Selecting a hearing protection Device

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October 2011

The selection and implementation of hearing protection devices today requires the knowledge of various parameters, such as the law, working conditions of employees, their levels of exposure to noise, the different hearing protectors available, and their characteristics.

This study will give you the key factors to keep in mind for selecting the best hearing protectors and ensuring they are worn.

We shall also see that the attenuation values displayed by the manufacturers of HPD (Hearing Protection Devices) do not match actual values, and reductions must be applied.

Protection against noise

E-121.4

Table of contents

1 Noise

Noise is a complex sound produced by various vibrations, that is often absorbed and not harmonic (Honneger, 1976 [[1]).

1.1 Everyday noise

Two out of three persons in France are affected.

According to a report by P. Meunier et C. Bouillon – Mission d'information sur les nuisances sonores (2011) (fact-finding report on noise) – prepared by a fact-finding expert mission on noise problems, two out of three persons in France are affected by noise caused by vehicles, or at the workplace or at home.

Five million French are affected with hearing impairment, of which 2 million are less than 55 years old. 15% of the population wears hearing aids. More than 5 million people suffer from tinnitus: an abnormal auditory sensation (buzzing, ringing in the ears) that is not caused by an external sound.

A recent report from the World Health Organization (WHO, 2011 [3]) estimates that each year, 1.6 million healthy life years are lost in Western Europe because of physiological and mental harm caused by excessive exposure to noise for long durations.

These (healthy) life years lost each year are divided as follows:

- 61,000 years for cardiovascular diseases
- 45,000 years for cognitive impairments in children
- 903,000 years for sleep disturbances
- 22,000 years for acute acoustic trauma
- 587,000 years for impairment

1.2 Noise at work

Three million employees in France reported being exposed to noise above 85dB (A) in 2003 (SUMER Report, 2003 [4]).

In Table 1, we see that while some sectors provide their employees exposed to noise with 85% protection, the average shows that one employee out of 3 is not protected. We also note that the more frequent the noise exposure is in an area, the better the hearing protection.

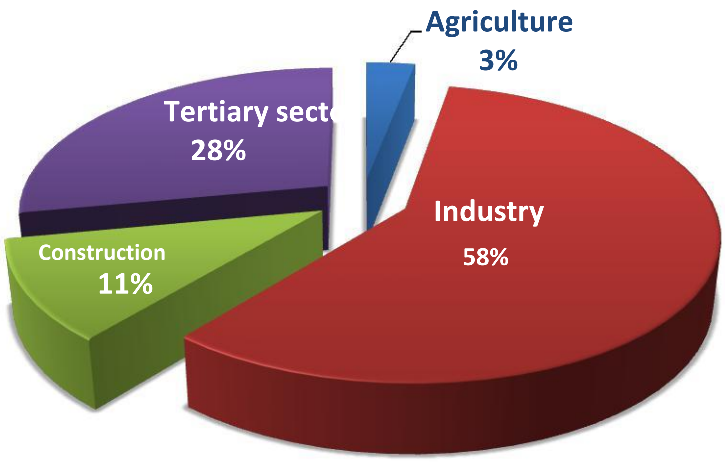
Economic sector	Employees exposed to noise noise > 85dB (A) + 20 hours/week	Among them, those without hearing protection
Pulp and paper industry	37.4%	18.1%
Metallurgy and metallurgical processes	33.3%	20.4%
Mineral products industry	26.3%	14.1%
Automobile industry	21.1%	18.6%
Mechanical equipment industry	21.0%	20.3%
Textile industry	20.0%	28.2%
Food and agricultural industry	18.2.%	26.1%
Chemicals, rubber, plastics	16.9%	23.7%
Household equipment industry	16.1%	17.8%
Agriculture, silviculture, and fishing	13.0%	32.9%
Shipbuilding, aerospace, and railway	13.0%	27.5%
construction	11.5%	29.5%
Clothing, leather	10.5%	NS
Publishing, printing and reproduction	10.4%	39.3%
Operational services	10.2%	40.0%
Automotive sales and repairs	9.4%	49.7%
Electrical and electronic components	8.5%	NS
Pharmacy, perfumery, and personal care	7.6%	NS
Electrical and electronic equipment	3.9%	NS
Wholesale trade	3.9%	49.4%
Transport	3.3%	66.2%
Recreational, cultural, and sports activities	2.2%	NS
Water, gas, electricity	2.1%	25.5%
Hotels and restaurants	2.0%	NS
Personal and household services	1.9%	NS
Health, social welfare	1.3%	59.1%
Research and development	1.2%	NS
Education	1.0%	NS
Guidance and support	0.7%	NS
Public administration	0.7%	NS
Associative and offshore activities	0.6%	NS
Retail trade, repairs	0.5%	NS
Real estate	0.5%	NS
Financial activities	0.3%	NS
Post and telecommunications	0.1%	NS
Together	**6.8%**	**32.0%**

Table 1: Extract from SUMER report 2003 *NS: Not Significant*

One in three employees exposed to sound intensities > 85dB (A) are not protected.

The 2003 SUMER report (medical and occupational risk surveillance) indicates that nearly 7% of employees are exposed to noise levels above 85dB (A) for longer than 20 hours/week.

In industries, 77% of employees exposed are provided with hearing protection. 71% are in construction and 67% in agriculture. However, in the tertiary sector, which is less affected by harmful noise, more than half of employees exposed to noise are not protected.



Graph 1: Nearly six out of ten employees exposed to harmful noise work in industries

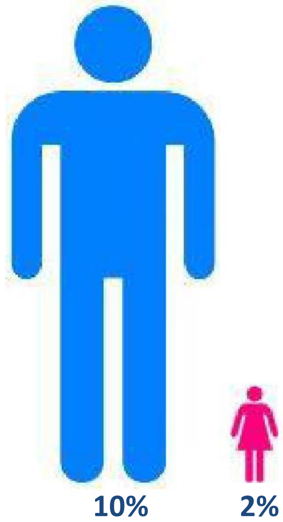


Figure 1: Harmful noise affects more men than women

Ototoxic substances

It is important to note that simultaneous exposure to noise and certain chemicals can become an aggravating factor (DARES, 2007 [5]). When we are exposed to toxic chemicals in the ear such as styrene or aromatic solvents (toluene used in paints, varnishes, inks, and degreasing agents), harmful noise has even more serious consequences on hearing. These factors affect more than half of the employees exposed to harmful noise.

1.3 Exposure to loud noise levels affects health

1.3.1 Two types of health effects

Exposure to noise can have two types of health effects: auditory and non-auditory.

Non-auditory effects are sources of:

- anxiety, depression, stress, irritability, or aggression
- sleep disturbances, insomnia
- fatigue, decreased concentration
- effects on the cardiovascular system
- an increased risk of occupational accidents

Auditory effects relate to hearing loss and may occur in the following forms:

- **Tinnitus**: whistling sound, buzzing in ears
- **Temporary hearing loss**: results from exposure to high sound levels. Hearing gradually returns after exposure (many hours)
- **Acoustic trauma**: hearing damage caused by loud and brief noise (explosion, gunshot, firecrackers, etc.)
- **Permanent hearing loss**: Typical of prolonged everyday exposure to noise (8 hours at 80 dB (A)). The gradual damage to hearing that takes place over months and years is insidious. It is noticeable only when it causes problems such as difficulties in communication between the subject and people around him. The injuries sustained are then irreversible and final.

1.3.2 The acoustic reflex naturally protects the ear

This is a reflex whose role is to protect the inner ear from excessive loudness. The stapedius muscle, which acts on the stapes (a bone in the middle ear which enables the transmission of tympanic vibrations to the inner ear), contracts and thus makes the system more inflexible, which then acts as a protection system against noise.

When the acoustic reflex is triggered, any increase in the perceived sound is attenuated, and thus an increase of 10 dB will cause only a transmission increased by 3 dB to the inner ear. The reflex essentially attenuates low frequencies (<2 KHz). It is ineffective on high frequencies.
However, like all muscles, the stapedius becomes tired, and this fatigue occurs more so as the noise level is increased.
At 121 dB, it relaxes after 7 seconds (risk of irreparable damage).
At 109 dB, it relaxes after about 1 minute 52 seconds.
At 100 dB, it relaxes after about 15 minutes on average.

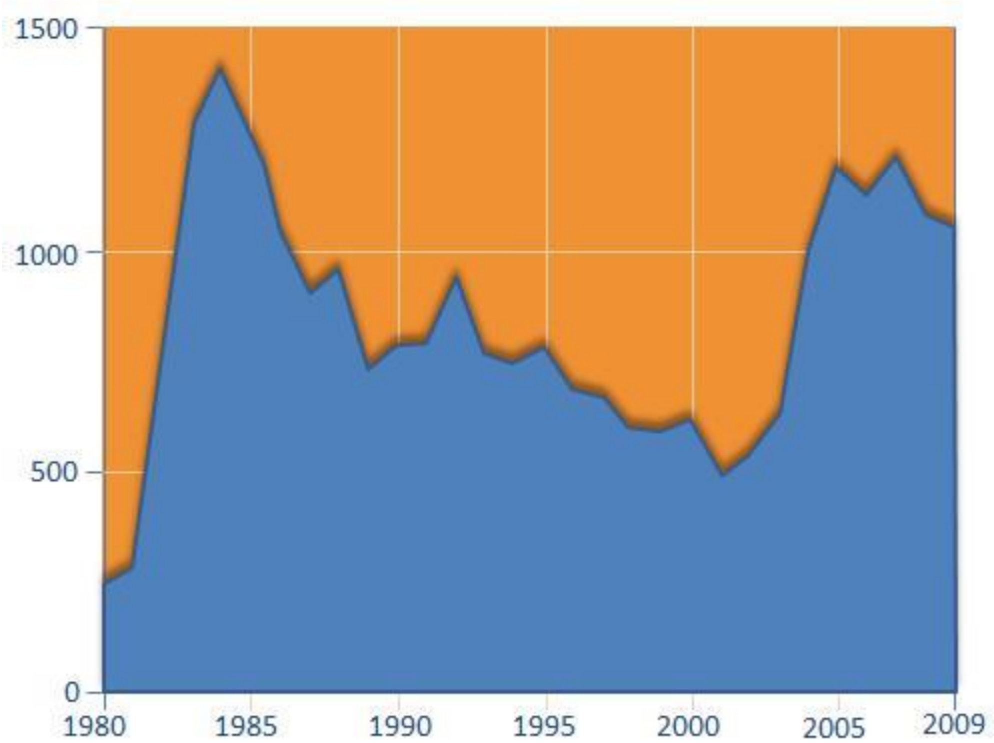
1.3.3 The noise factor of occupational accidents

According to DARES [5], difficult working conditions are often accompanied by an increased risk of accident. This is mainly in the case of noise: 8.6% of employees exposed to harmful noise (+ 85dB (A), + 20 hours/week) experienced lost-time injuries. A loud and constant noise can cause loss of alertness or prevent the perception of danger (Campo, 2005 [6]). Noise increases the risk of lost-time injury by 24%.

1.4 Hearing loss

Hearing loss is the fourth most common occupational disease. It costs on average 94,000 euros (2009 INRS [7]).

Prolonged exposure to loud noise levels gradually destroys the hair cells in the inner ear. It gradually leads to deafness (perceptive deafness), which is irreversible. In this case, surgery does not help. Electronic aids simply amplify the residual acuity; they do not restore the hearing function as a whole.



