SAPAN

Select the Appropriate Hearing Protector

Methodology

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The selection of a personal hearing protector is an important step; it will determine the level of protection of the wearer.

This selection must be made with great care to ensure that the user does not face risks due to inadequate attenuation.

We must take into account the user's environment and his specificities to determine the most suitable hearing protector(s).

SAPAN is a method used to describe the exposure to noise, the importance of sound perception, possible hearing loss, other personal protective equipment worn that may interfere with the effectiveness of the hearing protector, etc.

By complying with the various directives, laws, recommendations by standards or referring organizations (INRS, IFA, EPA...) in the selected country, a suitable HPD* is selected and offered through the software having the same name as this method.

**Hearing Protection Device*

Protection against noise

E-125.3

HearingProtech.com

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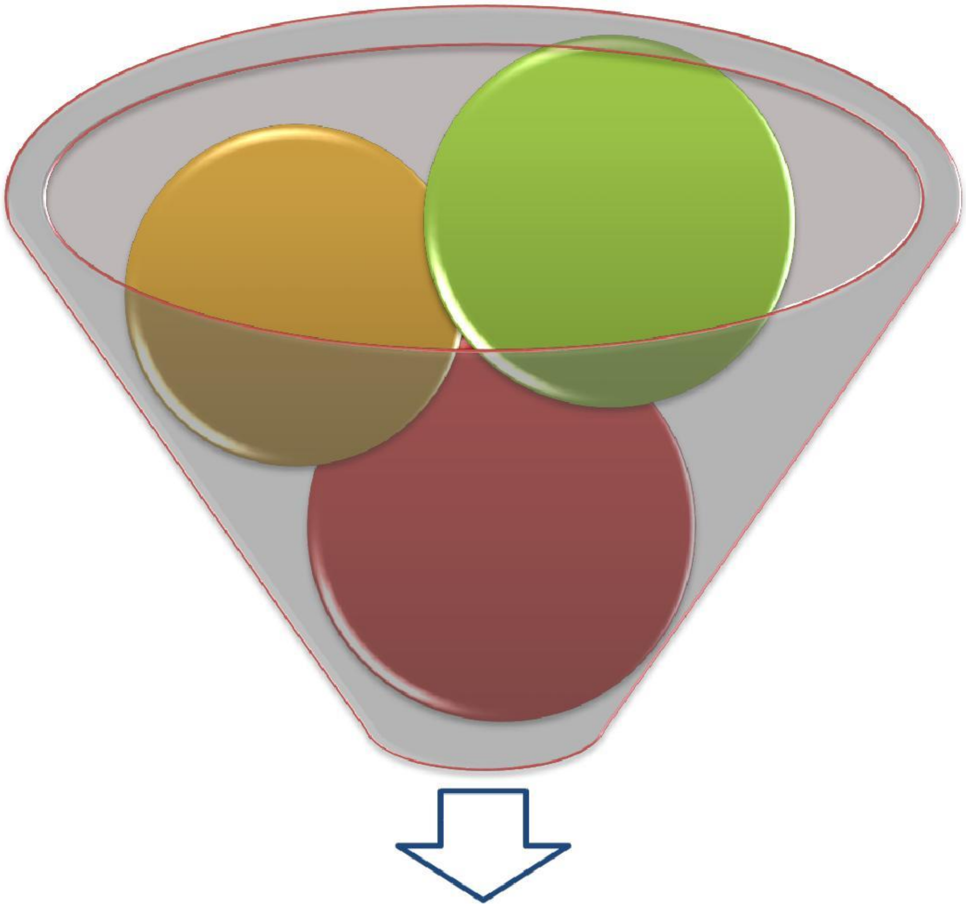
1 The principle

From data gathered on the user requiring hearing protection (exposure levels, specific features, environment, etc.), an attenuation level is determined in accordance with the standard recommendations, as well as recommendations by referring organizations for the protection of workers exposed to noise. A choice of HPDs (Hearing Protection Devices) is then offered.



Selection of suitable HPDs

Figure 1: Operating principle of the SAPAN method

During this selection, parameters such as the following are taken into account:

- the sound level of exposure
- the frequency spectrum of the sound levels
- the impulse characteristic of the noise
- the need to communicate
- the need to hear warning signals
- specific features of the user (other equipment, medical problems, etc.)
- the performance of the hearing protector can be lower than that measured in standard testing and published by the manufacturer

2 Noise exposure levels

To best assess the risk to the user, noisy areas should be identified and personal exposure to noise must be assessed.

Different methods are then used to predict the actual A-weighted sound pressure level at the ear when wearing personal hearing protectors. The method used will depend on the country in which the user is equipped with hearing protection, as well as the available survey data on noise.

2.1 Noise exposure level

It is important to know the level of noise exposure of the person to be equipped with hearing protection.

