evaluation can be summarized as follows:

- The homogeneous group of the varnishers, attendants to the movement of the vehicles and those responsible for washing the vehicles presents an exposure value higher than the lower value of action, i.e. at 80 dB (A). Therefore the employer has the obligation to plan a program of mitigation measures, make available to Hearing PPE workers and to provide suitable information and training of workers in relation to the risks arising from exposure to noise.
- The homogeneous group of beater/assembler, mechanical/electromechanical groups has an exposure that exceeds the upper values of action [85 dB (A)] and exceeds the exposure limit value of 87 dB (A). The employer has the obligation to subject workers to health surveillance, to plan a program of corrective measures and to require workers to wear Hearing PPE. Considering the attenuation of the PPE in question the Lex, 8h falls below 87 dB (A).

There is recommend to:

- review the time spent in the most critical areas, minimizing the time required to carry out specific activities
- replace the ear protectors currently supplied to the mechanics workshop and the bodywork department as they are in some circumstances unfit for use as they are not adequate to reduce the level of noise exposure below 80 dB (A)
- stay suitable signage inside the mechanical workshop and bodywork shop.

The assessment of risks deriving from noise exposure is repeated at least four years as required by art. 181 c. 2 of Legislative Decree 81/08, as well as updated in the case of significant plant-organizational changes or when the results of health surveillance show the necessity.

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