Graph 2: Number of occupational deafness recognized since 1980 [7]

Deafness can be recognized as an occupational disease according to specific medical, professional and administrative criteria, given in Table No. 42 of occupational diseases under the general system and Table 46 under the agricultural system. Table No. 42 has been amended several times, notably in 1981 and 2003, where the criteria for recognition were extended. So the number of cases of recognized deafness has increased sharply in the years that followed.

Graph 3 shows the different stages of development of occupational deafness.

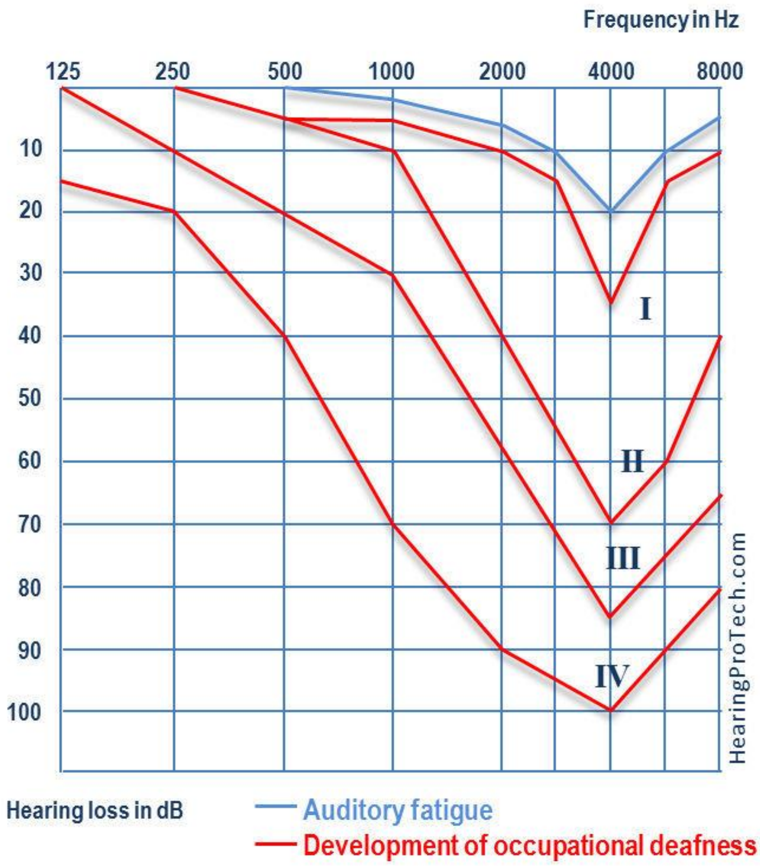
Adaptation phase: An audiogram performed late in the day can already show a reversible auditory scotoma ("deaf spot") at a frequency of 4000 Hz.

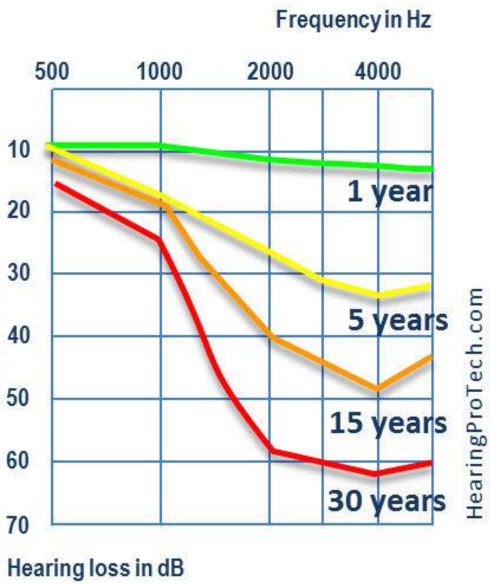
Stage I or latent deafness stage: Hearing loss is characterized by irreversible auditory scotoma at a frequency of 4000 Hz exceeding 30 dB.

Stage II or incipient deafness stage: Auditory scotoma is extended to neighboring frequencies (2000-6000 Hz) and exceeds 30 dB.

Stage III or the confirmed deafness stage: Hearing loss extends to frequencies 1000-8000 Hz and exceeds 30 dB.

Stage IV or the severe hearing loss stage: The hearing loss reaches all frequencies, including 500 Hz (≥ 30 dB), with a predominant extension over high frequencies.





Graph 4: Hearing development of an employee exposed to 95dB (A) for 30 years

Graph 3: Development of occupational deafness

We see in Graph 4 a study in the form of an audiogram done every 5 years on a worker exposed to noise during his entire career without hearing protection (Thiery, 2004 [8]).

1.5 Legislation

One directive and two standards regulate personal hearing protection devices (HPD) and their implementation:

- The 2003 European directive
- EN 352 standard
- EN 458 standard

Three other standards supplement the above two standards:
EN 4869-2 describes the different methods of calculation (per octave band, HML, and SNR) to estimate the levels of effective A-weighted pressures when using HPD. The standards EN 13819-1 and EN 13819-2 respectively describe the physical and acoustic testing methods implemented during the certification of EN 352.

1.5.1 Directive on 'Noise' 2003/10/EC

Transposed into French law by Decree 2006-892 of 19 July 2006 amending the Labor Code and the Order of 19 July 2006. Specifies the exposure limits for employees. It is these values that determine whether an employee requires hearing protection.

To summarize:

1- The threshold limit values for noise exposure for workers (TLV), taking into account the attenuation of HPD are:
- 87 dB (A) for a working day of 8 hours
- 140 dB (C) for peak pressure

<u>If this is exceeded:</u>

- Implementation of immediate measures to reduce the noise exposure
- Limiting the duration of the employee's exposure to noise

2 - Higher exposure values requiring action are:
- 85 dB (A) for a working day of 8 hours
- 137 dB (C) for peak pressure

<u>If this is exceeded:</u>

- Implementation of a technical measurement program to reduce exposure to noise
- Signage of noisy workplaces and limiting access
- Using HPD
- Periodic audiometric tests

3 - Lower exposure values requiring action are:
- 80 dB (A)
- 135 dB (C)

<u>If these thresholds are exceeded:</u>

- Provision of HPD

- Informing and training workers (noise hazards, measurement, and means of prevention, use of HPD)
- Audiometric tests suggested

1.5.2 EN 458 standard

A standard exists for each type of HPD:

- EN 352-1: for ear muffs
- EN 352-2: for earplugs
- EN 352-3 for earmuffs worn with hearing protection helmets

These standards establish the requirements for personal hearing protection in relation to the 89/686/EEC Directive. The special requirements concerning the capacity of personal hearing protection devices to reduce noise levels below the daily limits is addressed in EN 352, which sets the sound insulation of hearing protection devices (measured in accordance with EN 24869-1) to a specified minimum level. By additionally requiring a declaration of the measured sound insulation, the requirements help to select appropriate protective devices according to established practice, based on individual requirements.

They also specify the requirements in terms of hardware, assembly, and ease of use, as well as comfort for the user. They analyze the minimum performance on resistance to impact, low and high temperatures, and fire.

Frequencies in Hz	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
($M_f - S_f$) in dB	**5**	**8**	**10**	**12**	**12**	**12**	**12**

Table 2: Requirements as per EN352-2 for the minimum attenuation by frequency, Mf representing the average attenuation values, and sf representing the measured standard deviations

$M_f - S_f$ = APV (Assumed Protection Value), which is the average attenuation of the 16 test subjects where the standard deviation has been deducted.

1.5.3 EN 458 standard

"Personal Hearing Protectors - Recommendations for selection, use, care, and maintenance."

The standard was developed as a guide for any person who must buy or wear hearing protectors.

In order to make the most of the protection offered by hearing protectors, users should wear the hearing protectors as long as they are in a potentially dangerous noisy environment. Therefore, when it comes to selecting a personal hearing protection device, it is important to consider some factors that can affect comfort and acceptance.

Using a flowchart (Figure 2), EN 458 defines the steps to be implemented in case of a localized noisy area which could be potentially dangerous for the employees who work there.

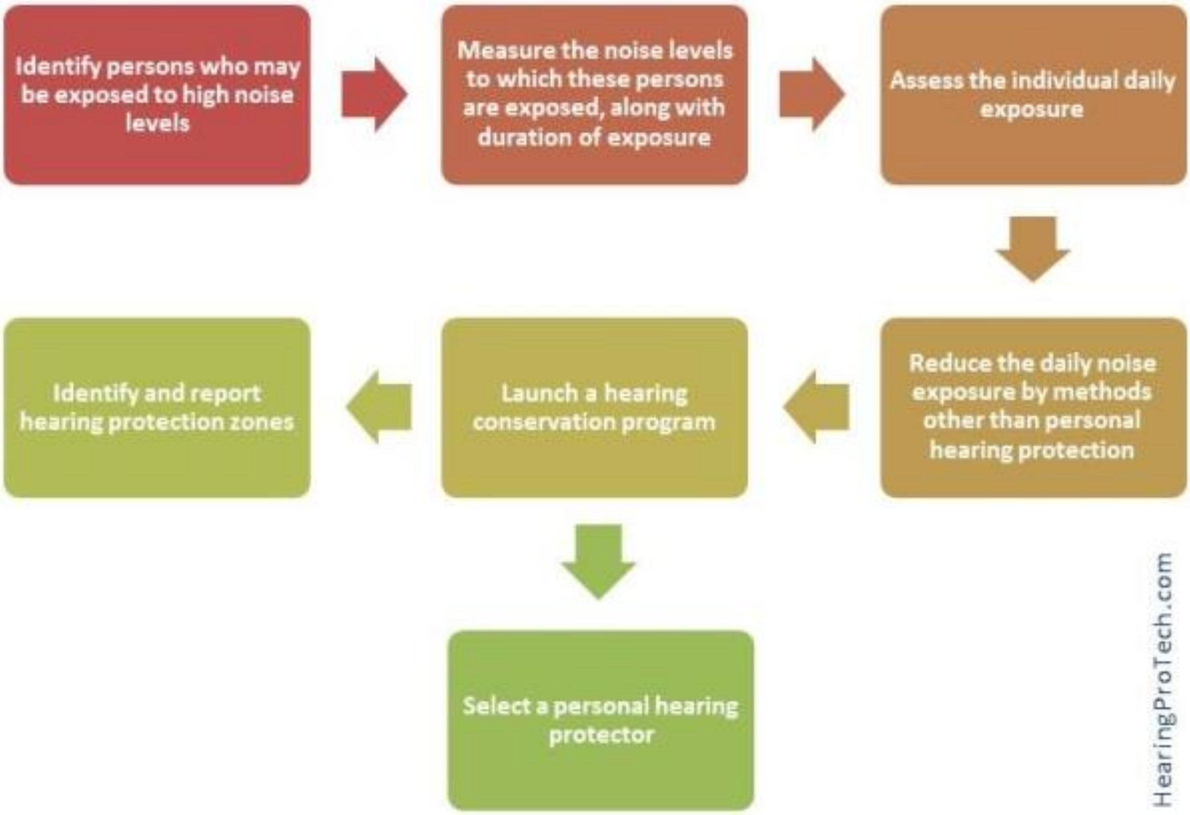


Figure 2: The flowchart describes the measures to reduce individual risk of hearing loss caused by noise (extracted from EN458)

The first objective is to try to reduce noise at the source. This will not be dealt with here. We shall consider that, for certain reasons (difficult or impossible to modify an area, very high investments, etc.), you choose to equip your employees with hearing protectors (HPD).