Ideally, a measurement must be performed using a dosimeter to accurately determine the level of risk. If not, the level of daily exposure ($L_{EX,8h}$) is calculated using the following formula:

$$L_{EX,8h} = L_{Aeq}, T_E + 10 \log (T_E / T_0)$$

where:

T_E is the actual total duration of the working day is

T_0 the reference period, set at 8 hours

L_{Aeq}, T_E is the sound A- weighted continuous equivalent sound pressure level

The European standard EN458 specifies four methods of calculation to estimate the residual level in the ear (they are described in the next chapter). Based on the information provided, the use of a particular method is specified. Regarding other countries, no particular method is specified. Access to the definition of noise data is different in different countries in which the SAPAN method is used:

- The European Community.
  1. dB(A)
  2. dB(C)
  3. dB(A) and dB(C)
  4. Based on frequencies
- Other countries
  1. dB(A)
  2. dB(C)

2.2 Calculate the residual level in the ear with the use (wearing) of HPD

2.2.1 Calculation methods used in the European Community for impulse

2.2.1.1 Four calculation methods

Four methods help arrive at the actual A-weighted sound pressure level in the ear when wearing personal hearing protection. They are detailed in EN 4869-2. These methods should be used primarily in the following order, based on the survey data available:

1. The octave band method, which consists of directly calculating the attenuation by comparing the sound levels by octave band readings on the workstation with the attenuation data per octave band with regard to the hearing protectors analyzed.
2. The HML method requires the C-weighted and A-weighted sound pressure levels of the noise and the H, M, and L values of attenuation of the hearing protectors analyzed.
3. The HML control, is a simplified version of the HML method. This method requires only a measurement in dB (A). It is complemented with information on the nature of the noise (medium to high frequencies or low frequencies).
4. The SNR method requires only one attenuation value, i.e. the SNR. This is subtracted from the C-weighted sound pressure level that was measured.

Recommended method	Information required	Priority
Octave band method	Sound pressure levels by octave band	1
HML method	Sound pressure levels in dB (A) and dB (C)	2
HML control	Sound pressure levels in dB (A) and type of noise	3
SNR method	Sound pressure levels in dB (C)	4

Table 1: Information required for each method of calculation of sound attenuation of the HPD

The calculation method is selected according to available information in the order of priority according to the recommendations of the standard (EN 458, 2005).

Each of the methods used will aim to determine L'_A, which corresponds to the A-weighted pressure level with regard to the hearing protector.
L'_A corresponds to the A-weighted sound pressure level.
L_c corresponds to the C-weighted sound pressure level.

Note that it is only an assessment based on the attenuation values of the HPD measured in the laboratory, and that only an actual measurement performed on the individual equipped with his hearing protectors will ensure that they are really appropriate and effective.

2.2.1.1.1 Octave band method

$$L'_A = 10.log. \sum_{f=125}^{8000} 10^{0.1\,(L_f + A_f - \mathrm{APV}_f)}$$

Where:

f: represents the median frequency of the octave band in Hz

L_f: is the sound pressure level of noise per octave band L_{oct} in dB in the octave band *f*

A_f: is the A-weighting in dB for the median frequency of the octave band

APV_f: is the estimated attenuation value of the personal hearing protector in dB

Calculating the frequency of 63Hz is optional.

2.2.1.1.2 HML method

It is based on the three attenuation values of H, M, and L (determined from the attenuation values per octave band). These values, together with the A-weighted and C-weighted sound pressure levels, are used to calculate the Predicted Noise level. Reduction (PNR).

$$If\ (L_c - L_A) \leq 2dB\ then\ PNR = M - \frac{H-M}{4}(L_c - L_A - 2)$$

$$Else\ PNR = M - \frac{M-L}{4}(L_c - L_A - 2)$$

The value obtained is then rounded off to the nearest integer.

We get the actual A-weighted sound pressure level in the ear with the following equation: $L'_A = L_A - PNR$

2.2.1.1.3 HML control method

This is a simplified version of the HML method that does not require knowledge of the C-weighted sound pressure level. Nevertheless, it requires a determination of whether the noise is characterized as medium or acute $(L_c - L_A < 5)$ or dominant low $(L_c - L_A \geq 5)$

Example of medium to high frequency noise ($L_C - L_A < 5$)	
Oxy-fuel welding with torch	Deburring of castings
Diesel engines	Woodworking machinery
Sugar coating machines	Hydraulic pumps
Rotating press with high speed reels	Stone polishing machines
Vibrating molding machines	Grinding machines
Impact tools	Pile drivers
Compressed air nozzles	Spinning frames
Mechanical nailers	Cotton machinery
Folding/embroidery machines	Abrasive cutting discs
Bottling machines	Mechanical looms
Centrifuge	

Example of dominant low frequency noises ($L_C - L_A \geq 5$)	
Excavators	Construction machinery
Compressor units	Blast furnaces
Motor generator sets	Water jet cleaning machines
Generators	Roller mills

Electric melting furnaces	Pressure casting machines
Cubitols	Annealing furnaces
Combustion furnaces	

We have repeatedly found an inconsistency with this calculation method. We will explain why and how to avoid this inconsistency.
According to the standard:
if it is a dominant "medium" to "high" noise, $(L_c - L_A \geq 5)$:

the value "M" is subtracted from the A-weighted sound pressure level:
$(L'_A = L_A - M)$
$If\ L'_A > L_{act}$
subtract the value "H" of the A-weighted sound pressure level: $L'_A = L_A - H$

We have repeatedly found the following inconsistency:
Take two hearing protectors:
Model A: SNR = 33 and HML respectively is 34/30/27
Model B: SNR = 28 and HML respectively is 33/25/19

According to the above formula we have L_A = 108 dB
Model A: $(L'_A = L_A - M)$ or 108 – 30 = 78
Model B: $(L'_A = L_A - M)$ or 108 – 25 = 83
In the case of model B, we have $L'_A > L_{act}$ the standard requires us to calculate $L'_A = L_A - H$ which is 108 -33 = 75

Result: the hearing protector with the most attenuation provides a residual level of 78dB (A) in the ear, while the one with the least attenuation provides better hearing protection with a residual level of 75dB (A).

To avoid this type of inconsistency, we define the following formula:
$L'_A = L_A$ – (((2 × M) + H) ÷ 3)
Which, for the example above gives the following results:
Model A = L'_A = 108 – (((2 × 30) + 34) ÷ 3) = 76.7 dB
Model B = L'_A = 108 – (((2 × 25) + 33) ÷ 3) = 80.3 dB,
The condition "$If\ L'_A > L_{act}$" disappears.
If there is a 'low' dominant noise $(L_c - L_A \geq 5)$:
Subtract the value "L" of the A-weighted sound pressure level: $(L'_A = L_A - L)$

2.2.1.1.4 SNR method
The calculation is as follows: $L_A = L_c - SNR$
The *SNR* is the overall attenuation index of the hearing protector.

2.2.2 Calculation methods used in the USA

The objective of the SAPAN method is to predict with maximum safety the level of the actual A-weighted sound pressure in the ear when wearing personal hearing protectors. It is therefore important to select the attenuation values of the hearing protector that have been measured using the method that takes the safety of the wearer into account in a better way.

Basic legislation on hearing protectors in the United States: The Noise Control Act of 1972 decreed that it is the Environmental Protection Agency (EPA) that regulates the labeling of HPD. As such, the EPA promulgated the law 40 CFR Part 211, Subpart B in September 1979. Since then (until today), the text requires the manufacturer to clearly indicate (before purchase) the "NRR" (Noise Reduction Rating) of the hearing protector. No minimum attenuation value is imposed.
(contrary to EU law (EN352-1 and EN 352-2)).

In law 40 CFR Part 211 (Subpart B), the procedure adopted for measuring the NRR is ANSI S 3.19-1974 (EPA, 1974). The measurement method is an REAT method
done on 10 subjects, with hearing protectors set up by the experimenter.

For years, scientists have shown that laboratory measured performance is far from reflecting the actual values in terms of attenuation (Casali, Berger, Franks, etc.).

The EPA has recognized this fact. In 1997, a new standard was published by ANSI: the ANSI S12.6 - 1997.

This standard provides two measurement methods: Method A (Experimenter-Fit) and method B (Subject-Fit), which is supposed to better represent actual values. The EPA would not amend the text of 40 CFR Part 211 for this new standard, in favor of the former (ANSI S3.19-1974).

In 2008, a revision of ANSI S12.6 resulted in a modification of method A under control of the experimenter, and now required 20 subjects rather than 10. The SAPAN method uses the attenuation values measured according to ANSI S12.6-2008 Method A, and only the low attenuation value (Low Value) will be taken into account.

The calculation is as follows: ($L'_A = L_C - NRS_A^{LV}$) if we have L_C .

If we have only L_A the calculation is: ($L'_A = L_A - NRS_A^{LV}$)

L_C corresponds to the C-weighted sound pressure level.
L_A corresponds to the A-weighted sound pressure level.
NRS_A^{LV} is the average attenuation of the hearing protector, according to the ANSI method
S12.6-2008 Method A, the attenuation value taken into account is the low value
(LV: Low Value).

2.2.3 Calculation methods used in Australia

The method is very similar to the method used in the European Community. Upon certification, two measurements of attenuation are performed on twenty subjects instead of 16, at the frequencies 125, 250, 500, 1 K, 2 K, 4 K and 8 KHz;

the optional frequency of 63Hz in Europe is not measured here. The standard deviation is taken from the average to obtain the SLC_{80}. No average HML exists.

The calculation is as follows: ($L'_A = L_C - SLC_{80}$) if we have L_C.
If we have only L_A the calculation is: ($L'_A = L_A - SLC_{80}$)

L_C corresponds to the C-weighted sound pressure level.
L_A corresponds to the A-weighted sound pressure level.

SLC_{80} is the average attenuation of the hearing protector, according to method AS/NZS 1269:2005.

2.2.4 Access to the SUVA database of professions/noise

In case we do not have an accurate assessment or measurement of noise levels, the SAPAN system provides access to the SUVA database "List of tables of sound levels"; this database identifies noise levels by sector and by occupation; more than 1,500 occupations are described. SUVA is the largest Swiss accident insurance agency.

2.3 Impulse noise

Impulse noise consists of one or more acoustic energy pulses, each having a duration of less than a second and separated by time intervals greater than 0.2 second. Impulsive noise of a sudden and unexpected nature is more harmful than a stable and continuous noise.

2.3.1 Calculation methods used in the European Community for impulse noise

These impulse noises are classified into three types, depending on the frequency distribution of the noise. They correspond respectively to frequency ranges that are low, medium, and high, and only high.
Some examples of impulse noise by type:

1. Bass frequencies: punching, vibrating molding machine, explosive, etc.
2. Medium and high frequencies: nail gun, hammer, shotgun, firing a weapon, etc.
3. High frequencies: gun

The calculation is carried out as follows:
L_{PC}: Impulse noise level recorded in dB (C)
d_m: Attenuation value modified depending on the type of noise
L'_{PC}: Actual level of the impulse noise in the ear

Depending on the type of noise, d_m will have the following value:

1. Low frequencies: $d_m = L - 5$

2. Medium and high frequencies: $d_m = M - 5$

3. High frequencies: $d_m = H$

The values *H*, *M,* and *L* are obtained from the attenuation data provided by the manufacturer. They correspond to an average of high frequencies (High), medium frequencies (Middle) and low frequencies (Low).
We thus have: $L'_{pc} = L_{pc} - d_m$

L'_{pc} is then compared to national action level $L_{act,pc}$ the hearing protector is considered suitable if $L'_{pc} < L_{act,pc}$

$L_{act,pc}$ is, at the time of writing this method, equal to 135dB for the European Community (DIRECTIVE on "NOISE" 2003/10/EC OF THE EUROPEAN PARLIAMENT, 2003)

2.3.2 Calculation methods used in USA for impulse noise

L_{pc} : Impulse noise level recorded in dB (C)
L'_{pc}: Actual level of impulse noise in the ear
The calculation is as follows: $L'_{pc} = L_{pc} - NRS_A^{LV}$

2.3.3 Calculation methods used in Australia for impulse noise

L_{pc} : Impulse noise level recorded in dB (C)
L'_{pc}: Actual level of impulse noise in the ear
The calculation is as follows: $L'_{pc} = L_{pc} - SLC_{80}$

3 The HPDs analyzed

Only the category of "passive" hearing protectors is analyzed for this first version of the SAPAN method.