1.6 Technical details

1.6.1 "A" and "C" weighting

The noise can be measured by A-weighted and C-weighted decibels. A-weighting has been defined from the equal-loudness contours (measurements of sound pressure in decibels, depending on the frequency that a person perceives as sound at the same level), which were used to characterize the sensitivity of the human ear at all frequencies.

These equal loudness curves (Figure 3) show that the ear perceives high frequencies (centered around 3200 Hz) with much greater sensitivity than low frequencies.

This natural resonance of our external ear in a conical shape amplifies acute noise from 10 to 15 dB on an average.

We see in Figure 3 (green curve) that a sound transmitted at an intensity of 20 dB at a frequency of 1 KHz (reference value) will be perceived earlier on the frequency of 3 KHz, around 13dB. On a low frequency, 125Hz for example, the sound must be increased up to 43dB to obtain the same sensation. It is a difference of 30dB between the perception of a treble sound and a bass sound. The higher the reference tone (1 kHz) transmitted, the more the difference between the treble/bass perception decreases.

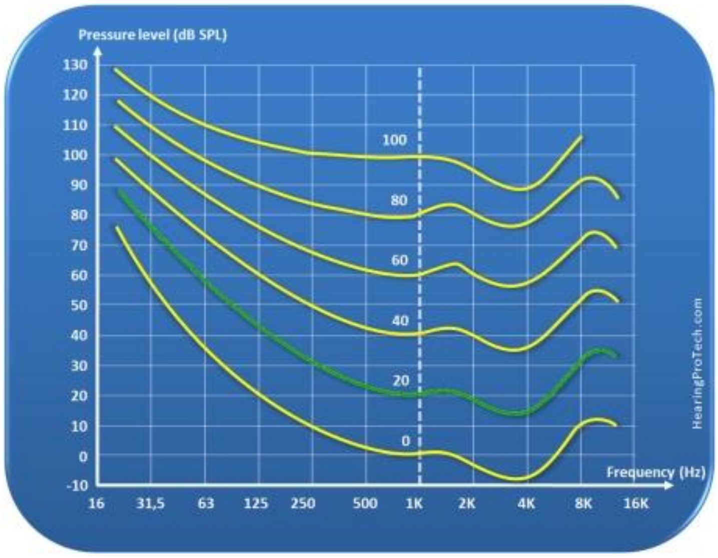


Figure 3 - Equal-loudness contours (ISO 226). Measurements of sound pressure in decibels, based on the frequency that a person perceives as sound at the same level.

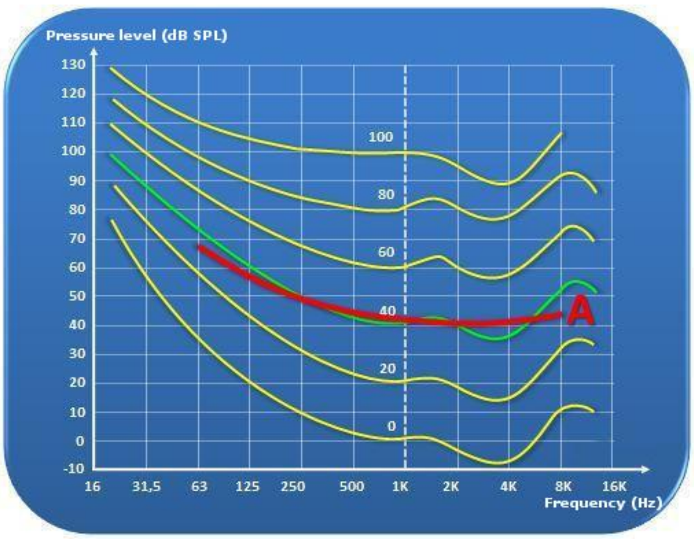
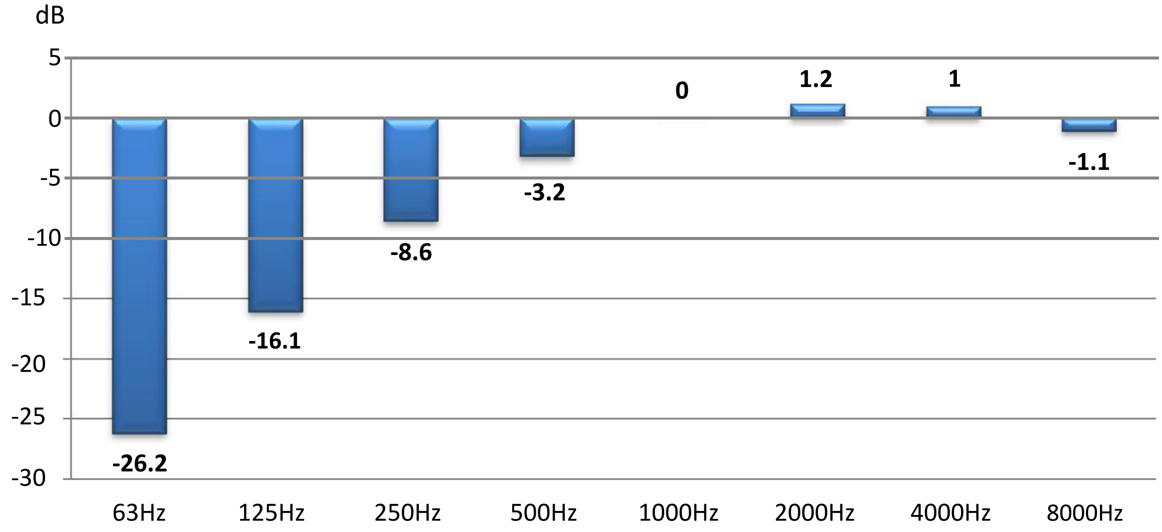


Figure 4 - A-weighting curve in red superimposed on equal loudness contours

A-weighting has been designed to represent the human perception across all frequencies and at low intensities. We shall also consider that it represents auditory fatigue and the harmfulness of noise.

Several studies show, however, that A-weighting seems to underestimate the adverse effects of low frequencies. These studies are described in the literature study of P. and A. Campo Damongeot of INRS [9].

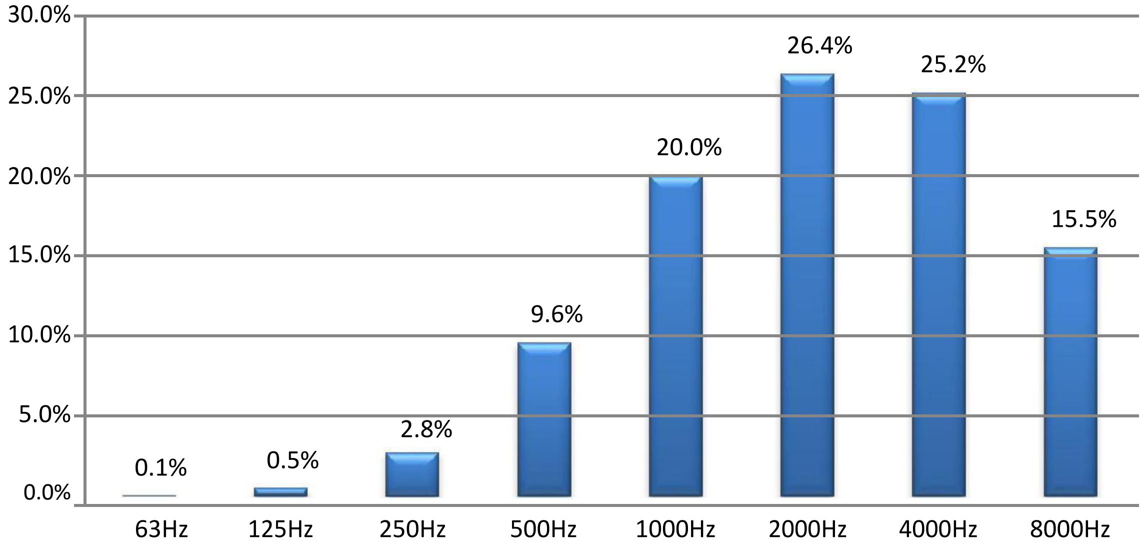
Figure 5 clearly shows that A-weighting takes little account of the low frequencies.



Graph 5: Weighting of each frequency to obtain the "dB (A)" weighting

1.6.2 SNR

The SNR (Single Number Rating) is the total attenuation coefficient, which is a weighted average of the attenuation at all measured frequencies.



Graph 6 - Weighting the SNR according to the frequencies. The percentage represents the weight of each frequency in the calculation of SNR

As we see in the graph above, the weighting of SNR favors medium and high frequencies. Three frequencies express over 70% of the SNR index (2000 Hz, 4000 Hz and 8 000 Hz).

1.6.3 HML

Are indices equivalent to SNR but indicative of high, medium, and low frequencies (HML: High, Medium, Low).

H: Average attenuation in a spectrum of high frequencies (> 2 kHz)

M: Average attenuation in a spectrum of medium frequencies (0.5 to 2 kHz)

L: Average attenuation in a spectrum of low frequencies (<0.5 kHz)

1.6.4 $L_{EX,8h}$

Daily exposure level to standardized noise over a reference period of 8 hours, expressed in dB (A). See the calculation method in Appendix 1.

1.6.5 L_{Aeq}

This value designates the average energy of a sound during the measurement. Noises in the environment are rarely stable; they vary in intensity. For this reason, it is necessary to determine the average sound level of a noise. The L_{Aeq} is expressed in dB (A).

1.6.6 $L_{p,C,peak}$

Peak sound pressure in dB (C) indicating the maximum level of instantaneous noise.

2 Personal hearing protectors

2.1 6 Criteria for choosing a HPD

"Since various existing hearing protectors can be used in a variety of acoustic environments, it is important to choose the most appropriate type of protector. In the selection process, it should take into account all the functions of personal hearing protectors, and also consider the aspects listed below and outlined in the following articles:

1. CE marking
2. Suitable sound insulation
3. Comfort of the wearer
4. Work environment and activity
5. Medical conditions
6. Compatibility with other personal protective equipment (PPE)

The process must be repeated at regular intervals to ensure that effective attenuation is maintained ".
Extract from EN458, paragraph 5.1

2.2 Criterion 1 - CE marking

To obtain the CE marking, the hearing protector must meet a number of requirements described in EN352.

The CE approval will be obtained after the "CE test" has been done to verify that the hearing protector meets the requirements of the corresponding EN352 standard. The tests and inspections are carried out by a certified laboratory.

The attenuation data of hearing protection devices are obtained after being measured by a testing laboratory, on a panel of 16 trained subjects. The average obtained from the subjects (which is subtracted from the standard deviation to obtain the APV) determines the attenuation of the hearing protection device.

The manufacturer therefore ensures that the products made available in the market are strictly identical to the certified model.

It is important to be vigilant and to verify that the manufacturer has the "CE test report" to his name.

2.3 Criterion 2 - Suitable sound insulation

In terms of attenuation, many people think that a hearing protector with high attenuation is more effective.

In the case of an employee exposed to high intensities, it is crucial to have sufficient hearing protection, but an employee exposed to low intensities such 85dB (A), will require an attenuation of about 10dB. Equipping this employee with an HPD that attenuates 30dB is a mistake; an employee who works in isolation cannot wear hearing protection: it would force him to remove them just to hear any signal or the slightest speech.

The objective is to lower the noise level received by the employee to under 80dB (A). The threshold of 72dB (A) of residual noise is a good compromise if we refer to the recommendations of the EN458 standard.