It is important that the hearing protector selected has been certified "CE" for the European Community, "EPA" for the United States, or AS/NZ for Australia and New Zealand. Few manufacturers allow verification of this. To avoid limiting the wide choice of HPD proposed by SAPAN software, this first version did not take this into account. Manufacturers are invited to send us this information for a future version. Users of the SAPAN method are advised to approach leading supplier(s) for these documents before making their final choice.

Ensure that the manufacturer offering the HPD is the same one that has been certified.

Attenuation values

The attenuation values associated with each HPD constituting the SAPAN software database were entered based on the values provided by the manufacturers. Despite the great care given to this collection, the hearing protection device is not responsible for possible errors. This data is purely informative and indicative. We invite users to double-check the data before making the final choice. We also invite manufacturers to report any abnormalities or changes to enable us to provide reliable and up-to-date data.

Double hearing protection

Exposure to extreme levels of noise may require a higher level of protection than the proposed HPD. The ear muffs/earplugs combination may, in some cases, help to increase the attenuation level. It should be noted that the combination is not equal to the sum of the two hearing protectors. A calculator "*Estimate of the attenuation level of double hearing protection*" available at no charge on our website TheHearingProtection.com helps perform simulations of combinations. The concept of double hearing protection is not handled in this method.

Comfort

Comfort is an important parameter in the selection of personal hearing protectors. The pressure of the ear cups for the ear muffs and ease of wearing and removal for earplugs are elements that influence the comfort of the user. The more comfortable the HPD is, the better it will be accepted and worn, the objective being to wear it throughout the duration of noise exposure. We must remember that a period of non-use of two minutes a day reduces the effectiveness of the HPD by 25%.

This notion of comfort is not considered in the SAPAN method. It is very difficult to estimate, and is unique to each individual. Therefore, it is necessary, when possible, to allow the user to participate in choosing his future hearing protector.

3.1 Earplugs that require molding

Made of expandable foam, its particularity is that it must be compressed before introduction into the ear canal; once introduced, it expands to "close" the ear canal. Inexpensive to purchase, it must be replaced after each use.

3.2 The preformed earplug

Preformed earplugs can be introduced directly into the ear canal without the need for shaping/compression. Their shapes vary widely, and so do the materials used (silicone, rubber, PVC, etc.). They come in two or three sizes.

3.3 The customized earplug

Made from an impression of the intended wearer's ear, it offers good comfort and lifespan (five years on average) with regard to its initial investment. It is made of a flexible (silicone) or hard (acrylate resin) material.

3.4 Canal caps

There are preformed earplugs or are shaped by the user, and are connected by an arch which holds the plug inside or outside the ear canal.

3.5 Ear muffs

These are made of two ear shells with the ear pads, connected by a headband. The shells are usually filled with a material for sound absorption. The arch is designed to hold the ear shells on the wearer's ears, and the ear pads (PVC or polyurethane) offer a comfortable pressure. Adjustments allow adaptation to the morphology of the individual; a normal size and a smaller size are generally offered. Some pads are interchangeable; they must be changed every 24 months to continue to ensure a good seal.

4 Adapting to the constraints and specificities of the user

A variable "*V*" will weight the attenuation level required to meet different constraints and specificities related to the user and his environment. This variable shall not in any case put the user in a critical situation (over-exposure or under-exposure). The choices suggested by default are underlined.

4.1 Perception: the need to hear warning signals, and to communicate in noise.

In the industrial environment, various warning alarms are present. They differ based on their purpose. In most cases, it is mandatory that employees working nearby perceive warnings of imminent danger, signals, or oral information.

If the noise level is too high, it saturates our ear, and it is not able to properly process the information received. Wearing personal hearing protectors favors, in most cases, better understanding (comprehension) by avoiding saturation of the ear (Casali J. G., Robinson G. S., 2000).

4.1.1 Intelligibility

In acoustics, speech intelligibility is the ability of a listener to understand a nearby monologue (or conversation). The level of intelligibility is linked to a multitude of parameters, such as:

a. Ambient noise (intensity, spectrum, variation, etc.)
b. The signal emitted by the speaker (clarity, spectral range, perception of one's own voice, wearing a hearing protector, etc.)
c. The listener (hearing thresholds, masking effect, ability to reconstruct the message, language proficiency, lip-reading skills, wearing a hearing protector, etc.)
d. The configuration of the environment (distance between the speakers, angle of receiving the message, location of the noise, acoustics of the environment, etc.)

If it has been specified that intelligibility is important for the future wearer of the hearing protector, the method should allow for selection of the best or most suitable hearing protector to promote this intelligibility.

In case the need to communicate in noise is important, the classification of hearing protectors will no longer be based on their ability to approach the ideal residual level for the wearer, but on always making sure that the future user is properly protected, by sorting the results on the criterion of intelligibility.