Actual levels in the ear with attenuation of HPD, according to EN458

2.3.1 The different hearing protectors available

A wide number of models are available in the market. In order to look at them more clearly, let's classify HPDs into 4 families:

2.3.1.1 HPD with ear shells

Also called ear muffs, headphones or ear shells, this HPD can either be assembled on an industrial safety helmet, or worn independently. It is positioned "around" the ear, and is connected by a hoop or headband passing overhead. It is reusable. It is advisable to change the ear pads (earpiece) every year to ensure effective sealing.

2.3.1.2 Canal caps

It is worn either at the ear canal or is placed within. The earplugs are connected by a plastic band (hoop) which holds them together.

2.3.1.3 The "standard" earplug

- The pre-formed/pre-molded earplug is made of silicone, rubber, etc. It can be inserted into the ear without prior shaping.

The earplug that must be shaped by the user is generally malleable and/or made of compressible foam. It will thus be shaped by the employee prior to being placed in the ear canal. This type of earplug is generally of the disposable type.

2.3.1.4 The personalized molded earplug (customized)

Made from an impression/mold of the employee's ear, this hearing protector is made of silicone or acrylic resin. New technologies now allow for full digital manufacturing of these hearing protectors, offering an accuracy of about 100µ. A passive acoustic filter helps select the attenuation level to meet the needs of the wearer.

2.3.1.5 Active systems

In this study, we are interested in "passive" systems, i.e., systems that have no electronic components; their only function is to "block" the sound before it enters the ear canal of the employee.

We shall now briefly describe existing active systems.
Today there are 3 types of "active" hearing protection systems:

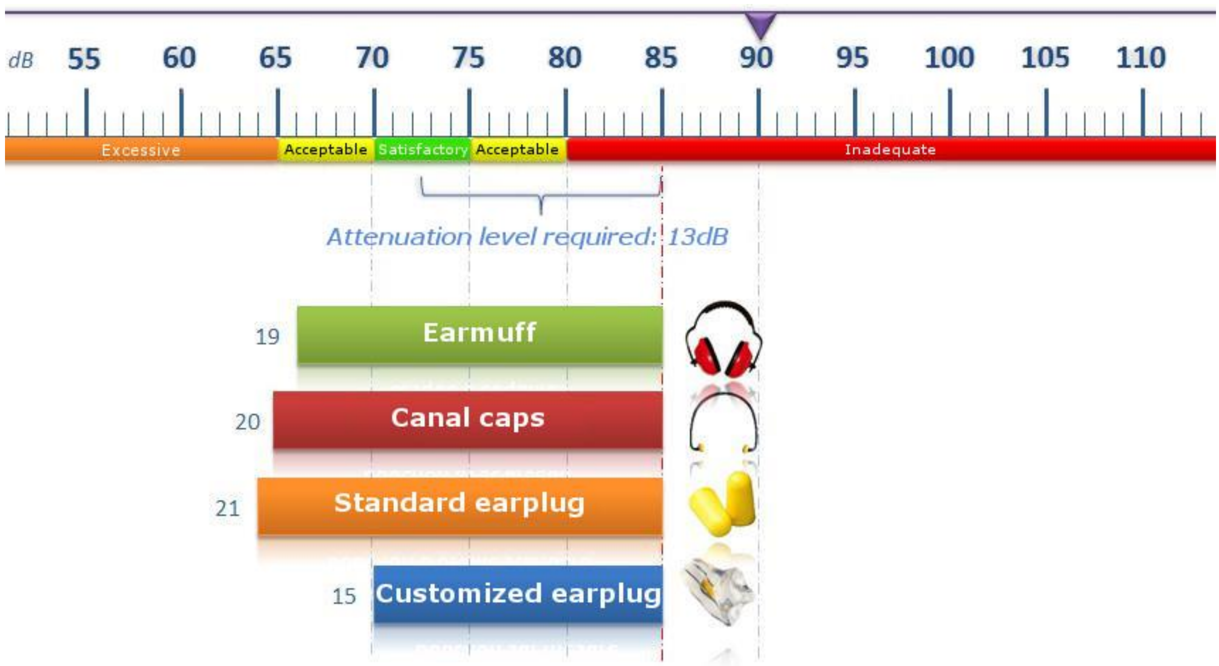
a. The nonlinear filter that is fitted to hearing protectors intended for very high impact noise (hunters, soldiers, etc.). This filter does not have any electronic components for specifically blocking the sound waves as they become too strong. It allows low or medium noise to pass through completely. It is ideal for hunters or soldiers who must be able to hear their environment perfectly well. However, it has the disadvantage of being able to reduce noise only from a sound level of 110dB; from this level, there will be a reduction of about 15dB attenuation. At a sound level of 150dB, the attenuation will be 24dB, which is highly insufficient for an employee exposed to noise.
b. Clipping systems that capture ambient noise using a microphone that analyzes the sound level and restores it to a lower level through a speaker. The main drawback of these systems is that the electronic restoration of the sound environment can be difficult to accept by the employee affected by this artificial perception.
c. Active noise reduction systems more commonly known as "active noise cancelling headphones". As in the previous system, the sound is captured and returned to the wearer electronically, but the peculiarity of this principle is that it does not send a weakened sound, but sends a sound in the opposite phase, which results in the cancellation of the sound heard through the helmet by the wearer. These technologies enable relatively high attenuations, particularly in the low frequencies that are the most difficult to eliminate.

2.3.2 Attenuation range of HPDs

Graph 6: Theoretical attenuation ranges (laboratory measurements) of different HPDs

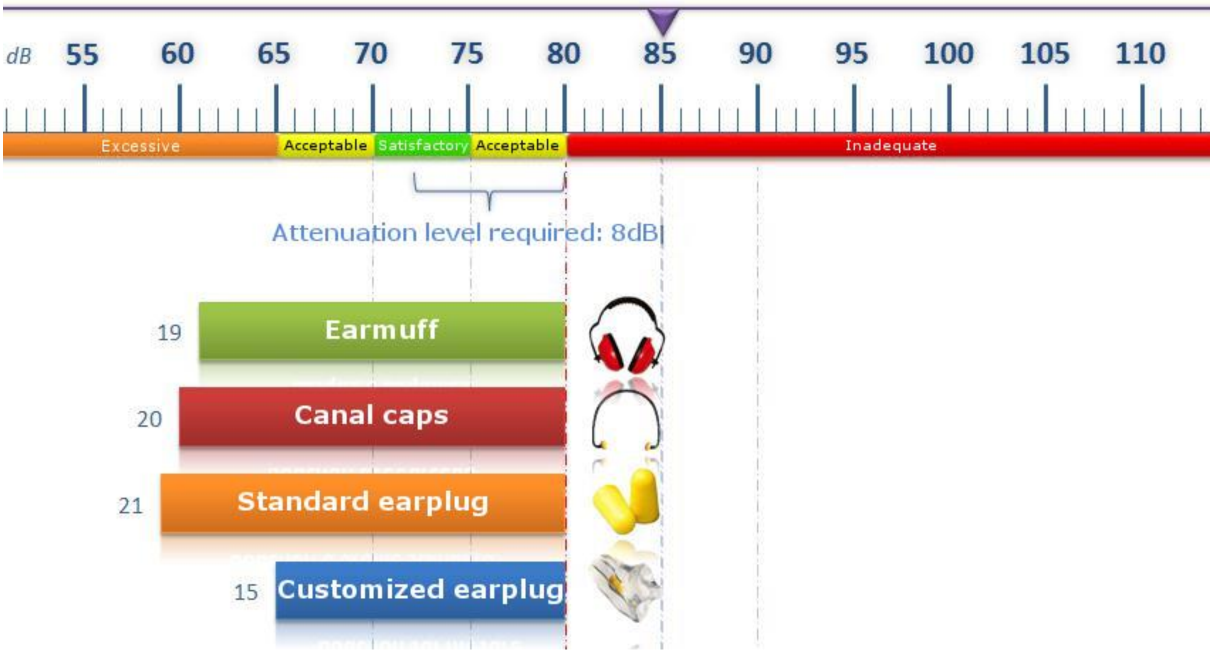
The following figure shows the attenuations (minimum and maximum) for each category of HPD. Attenuation is expressed in SNR.

Check the correlation of the attenuation ranges of HPD and a noise level given through five simulations at different noise levels. The objective is a residual noise of 77dB (A) at the ear of the employee.



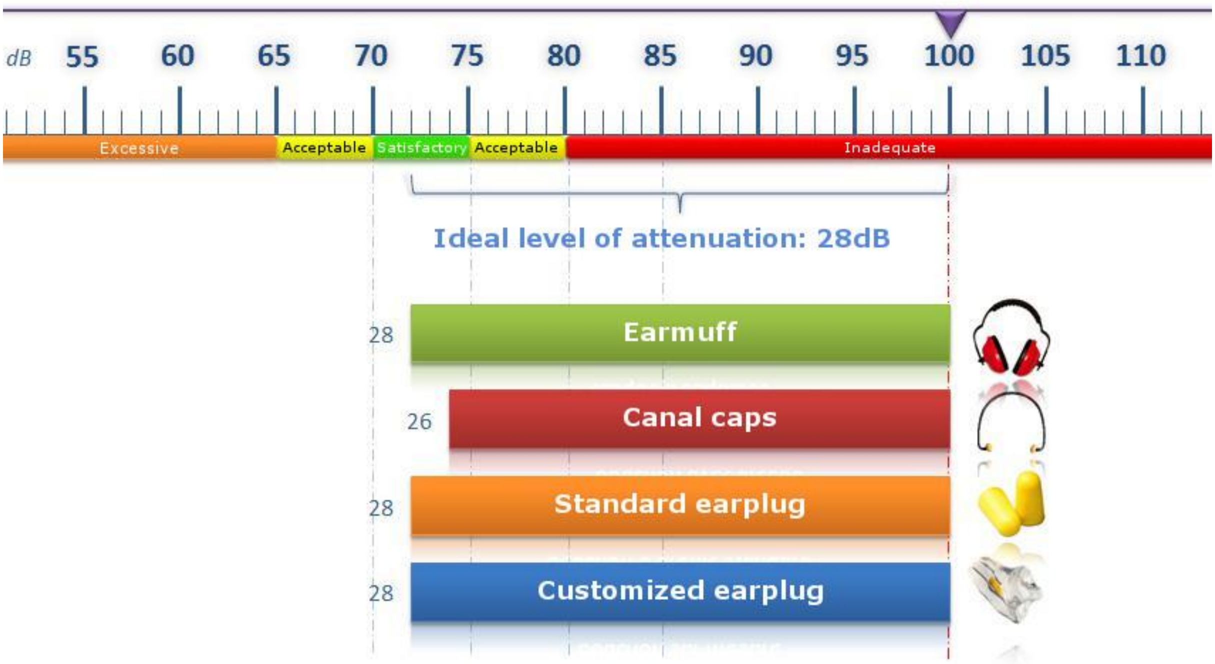
Graph 7: Simulation of a noise level of 90dB (A)

We note that at 85dB (A), all HPDs fulfill their task of noise protection, while the earplugs model with the least attenuation slightly exceeds the acceptable zone and gives rise to overprotection.



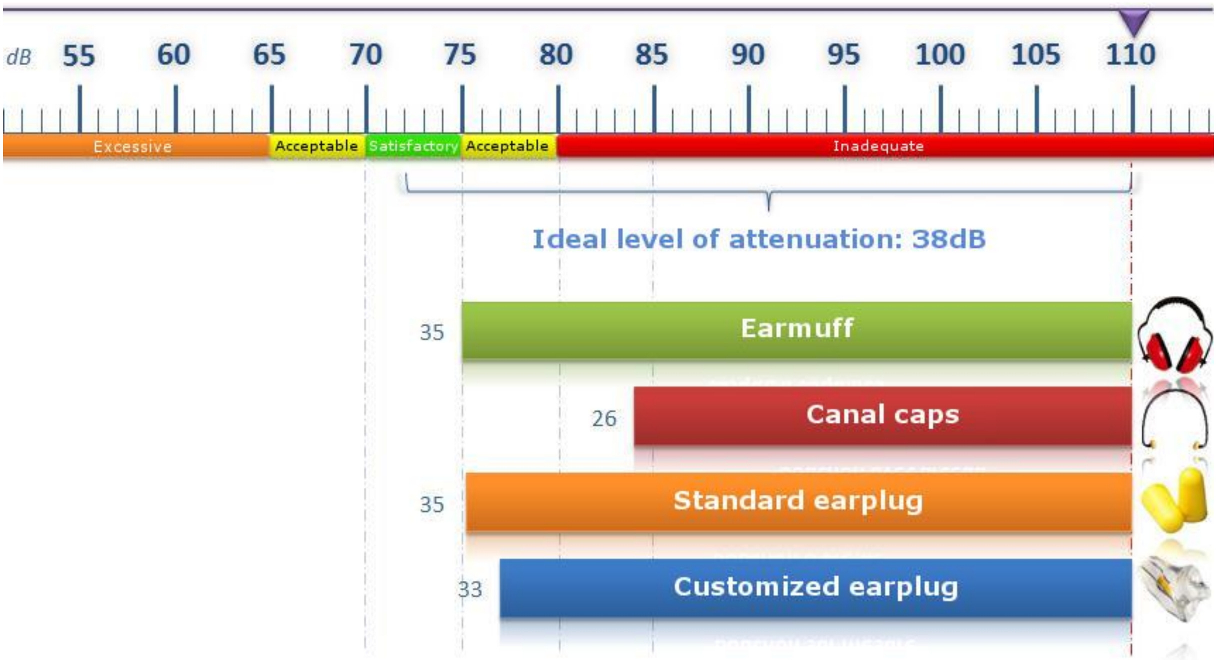
Graph 8: Simulation of a noise level of 85dB (A)

As soon as the intensity is reduced, we find that three quarters of HPD (always taking the model with the least attenuation in the category) are excessive attenuators, generating excessive protection. Only customized earplugs remain within the acceptable limit.



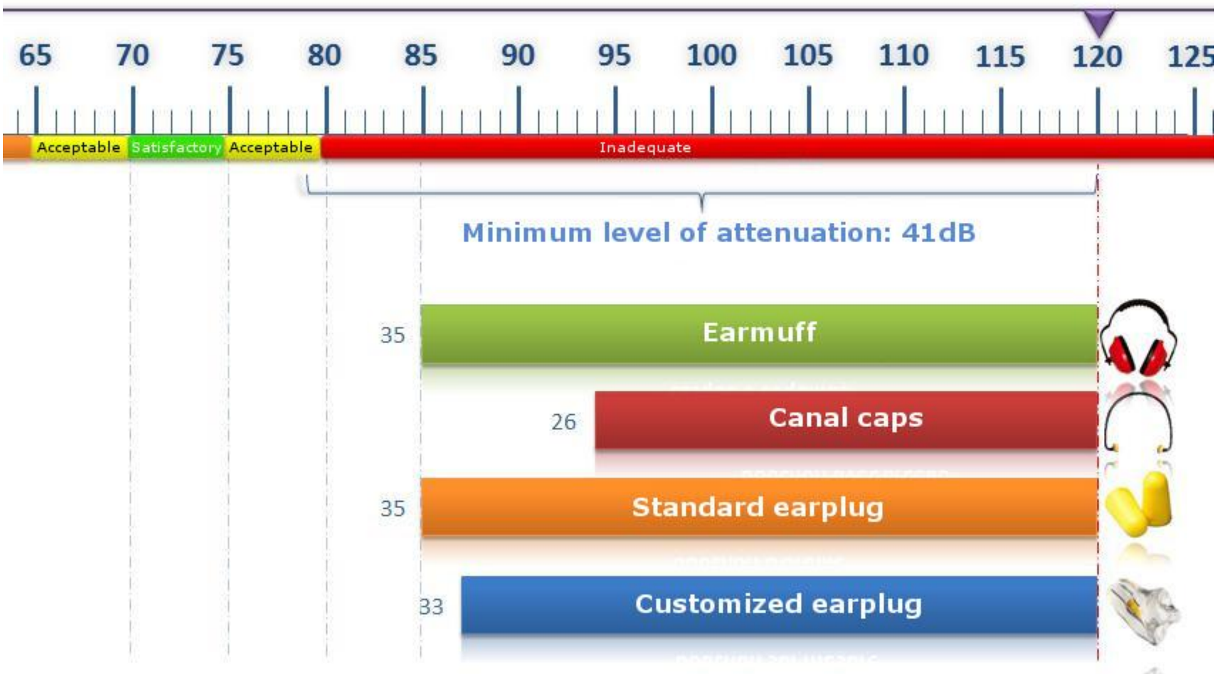
Graph 9: Simulation of a noise level of 100dB (A)

At a high enough level (100dB (A)) all of the HPDs have adapted models that fully meet the needs. According to SUVA reports [10] [Swiss National Accident Insurance Fund], [3] only 1.2% of professions are subject to intensities higher than 95dB (A) for 8 hours.



Graph 10: Simulation of a noise level of 110dB (A)

At 110dB (A), which is a very high level, the majority of HPDs are suitable. Earplugs with hoops do not allow sufficient protection since in theory, they allow residual noise with a level of 84dB. This type of hearing protector is generally used occasionally. It may be enough if the employee is not continuously exposed to noise of this intensity.



Graph 10: Simulation of a noise level of 120dB (A)

Here we have a very high level (Figure 11) which is quite rare.

We note in this latest simulation that the HPDs do not attenuate enough at this level of 120dB (A), not even for a minimum level of protection, and are not ideal.

What solution exists in case of 120dB (A)?

- The introduction of double protection (ear muffs + earplug) can significantly increase the degree of attenuation, but note that the attenuations of the protectors do not add up.

The formula is:
33 x log ((0.4 x attenuation of the in-ear device) + (0.1 x attenuation of ear muffs)
(Study by A. Damongeot et al. [11])

This gives, for example:

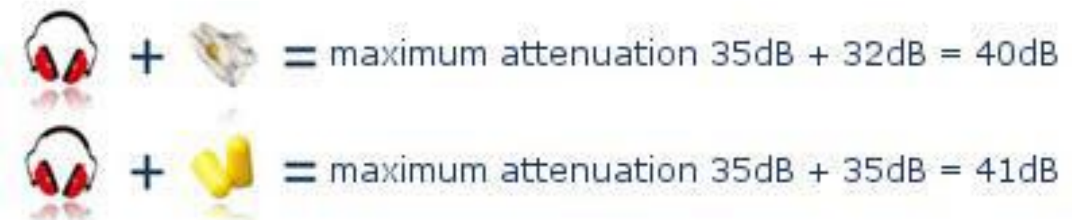


Figure 12: Example of results from double protection

What solutions are there if the double attenuation is insufficient?
- Reduction of noise at source
- Reduction of exposure time of the employee at such high intensities.

2.3.3 Do the theoretical values differ from actual values?

We have just studied the attenuation levels recommended by EN458 to ensure effective noise protection for the employee without overprotection. We also saw how to position the various ranges of hearing protectors with respect to these recommendations.

We shall now see that the attenuation values claimed by different manufacturers of HPDs are often much higher than in reality.

"The actual sound attenuation values estimated in situ are still lower than the sound attenuation values obtained with laboratory measurements, regardless of the type of hearing protector." (Kusy, 2008 [12])

In Figure 15 below, observe the average of the differences obtained with the literature study mentioned above: it is a compilation of six European studies and 21 American studies.

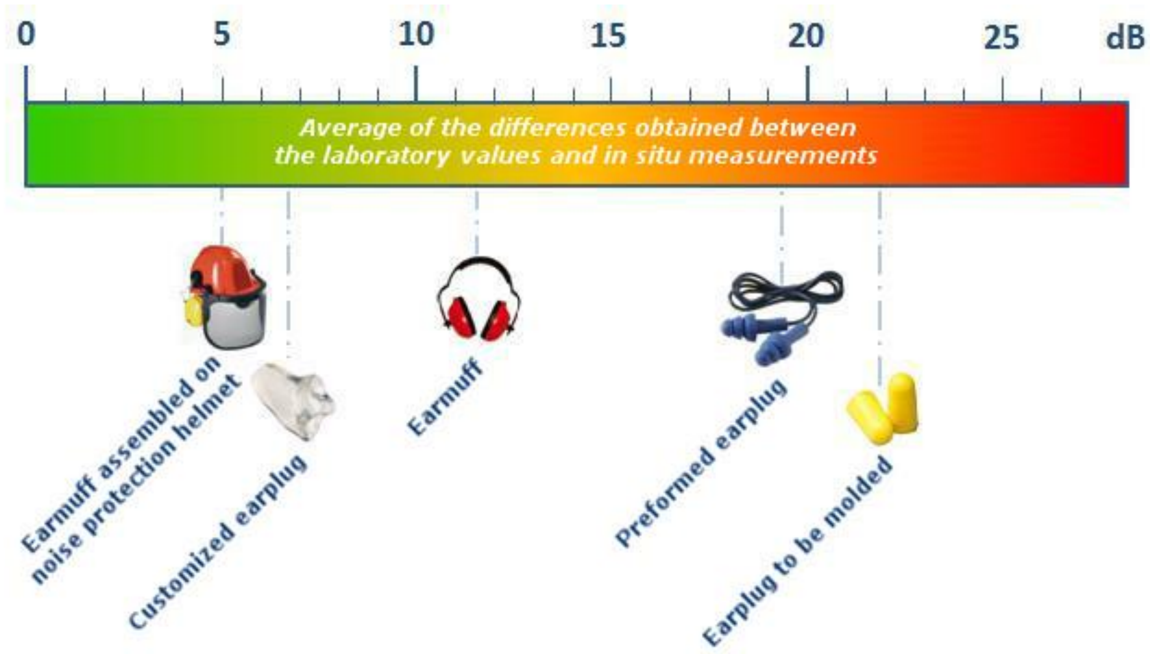


Figure 13: Average of the differences between the values displayed and in situ measurements (in decibels)

<u>Why do such differences exist between measurements performed in a certified laboratory and actual measurements?</u>

There are various reasons:

1. Employees are not trained in the implementation of the HPD; they do not follow the instructions, the earplug is not inserted deep enough into the ear cavity, for example.
2. Movements made by employees cause the hearing protector to move. While performing measurements in the laboratory, the subjects must not move.
3. The shape of the ear canal does not allow the insertion of a standard cylindrical shaped earplug, since the ear canal is oval

4. The frequency and nature of the in situ noise exposure could be one reason for the differences
5. Working conditions and heat easily cause sweating under the pads of earmuffs and reduce the tightness
6. Glasses, beard, long hair, etc. decrease the tightness in HPDs with earmuffs. Other PPE used simultaneously cause similar effects.
7. Abundant hair in the ear canal hinders the achievement of a perfect seal
8. In the case of earmuffs, the wearer may have a morphology (large jaw, protruding bones, narrow cranium, etc.) which impedes a good seal between the ear pads and the cranium.
9. The aging of hearing protectors, mainly ear muffs (BGIA study [13]). The difference between a new HPD with earmuffs and a HPD that is 2-3 years old can go up to 8 dB. The measurements in the lab are performed on new HPDs
10. Comfort, the need to communicate, and the design of the HPD, are also factors that alter their effectiveness

Rainer Weiß [14] gives us further information about the movements made by the employees mentioned in Point 2 above.