We have seen that the parameters affecting the intelligibility are many. We will retain only five that seem the most important to determine the level of intelligibility in noise, and which have been studied and described by HearingProTech (NIEL, et al., 2013) namely:

1 - The level of ambient noise (environmental) in dB (A)
2 - The distance between the speaker and listener
3 - The speaker's vocal effort (Lombard effect)
4 - The attenuation of the hearing protector
5 - The effect of the hearing protector

4.1.1.1 The noise level described in A-weighted decibels

This value is essential to obtain a result.

4.1.1.2 The distance between the speaker and listener.

The default value entered in the SAPAN system is **1** meter (modifiable value)
Speech level at L meters = NP1L – 20 log (L)

where NP1L corresponds to the A-weighted speech at a distance of 1 m from the mouth of the speaker.

Table 2 indicates the average distances, depending on the type of interaction between the speakers.

Areas of interaction	Distances
Intimate zone	< 0.50 meter
Personal zone	0,50 at 1.20 meters
Social zone	1,20 at 3.00 meters
Public zone	> 3.00 meters

Table 2: Zones and distances of communication between persons

4.1.1.3 The speaker's vocal effort

Figure 2 below shows the relationship between the below (ISO9921 standard) gives the relationship between the **vocal range** (continuous sound level equivalent to the speech) and the ambient noise level in the position of the speaker.

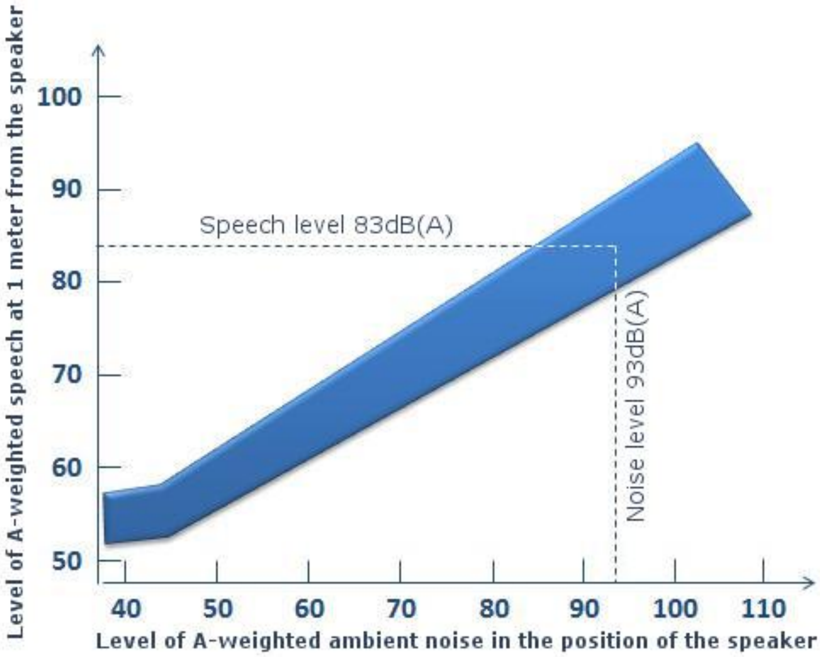


Figure 2: Effort of the speaker based on the background noise

We can estimate the relationship shown in Figure 2 By NP1L = 0.57 * NBA + 30

NP1L = A-weighted speech level at a distance of 1 m from the mouth of the speaker.
NBA = Ambient noise level in the position of the speaker.

for example, if NBA = 93 dB(A): NP1L = (0.57 * 93) + 30 = 83
The speech level of for ambient noise level of 93dB (A) will be 83dB (A)

4.1.1.4 - The attenuation slope of the hearing protector

This is calculated using the following formula $P = H - L$ where

"P" is the slope, "H" and "L" are respectively the average attenuation at the high and low frequencies (H: High and L = Low) provided by the HPD manufacturers certified in the European Community as "HML". The slope offers a simple and accurate indicator of the level of uniformity of the attenuation of a hearing protector at all frequencies. The study cited above clearly shows that the quality of intelligibility is highly dependent on the level of uniformity of hearing protectors.

The "P" value is available in the SAPAN database; the hearing protectors have not been certified in the European Community and require processing (calculation of HML and then the slope) before integration in the database.

In the specific case of a hearing protector that has been certified both in the European Community and in the United States, for example: when SAPAN is used in the United States, the American certification values are used in the calculations of HML and slope, and not the HML measured in Europe.

4.1.1.4.1 The effect of hearing protectors

By wearing a hearing protection device, the speaker's hearing of his environment is reduced. However, he perceives his own voice at a louder level. This effect is due to the phenomenon of occlusion that increases the perception of physiological noise and changes the perception of the person's own voice.

ISO 9921 states that the vocal effort of the speaker decreases by 3dB with hearing protectors.

Example:

Ambient noise 93 dBA → Vocal effort = 83dB → with hearing protector: 80dB

4.1.1.5 Other parameters

Other parameters affecting intelligibility will be set as and when they are known, either determined by taking the values closer to known situations of a user communicating in noise, or will be ignored to avoid making it more complex, at the risk of nullifying our method of assessing intelligibility.

4.1.1.5.1 Signal distortion

The voice quality degrades with vocal effort, making it harder to understand. The more the speaker shouts, the more distorted his voice becomes.

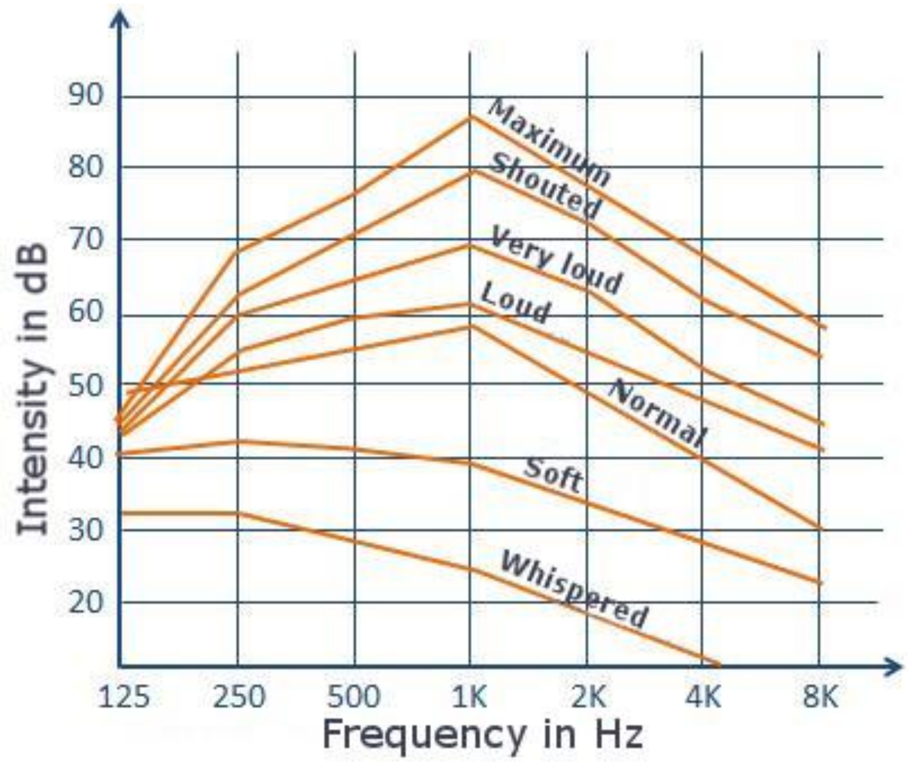


Figure 3: Average speech spectrum over a long term for different voice levels of a man, measured at 1 m in front of the subject (Webster, 1979)

According to various estimates, a loss of two to four decibels on the signal can occur if the vocal effort exceeds 75dB (A). This parameter has not been taken into account in the SAPAN method.

4.1.1.5.2 Directivity of the head

The angle between the signal source and the listener's head has a significant influence on his sound perception. Some frequencies are more or less attenuated based on the angle of the sound source, such as voice.

In general, lower frequencies are less affected by this directivity than high frequencies.

This parameter was not included in the SAPAN method. We consider that the speaker and the listener face each other.

4.1.1.6 Calculation method of intelligibility

We will use the formula described in the study (NIEL & Nexer, 2013) to determine the percentage of word intelligibility for an HPD, by taking into account some of the parameters described above:

$$\text{intelligibility\%} = \frac{47 - |\text{Slope}|}{58} + (0.06 * (10 + \text{Signal} - \text{Noise}))$$

Example:

Ambient noise 93 dBA

Vocal effort = 83dB → with hearing protector: 80dB

Slope of the HPD = 1.8

Which gives us: $$\frac{47 - |1.8|}{58} + 0.06 * (10 + 80 - 93) = 0.6 = 60\%$$

The ISO9921 standard considers that an intelligibility of 60% of word recognition is poor. We will consider that an HPD with a level below 60% may not be offered, if the "intelligibility" parameter has been described as significant ("high") in the job description of the user who must be equipped with hearing protection.

Evaluation of intelligibility	Score by type of phonetically balanced words having meaning in %
Excellent	> 98
Good	93 to 98
Appropriate	80 to 93
Low	60 to 80
Bad	< 60

Table 3: Evaluation of intelligibility according to ISO 9921

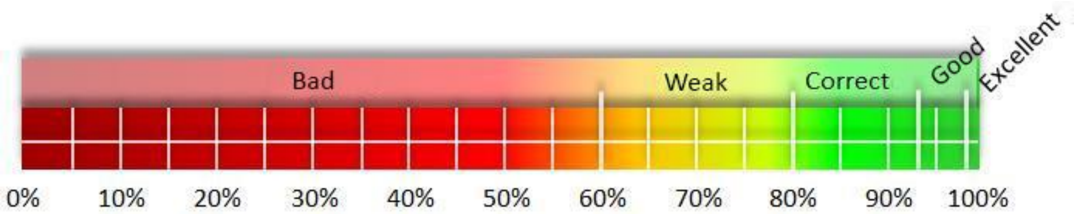


Figure 4: Quality scale of intelligibility according to ISO 9921

The scale in Figure 4 describes the quality of intelligibility. In the case where the index is less than 60%, it will be necessary to use either a suitable communication system (Transmission/reception electronics), or to come closer to the speaker to improve the signal/noise ratio. Without going into the "intimate" zone of the speaker, it is possible to enter his "personal" zone, by going closer, up to 0.5 meters, to improve the perception.

4.1.1.7 The SAPAN parameters for intelligibility

"Perception" section

“Degree of importance of oral communication"
Three choices are available: *None/Medium/High*

“Average distance between the speaker and the listener, in meters.
Blank entry field for one decimal place, by default set to "1.0"

Classification into "*ideal*, *acceptable,* or *unsuitable*" results will be as follows:

The degree of importance of oral communication is *Medium*
Intelligibility percentage < 60%: “*unsuitable*”
Intelligibility percentage ≥ 60% AND < 75%: "*acceptable*"

Intelligibility percentage < 75%: “*ideal*”

In this case, the sorting of models will be continued on meeting the estimated actual level at the ear and its distance from the ideal actual level to the ear.