In Table 3 of this study, on the differences in attenuation of customized earplugs in acrylic according to the position of the wearer, we see that very few changes in attenuation exist for the type of intra protectors (inner ear), but that significant changes are detected on the ear shells with conical shape (larger protectors that cover the cone of the ear).

		Frequency measurement							
Type HOD	*Situation*	*125*	*250*	*500*	*1K*	*2K*	*4K*	*8K*	***SNR***
intra-aural	Normal	20	15	25	25	35	40	35	**27**
intra-aural	Open/closed mouth Chin on chest	20	15	25	25	35	40	35	**27**
intra-aural	Open/closed mouth Head back	20	15	25	20	25	35	30	**25**
Cone shaped	Normal	10	15	20	25	35	30	28	**25**
Cone shaped	Open/closed mouth Chin on chest	5	5	18	20	25	25	23	**19**
Cone shaped	Open/closed mouth Head back	0	0	0	3	2	3	5	**4**

Table 3: Differences in attenuation of customized earplugs according to the position of the wearer (Weiß, 2006)

Customized HPD of the intra-aural type

- No difference for open/closed mouth with chin on chest
- Slight difference (2 dB over the average SNR) with head down.

Customized HPD cone shaped

- Difference of 6dB for open/closed mouth with chin on chest
- Very high difference (21dB on the SNR) with head down.

2.3.4 Recommendations for reductions in attenuation values of HPD

Given these differences, which can be significant for some HPDs, preventive organizations (INRS for France, IFA for Germany, NIOSH for the United States, etc.) recommend the removal of a value or percentage of the displayed attenuation of the HPD.

Recommendations: values to be removed from the attenuation displayed by the manufacturer					
Recommendations of	***INRS - France***		***IFA - Germany***		***NIOSH - USA***
Parameters **Type of HPD**	***With training***	***Without training***	***With efficiency test***	***Without efficiency test***	
Indus. Ear muffs	- 5 dB	- 12 dB		- 5 dB	*ND*
Ear pads with hoop/headband	- 5 dB	- 10 dB		- 5 dB	- 25%
Earplug to be molded	- 5 dB	- 15 dB		- 9 dB	- 50%
Preformed earplug	- 5 dB	- 15 dB		- 5 dB	*ND **
Customized protection	- 5 dB	- 10 dB	- 3 dB	**	*ND **

** ND: Not Documented*

***According to the noise regulation "Technische Regel Lärm und Vibration (TRLV Lärm)" from the Bundesministerium für Arbeit und Soziales (Ministry of Labor and Social Affairs) no customized hearing protector must be worn if an efficiency test does has not been done.*

Table 4: Reductions recommended by occupational risk prevention agencies

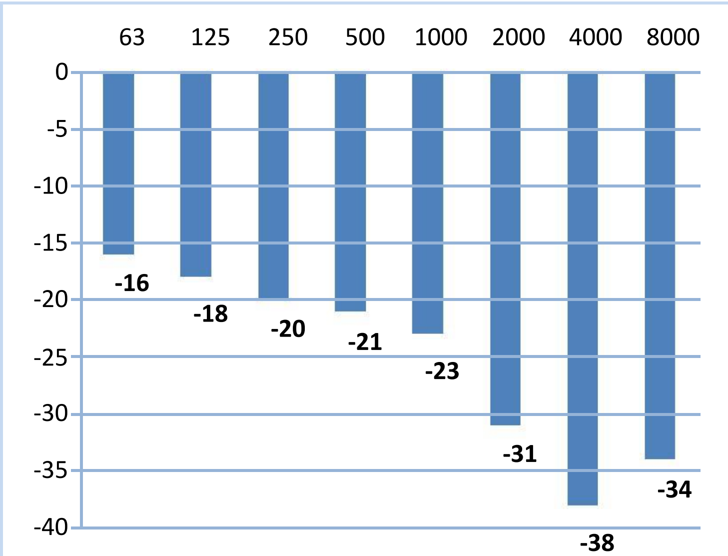
In France, INRS recommends doubling the standard deviation, which is subtracted from the average (see calculation of APV), to facilitate the reading of data from the above table. We agree that doubling the standard deviation resulted in an additional reduction of 5 dB. You can then verify the exact result of this doubling of the standard deviation, using the specific data of the HPD you want to study.

The above recommended reductions provide a more reliable and safer basis for attenuation than the certification data measured in the laboratory, but they are not less than averages. Thus, as increasingly required in Germany, only an efficiency test of the HPD using a suitable measurement tool shows whether an employee is actually protected.

2.3.5 Frequencies

We have seen that it is important to select an HPD with an attenuation level sufficient to protect the employee, but this level must not be excessive so that isolation does not occur. Another concept must also be taken into account: frequencies.

For the frequency of noise that the employee is exposed to in his working environment from which he must be protected, or to perceive frequencies to carry out his work in good conditions (signals, conversation ...), it is important to question this point to choose a suitable HPD.

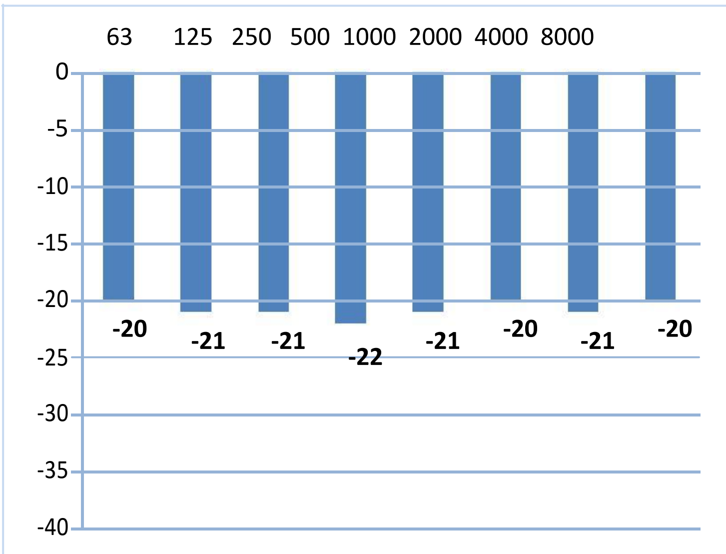


Graph 7: Attenuation of a conventional protector

As we have described, the dB (A) taking into account the natural amplification of our ear for high frequencies.
When the ear canal is
"Closed", for example, by a hearing protector or even by our finger, this amplification of the high frequencies is removed. Result: conventional hearing protection with loud noise highly and naturally attenuated by the simple act of plugging the ear canal.

In Figure 7, we see the attenuation curve of a standard earplug. The reduction is up to twice as high on 4000Hz (high frequencies) as on 125Hz (bass frequencies.

Some situations (need for communication, perception of warning signals, hearing loss including auditory scotoma type at 4000Hz...) nevertheless require that we verify that the wearer does not require an HPD with uniform response attenuation. This type of protector permits attenuation that is equivalent across all frequency bands. It is important to be vigilant in choosing this type of HPD. Claims by suppliers are sometimes very different from one another with actual values (Nexer, 2011 [15]).



Graph 8: Attenuation of a uniform response protector

2.3.6 How to read a table of attenuations of an HPD

Frequencies in Hz	*63*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
Average attenuation (dB)	**21.5**	**25.2**	**23.9**	**26.1**	**27.8**	**26.2**	**23.5**	**32.8**
Standard Deviation (dB)	**3.2**	**5.8**	**4.3**	**3.6**	**4**	**4.2**	**3.4**	**6.6**
APV (dB)	**18.3**	**19.4**	**19.6**	**22.5**	**23.8**	**22**	**20.1**	**26.2**

H (dB)	**22**	**M (dB)**	**22**	**L (dB)**	**21**	**SNR (dB)**	**24**

Table 5: Example of a display of attenuation data of a HPD

On the first line of Table 5 are given the 8 measured frequencies.

The second line gives the average attenuation measured on each of the frequencies. This measurement is performed by the certifying body, on 16 selected and trained subjects.

Line 3 shows the deviations obtained while measurements are done on the subjects.

The APV in line 4 is the result of (average attenuation - standard deviation). It is the value to be taken into account. When INRS (in France) recommends the removal of twice the standard deviation, we would have, for 1000Hz for example: (27.8 dB - (2 x 4)) = 19.8 dB attenuation instead of 23.8 dB.

We find the average on the last line; HML and SNR (see chapter 1.6.2 and 1.6.3).

If we take the reductions in Table 6 recommended by various organizations, we would have, from an SNR value of 24dB given above, the following results:

Example of the reduction applied to a SNR of 24dB according to recommendations					
Recommendations of	***INRS - France***		***IFA - Germany***		***NIOSH - USA***
Parameters / **Type of HPD**	***With training***	***Without training***	***With efficiency test***	***Without efficiency test***	
Indus. Ear muffs	19 dB	12 dB	*ND **	19 dB	*ND **
Ear pads with hoop/headband	19 dB	14 dB	*ND **	19 dB	14 dB
Earplug to be molded	19 dB	9 dB	*ND **	15 dB	12 dB
Preformed earplug	19 dB	9 dB	*ND **	19 dB	*ND **
Customized protection	19 dB	14 dB	21 dB	**	*ND **

** ND: Not Documented*

***According to the noise regulation "Technische Regel Lärm und Vibration (TRLV Lärm)" from the Bundesministerium für Arbeit und Soziales (Ministry of Labor and Social Affairs) no customized hearing protector must be worn if an efficiency test does has not been done.*

Table 6: Example of reductions on an attenuation of24dB of SNR

2.4 Criterion 3 - Comfort of the wearer

Standard earplug to be molded

We have thus seen the most significant differences between the attenuation values displayed and actual values with HPDs that are of the "to be molded" earplug type.

- They do not fit into all ear canals
- They require minimal training for their implementation
- Their adjustment is generally better than the preformed earplugs or HPD with hoop/headband
- Messy when handled, its implementation requires regular replacements to avoid the insertion of dirty earplugs in the ear canal.

Standard preformed earplug

Equally significant differences are identified with the "preformed" earplug type of « HPD.

- Faster implementation than earplugs that require molding
- The part to be inserted into the ear does not need to be handled (reduced risk of infection)
- Requires regular and careful maintenance (cleaning)
- We need to find a model suited to the morphology of the ear, with the risk of discomfort and inefficiency of the product

Standard canal caps

Limited effectiveness. The canal cap remains simply pressed onto the entrance of the ear canal.

- Convenient for occasional use
- The part to be inserted into the ear does not need to be handled (reduced risk of infection)
- Requires regular and careful maintenance (cleaning)

Ear muffs

The earmuff hearing protector presents no difficulty in implementation as it is well adjusted and up-to-date. Good efficiency in terms of attenuation.