The degree of importance of oral communication is *High*
Intelligibility percentage < 60%: “*unsuitable*”
Intelligibility percentage ≥ 60% AND < 80%: "*acceptable*"
Intelligibility percentage < 80%: “*ideal*”

In this case, the sorting of models will be on the level of intelligibility: the higher a HPD's level of intelligibility, the better it ranks. A difference of 3% separates each rank from the highest level of selection. Example: we have 7 models termed "acceptable" or "ideal"; we have:
- Rank 1: model with 72% intelligibility (the highest value in our example)
- Rank 1: model with 70% intelligibility
- Rank 2: model with 69% intelligibility
- Rank 2: model with 69% intelligibility
- Rank 4: model with 63% intelligibility
- Rank 4: model with 62% intelligibility
- Rank 5: model with 60% intelligibility

In this example:

- Rank 1 will include models with an intelligibility of 72, 71, and 70%
- Rank 2 will include models with an intelligibility of 69, 68, and 67%
- Rank 3 will include models with an intelligibility of 66, 65, and 64%
- Rank 4 will include models with an intelligibility of 63, 62, and 61%
- Rank 5 will include models with an intelligibility of 60%

Always, in the case where the degree of importance of oral communication is "*High*" and no hearing protector can be proposed (all intelligibility levels below 60% due to a high volume level, for example), the selection will have to be done only on electronic communication systems which enable speech using a type of phone or transceiver system while offering protection by a certified HPD. These will be identified in the database.

4.1.2 Telephone communication

"Telephone communication"

Three choices are available: *None/Occasional/Frequent*

Telephone communication with handset for the ear has not been studied.

The quality of perception depends, just as for intelligibility, on the ambient noise level and attenuation slope of the protector.

Other factors are important, such as the reception quality of the phone, the volume of the speaker, the location of the speaker, the ability to "stick" the handset to the hearing protector by juxtaposing the output sound from the handset to the "filter" opening of the protector.

Only the parameters associated with intelligibility discussed in the previous chapter will be taken into account. It should be ensured that the hearing protector and the phone have some compatibility.

The "occasional" value will be associated with the "medium" value of the previous chapter and the "frequent" value with the "high" value.

Pending a study to assess the ability to communicate on the phone in noise, we will use the intelligibility parameters described above. We know that even if the hearing protector allows very close contact with the handset, loss of intelligibility will occur, only because of the number of reduced frequencies transmitted by the phone system. We decided to reduce the transmitted signal (the speaker's voice) by 3 decibels.

The HPD equipped with an electronic communication system to communicate with a phone or a transceiver will be offered in addition, if the choice is indicated as "frequent".

4.1.3 Perception without distortion

"Sound staging of the environment without distortion (musician, machine setup, sound engineer, etc.)"

This is to give preference to hearing protectors that have the best attenuation uniformity across all frequencies. For a hearing protector that would bring a totally flat attenuation, the sound quality is perfect; only the noise level would be reduced. The selection and classification will be based on the measurement of dispersion (standard deviation) calculated on all frequencies.

σ_f: Corresponds to the standard deviation of the attenuation of the octave band (125 to 8KHz)

$$\sigma_f = \sqrt{\frac{\sum(f-\bar{f})^2}{7}}$$

There are two choices: *Yes*/<u>*No*</u>

If "***Yes***": Protectors will be classified according to their standard deviation. A standard deviation of ≤ 3 ranks the protector as "*ideal*"
A standard deviation > 3 and ≤ ranks the protector as "acceptable"
A standard deviation of > 6 ranks the protector as "unsuitable"

To be classified in one of the first two categories, an HPD must meet the prerequisite residual level at the ear < L_{act}

The classification of models is done on the level of perception without distortion, on the standard deviation. Thus the weaker the standard deviation of an HPD, the better its rank. Example: we have 5 models deemed "acceptable" or "ideal". The best of them has a standard deviation of 1.56. We have:
- Rank 1: model (s) with standard deviation ≥ 1 AND < 2
- Rank 2: model (s) with intelligibility ≥ 2 AND < 3
- Rank 3: model (s) with intelligibility ≥ 3 AND < 4
- Rank 4 ...

In case the user selects the intelligibility requirement as "high" AND a need for sound reproduction without distortion, it is the latter parameter that will be used to classify HPDs by rank. To be considered "ideal", an HPD must be included in the two criteria, as well as for the "acceptable" category.

4.1.4 Perception of warning signals

"Perception of warning signals transmitted on such frequencies":

There are four choices: *<u>none</u>/low/medium/high*

Here, we consider that the sound signal level is higher than the level of ambient noise. In the case where the noise would have a masking effect on the signals, the selection of a particular hearing protector does nothing to resolve the lack of signal.

We see in Figure 5 that a 60 dB noise localized at 500 Hz can mask a signal placing it on 1 or 2 KHz.