- Well suited to intermittent use
- A good solution in case of ear infection or surgery
- The entire outer ear should be completely contained within the earmuff. Be careful with the arms of spectacles, beard, or long hair ...
- Sweating can disturb the employee and encourage intermittent use of the device
- Creates an uncomfortable pressure on the cranium

Customized earplugs

The personalized molded earplug (customized) is adapted to the wearer's ear, which makes it very comfortable and easy to use.

- Incorrect placement is quickly detectable by the wearer, who can immediately feel discomfort
- The part to be inserted into the ear does not need to be handled (reduced risk of infection)
- Requires regular and careful maintenance
- An impression (measurement) must be taken by a professional trained for this purpose (poor quality impressions will greatly reduce its effectiveness)

2.5 Criterion 4 - Work environment and activity

Some examples of constraints:

Constraints	Earplug to be molded	Preformed earplug	Canal caps	Intra-aural customized earplug	Intra-aural customized earplug with uniform frequency attenuation	[illegible] earplugs	Ear muffs	Earmuffs assembled on noise protection helmet
Head lowered	ND *	ND *	ND *	Suitable HPD	Suitable HPD	Unsuitable HPD	ND *	ND *
Long hair, beard	Suitable HPD	Suitable HPD		Suitable HPD	Suitable HPD	Suitable HPD	Unsuitable HPD	Unsuitable HPD
Wearing glasses	Suitable HPD	Suitable HPD	Unsuitable HPD	Suitable HPD	Suitable HPD	Suitable HPD	Unsuitable HPD	Unsuitable HPD
Ambient temperature > 25 ° C	Suitable HPD	Suitable HPD	Suitable HPD	Suitable HPD	Suitable HPD	Suitable HPD	Unsuitable HPD	Unsuitable HPD
Humid environment	Suitable HPD	Suitable HPD	Suitable HPD	Suitable HPD	Suitable HPD	Suitable HPD	Unsuitable HPD	Unsuitable HPD
Face shield	Suitable HPD	Suitable HPD	Unsuitable HPD	Suitable HPD	Suitable HPD	Suitable HPD	Unsuitable HPD	Unsuitable HPD
Hood	Suitable HPD	Suitable HPD	Unsuitable HPD	Suitable HPD	Suitable HPD	Suitable HPD	Unsuitable HPD	Unsuitable HPD
Safety helmet	Suitable HPD	Suitable HPD	Unsuitable HPD	Suitable HPD	Suitable HPD	Suitable HPD	Unsuitable HPD	Unsuitable HPD
Breathing device / mask	Suitable HPD	Suitable HPD	Unsuitable HPD	Suitable HPD	Suitable HPD	Suitable HPD	Unsuitable HPD	Unsuitable HPD
Very narrow ear canal	Unsuitable HPD	Unsuitable HPD	Unsuitable HPD	Suitable HPD	Suitable HPD	Suitable HPD	Suitable HPD	Suitable HPD
Need for communication (oral, phone)	Unsuitable HPD	Unsuitable HPD	Unsuitable HPD	Unsuitable HPD	Suitable HPD	Unsuitable HPD	Unsuitable HPD	Unsuitable HPD
Discretion	Suitable HPD	Suitable HPD	Unsuitable HPD	Suitable HPD	Suitable HPD		Unsuitable HPD	Unsuitable HPD
Need for very occasional protection			Suitable HPD				Suitable HPD	

Suitable HPD	Unsuitable HPD	* ND: Not Documented	Unsuitable HPD

Table 7: Constraints related to equipment worn by the employee, his environment, his hearing etc.

It is important to ensure that the use of other equipment necessary for the activity and/ or the safety of the employee does not affect the performance of the hearing protector. Similarly, the physical characteristics of the employee (beard, long hair, glasses, etc.), as well as the needs related to his job or function (communication, discretion, etc.), must be taken into account when choosing the HPD.

2.6 Criterion 5 - Medical conditions

Before choosing a HPD, it is important to know if the employee suffers or has suffered from ear problems: irritation of the ear canal, ear ache, flow of ear wax, or loss of hearing.

In the case of hearing loss (auditory scotoma or "deaf spot" at 4000Hz, for example), a uniform response attenuation may be advised.

2.7 Criterion 6 - Compatibility with other personal protective equipment

Table 7 compiles the business constraints, environmental constraints and compatibility with other equipment for personal protective equipment (PPE).

2.8 Maintenance of hearing protectors

EN 4869-2 specifies in its introduction:

That the efficiency values of HPD are only valid if the HPDs are properly maintained.

M Rainer Weiß explains in his study [14] that it is necessary to regularly maintain the HPD, including customized earplugs (objective of the study). They must be cleaned in order to avoid decreasing the effectiveness of the hearing protectors, irritation, and other problems. After each day's work, it is recommended to clean the HPD with a wipe containing alcohol or cleaning according to manufacturer's instructions.

Regarding helmets with ear muffs, we have seen that it is recommended to change the ear pads, ideally every year, and every two years at the most.

The EN458 standard in Article 7.2 Hygiene and cleaning, says:

"Contamination of hearing protectors by foreign substances, solutions, liquid waste, dust, particles etc. can cause irritation or abrasion of the skin. The user must ensure that his hands are clean when handling personal protectors, especially ear plugs, and seek medical advice in case of irritation of the skin during or after the use of protectors. In this case, the use of disposable protective earpieces may be appropriate. However, it should be noted that such a device can lead to lesser attenuation.

After use, the ear muffs, especially the earpieces, must be cleaned according to the manufacturer's instructions.

Reusable earplugs must be cleaned carefully, according to the manufacturer's instructions, and then stored in a clean case until the next use. "

In this same standard, EN458 Article 7.3 entitled "Review and replacement" recommends the frequent examination of the HPD to identify those who would be damaged...The hoops must not be subjected to intentional or accidental deformation. The earpieces of the ear muffs must be replaced according to the manufacturer's instructions as soon as they lose their original form, harden, crumble, or crack, or when any decrease in performance is noticed for other reasons. It is recommended that spare parts or new products are provided quickly.

2.9 Training, awareness

1 - Raising awareness on noise hazards
2 - Training on the correct use of HPD

"Adequate information and appropriate training must be provided to all persons who need to wear personal hearing protection devices." (Thiery, 2004 [8])

Here is a concrete example put forward by Dr Anne-Marie Robert, occupational physician at SMIRR, Reims (France).

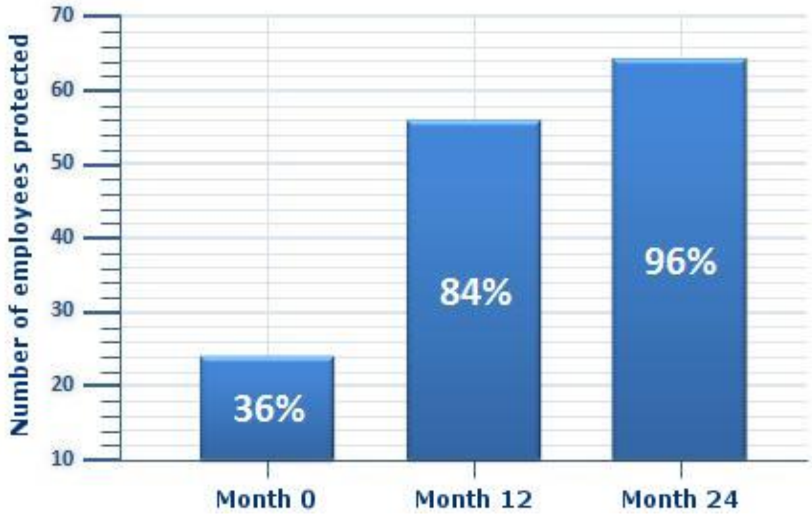
It takes place in a metallurgy company.
Out of 111 employees, 67 are exposed to noise levels above 85dB (A).

Month 0: From the beginning, 24 employees were wearing HPD (either standard earplugs or headsets).

Month +12: Through close collaboration between the doctor and employees, a year later 56 employees were accustomed to wearing hearing protectors.

Month +18: Eighteen months later, based on the good results, the company decided to invest in customized earplugs.

Month +24: In two years, 64 employees were continuously wearing their customized hearing protectors.



Changes in wearing HPD following an awareness campaign as a first step, and the implementation of customized earplugs as a second step

We see that with Standard HPD, without any action, 36% of employees are protected temporarily.

1 - The first awareness session, conducted for 12 months, helped increase the percentage of employees protected from 36 to 84%.

2 - A second action was implemented following these good results: by offering more comfortable customized hearing protectors, 96% of employees benefit from permanent hearing protection.

2.10 Advantages and disadvantages

HPD	Advantages	Disadvantages
Ear muffs	Intermittent use Reduced losses	Problems related to comfort (heat, pressure…)
	Easy setup Ideal during infections or following ear operations	Reduced efficiency while wearing glasses, or in case of beard or long hair morphology of the skull
	Increased attenuation	Low compatibility with with other PPE
Customized earplugs	Easy setup	Regular maintenance
	Comfort Lifetime	Requires the taking of impressions done by a professional
	Good fit Hygiene (no handling of the portion inserted in the ear canal when the protector is fitted with a handle)	Not suitable for sick/infected ears
	Good compatibility with other PPE High wearing rate	High initial investment
Earplugs to be molded	Low investment	Hygiene problem during shaping if the hands are not clean
	Adjustment is more adaptable than preformed earplugs	Risk of itching Systematic replacement Not suitable for sick/infected ears
	Good compatibility with other PPE	Instructions for set up comply scrupulously complex or impossible implementation for some ear morphologies
	No maintenance required	High production cost in the long term
Preformed earplugs	Hygiene (no handling of the portion inserted in the ear canal when the protector is fitted with a handle)	Regular maintenance Not suitable for sick/infected ears
	Low investment	Risk of itching
	Washable and reusable	Instructions for set up comply scrupulously
	Good compatibility with other PPE	The earplug's diameter should be adapted to the size of the ear canal Reduced effectiveness for very hairy ear canals

2.11 Summary

	Ear muffs	Preformed earplugs	Customized earplugs	Customized earplugs
Cost	●●●		●	●
Comfort		●	●●	●●●
Training				●
Attenuation	●●	●	●	●●
Compatibility		●●	●●	●●●
Ecological	●		●	●●
TOTAL	**6**	**4**	**7**	**12**

Table 8: Comparison of HPD

[ ] Not present
[•] Low
[••] Average to good
[•••] Very good

Cost

Measurement of economic interest over a period of 5 years

- As we have seen, ear muffs must be changed every 2 years. Base cost of the headset is about €25 (€50)
- Moldable earplugs are of the disposable type. Two pairs/day are used with an average price of 0.16 € a pair (4200 pairs of earplugs over 5 years = €672)
- Preformed earplugs at an average price of €3.50 a pair, replaced every month (€210)
- A pair of customized earplugs and all maintenance products for 5 years, base cost €100, to which is added about €30 of maintenance products per year (€240)

Comfort

Comfort rating for a wearing time of 8 consecutive hours

Training for implementation and awareness provided to employees

Three stars were awarded to customized earplugs as some manufacturers routinely provide training/awareness. However, not all manufacturers offer this, so it is better to stay informed.

Average

Range of attenuation corresponding to employees' exposure levels, helping them avoid a risk of exposure to high sound intensities as well as overprotection. The value also takes account of the differences between the displayed values and actual values.

Compatibility with other equipment and constraints

In Table 7, only customized earplugs with a uniform response filter are given 3 stars because of their ability to enable communication and compatibility with other equipment among employees with severe hearing loss. Please note however, that this is a specific filter that can be fitted to only a small proportion of customized earplugs.

Ecological

None of the HPDs are recyclable. Not even one can be subject to a sub-cycle. We therefore analyze their composition and volume of release into the environment.

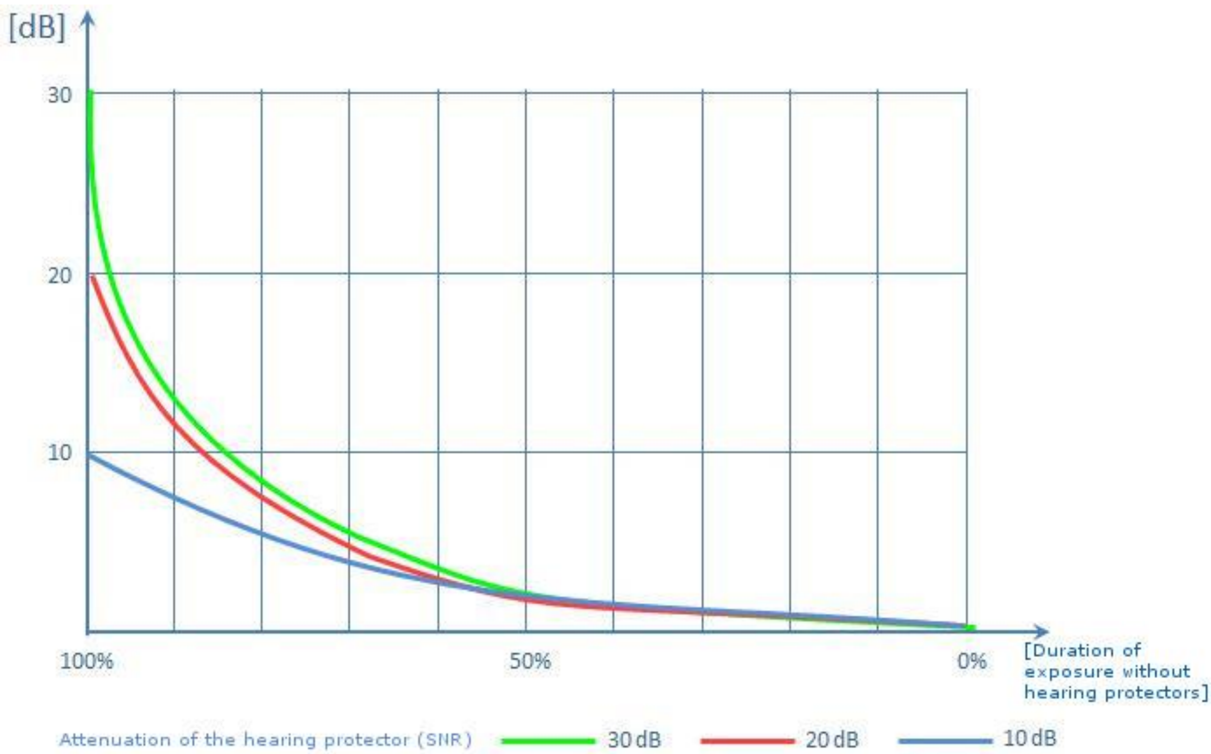
2.12 Rate of wearing (use)

The wearing rate is an extremely important factor for the efficiency of personal hearing protectors. The best HPD is the one that is worn, but to be truly effective it must be worn continuously during exposure to harmful noise levels.

The right conditions for a wearing rate of 100%:

1. An HPD that is comfortable
2. A suitable attenuation that is neither too high nor too low
3. Employee's awareness of noise hazards
4. Training of the employee for wearing the HPD

A 100% wearing rate is vital to protect the hearing of the employee. Graph 9 shows three hearing protectors with different attenuations.



Graph 10: Effective protection provided by the HPDs based on the decrease in the wearing duration (EN458)

As a first observation, when the HPD is not worn even for a short duration, the effectiveness of the HPD is reduced extremely quickly. If the employee wears his HPD for 50% of the duration of exposure to noise, the effectiveness of the HPD would be about 3 dB, which is as good as zero.

Two concrete diagrams illustrate the previous graph and show the importance of wearing a HPD for 100% of the duration of exposure to noise (figures 16 and 17).

Loss of efficiency of the HPD when it is not worn (Example 2) [4]

In this first example, we find that not wearing the HPD for 2 minutes in an 8-hour day reduces the effectiveness of the HPD by 25%.

Figure 15: Loss of efficiency of the HPD when it is not worn (Example 2)

The second example shows an almost total loss of effectiveness of the hearing protector when its use (wearing) is interrupted for only 2 hours in a day.

3 Conclusion

If 7% of employees are exposed to harmful noise for at least 20 hours per week, more than 2% of these employees are still without any real hearing protection. Men are 5 times more affected than women, especially in industries.

Noise generates numerous disturbances in the body; the most serious, deafness, is irreversible. It is currently the fourth most common cause of occupational disease and remains the most expensive.

The legislation requiring companies to protect their employees was strengthened in 2006. Every employee must be provided with hearing protectors (HPD) as soon as the noise level exceeds 80 dB (A) for 8 hours/day. In case this level is higher than 85dB (A), wearing hearing protectors becomes mandatory and the company must make every effort to ensure that the HPD is worn.

To choose an HPD, the EN458 standard specifies several selection criteria:

- The HPD must be CE certified; it must meet the requirements of standard EN352 (Minimum attenuation, resistance...).
- The level of sound reduction must be adapted to the needs of the employee. It must allow good hearing protection without over-protecting its wearer. It will be necessary to underestimate the attenuations reported by the manufacturers, their data from measurements made by the certification laboratories are overestimated in relation to the actual values.
- Comfort. To order to be worn, a hearing protector must be comfortable. Importance must be given to this point.
- The work environment, business, and compatibility with other personal protective equipment must also be taken into account
- The physician should be consulted in case of medical disorders, hearing loss, or ear problems.

Maintenance of protectors, as well as their replacement, must be followed to ensure their good efficacy, avoiding problems of irritation or other hearing problems.

So that hearing protection is worn, raise employee awareness on the risks of noise and train them in the proper implementation of the HPD provided to them.

In an analysis of all types of HPD in relation to different criteria studied, customized protectors appear to be most interesting. They are economical in the long run, comfortable, have good compatibility with other equipment, and have a good response to the constraints of the activity and the working environment of employees.

Ear muffs and preformed earplugs receive the same number of points. The most economical protection is provided by ear muffs with medium comfort and incompatibility with certain professions, or the wearing of some personal protective equipment.

The standard preformed earplug is easy to use, economical, and consistent, but, just like the standard earplug to be shaped, there is lack of training on implementation, which generates attenuation well below the levels put forward by manufacturers.

The standard disposable earplug to be shaped, besides the implementation problem, is also the most costly in the long run. With two pairs per day, the budget is around € 700 over five years.

The wearing time of HPD is the most important factor. 2 minutes of not wearing it and its efficiency is reduced by 25%.

Finally, there is only one objective: a wearing rate of 100% for HPD.

Two conditions for achieving the objective:
1 - Train and educate employees
2 - Provide suitable HPD.

1 **100% wearing rate**

objective

2 **1 - Train and sensitize employees**

2 - Provide suitable HPD.

Conditions

4 Notes and References

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Appendix 1 - Some guidelines for calculations…

Calculating the level of exposure to noise $L_{EX,8h}$

The employee is exposed to a single level of noise but for a period more or less than 8 hours

The L_{ex8} can be calculated from the following equation:
$L_{ex8} = L_{eqT} + 10Log(T/8)$
Where T is the duration of the shift in hours.

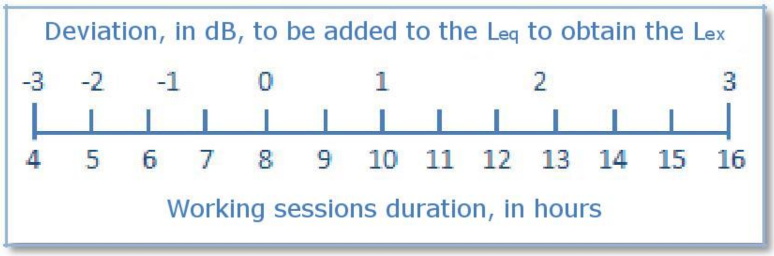

Figure A1: scale of corrections in dB based on shift duration

We will get the same result with the scale given in Figure A1 where the corrections to be made to L_{eq} in dB are given based on different shift durations. The lower figures represent the actual duration of the shift, the top ones are the indices of correction corresponding to the addition of L_{eq} for the shift, to obtain the L_{ex}.

Consider a 10 hour shift. The scale gives a correction of 1 dB (A) for the L_{eq}. An employee exposed to a level of 88 dB (A) for 10 hours will have a L_{ex8} of 88 dB (A) + 1 = 89 dB (A).
For a 12-hour shift we would have (88 dB (A) + 1.7 = 89.7 dB (A).

Adding several sound levels

Sound levels do not add up linearly but logarithmically. E.g. 85dB + 85dB does not give 170dB but 88dB. With each doubling of the level, 3dB must be added.

But what about when the levels to be added are not equivalent?

We can:

Either make the following calculation: 10*log (10 *S1*/10 + 10 *S2*/10 + ...+10 *Sn*/10)

Or use Table A1. Let's take an example:

We measure the contribution of 3 sound sources at a given point, each producing:

- Source 1: 78dB
- Source 2: 87dB
- Source 3: 89dB

Difference between the 2 sound levels to be added	Correction to be added to the highest level
0	+ 3
1	+ 2.54
1,5	+ 2.32
2	+ 2.12
2,5	+ 1.94
3	+ 1.75
4	+ 1.45
5	+ 1.20
6	+ 0.97
7	+ 0.78
8	+ 0.63
9	+ 0.51
10	+ 0.41
12	+ 0.27
14	+ 0.17
16	+ 0.11
18	+ 0.07
20	+ 0.05

Table A1: Addition of several sound levels. Correction to be added to the highest value.

The overall sound level once the three sound sources are simultaneously emitted, after calculating the differences between the 3 sound levels classified in ascending order, will be:

We take two of the weakest sources: 87-78 = 12 which is a correction of + 0.27 dB (Table A1) added to the highest level (87dB). This gives us 87 + 0.27 = 87.3.

We then take the highest value and calculate the difference from the previous result: 89 - 87.3 = 1.7 which is a correction of + 2.32 dB (see Table A1) to be added to the highest level (89dB).

The overall level will be around (89 + 2.32) = 91.3dB.

3 decibels are added when adding two sounds that have the same intensity. When the difference between two sounds is more than ten decibels, the sum of two noises is equal to the highest noise.

Noise exposure duration

Sound Level in dB(A)	Maximum duration of exposure in hours
80	08:00:00
83	04:00:00
86	02:00:00
89	01:00:00
92	00:30:00
95	00:15:00
98	00:07:00
101	00:03:45
104	00:01:22
107	00:00:41
110	00:00:20

We have seen that doubling a noise level increases its level in decibels only by 3dB. This criterion also applies to daily doses of noise defined by a noise level and duration of exposure.

We can say that "if the noise level is doubled (+3dB), the noise dose remains unchanged if the exposure time is halved."

Table A2: Correlation between the noise level and the maximum exposure (in the absence of any other noise exposure)

Several Excel files containing these acoustic calculations and more are available for download at: http://siteExpert/calculs-acoustiques