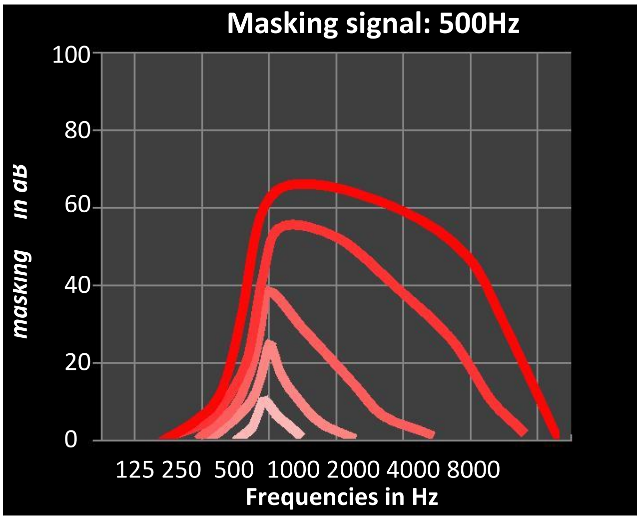


Figure 5: The masking rate produced by pure tones at 500Hz for various levels of the masking signal. Adapted from Ehmer (1958 [15])

To determine whether the HPD is suitable, we ensure that the average attenuation level (H, M or L) is lower than other average levels. If for instance the warning signal is high, we check that the hearing protector does not have a level of average attenuation at high frequencies that would mask the signal with regard to other average attenuations, to which are added two decibels for a slight tolerance.

"Low": If $L \le \left(\frac{M+H}{2} + 2\right)$ the HPD is approved

"***Medium***": If $M \leq \left(\frac{L+H}{2} + 2\right)$ the HPD is approved

"High" If $H \leq \left(\frac{L+M}{2} + 2\right)$ the HPD is approved

Example No. 1

Frequencies in Hz	125	250	500	1000	2000	4000	8000	H	M	L
Average attenuation (dB)	14,1	16,1	22,5	28,5	34,7	44,3	41,0	31,3	22,3	15,3
Standard-deviation (dB)	4,6	3,0	2,5	3,9	3,3	3,1	4,4			
APV (dB)	9,4	13,1	19,9	24,6	31,4	41,2	36,6			

Table 4: Attenuation of HPD according to European standards

The HPD is adapted to the perception of a signal of the "*low*" type because:

$15{,}3 \leq \left(\frac{22{,}3+31{,}3}{2} + 2\right) = 15{,}3 \leq 28{,}8$. It is also suitable for signals of the "medium" frequency because $22{,}3 \leq \left(\frac{15{,}3+31{,}3}{2} + 2\right) = 22{,}3 \leq 25{,}3$. It is not suited to signals of the "high" type because the condition $31{,}3 \leq \left(\frac{15{,}3+22{,}3}{2} + 2\right) = 31{,}3 \leq 20{,}8$ is not verified.

For this criterion "perception of warning signals" whether the IPCB is approved or not, it will be unsuitable in the latter case. The classification by categories "*ideal*", "*acceptable*", and so on, is done with regard to other criteria, and in all cases, based on the ideal residual level.

4.1.5 Cumulative criteria of perception

It is possible in some situations that a user requires the ability to communicate, as well as perceive communication without distortion or the ability to perceive a warning signal.

In this case, it is necessary to gather the criteria in each category to obtain in "ideal" HPDs only those that meet the various criteria, others will be ranked

« acceptable or even "unsuitable". An HPD classified as "ideal" for excellent intelligibility could be reclassified as "acceptable" if the perception parameters without distortion are not excellent (poor?), or even

« unsuitable" if they are below the required minimum.

4.1.6 Desire for insulation

"The user wants to be: well insulated from the noise"

There are two choices: *Yes/No*
If "Yes": *V = V* + 3 *dB*

4.2 Specific features of the user

4.2.1 Current level of protection

Depending on the wearing habits and the type of HPD used previously, weighting will be done to the attenuation to ensure that the wearing of the new hearing protector is effective.

We know from experience that a user accustomed to wearing an HPD with significant attenuation, e.g. ear muffs with high attenuation, may reject his new hearing protector if the degree of attenuation required is much lower. The significant gap in attenuation will give the user the sensation of not being properly protected.

In this case, an adaptation phase is necessary. An HPD providing a median level of attenuation would provide an interesting step in our example.

"Current level of protection"

Three choices are available: *None or low/normal/large*
If “none or low”: *V = V – 1dB*
If “normal”: *V = V*
If “large”: IR “Insulation requirement” = “Yes” WHERE *V = V + 1dB* IF NOT *V =*
V + 3dB

4.2.2 Noise sensitivity

Sensitivity to noise varies from one individual to another. While choosing the attenuation level of the future hearing protector, it is important to consider the user who may find the attenuation too high (feeling of insulation) or too low.

"Noise sensitivity of the user (e.g. the subject cannot bear the noise: high sensitivity)"

There are two choices: *low* or *medium/high*
If “low or medium”: *V = V*

If “high”: IR (“insulation requirement" = “Yes” OR “Current level of protection” = “high”) WHERE *V = V + 1dB* IF NOT *V = V + 3dB*

4.2.3 Medical conditions

4.2.3.1 Ear Problems

When selecting hearing protectors, it is important to know if the user suffers from or has suffered from ear problems (irritation, earwax flow, treatment taken for a skin disease, ear condition, etc.). In one of these cases, consult a doctor to determine the best-suited hearing protector; generally, an ear muff type of protector should be worn at least during the time taken to treat the subject. Intra-aural protectors (earplugs placed inside the duct) should be avoided.

"The user is suffering from ear problems (irritation, discharge, etc.)"

There are two choices: *Yes/No*
If "Yes": *V = V* with the exclusion of all earplugs

4.2.3.2 Hearing loss

« Individuals with hearing loss will have their handicap amplified by wearing personal hearing protectors. In the case of significant hearing loss at high frequencies (scotoma of 4000Hz) often due to noise exposure or age, it is desirable to recommend a hearing protector with a uniform attenuation across all frequencies. A conventional protector will significantly amplify the hearing loss, prohibiting its user from any chance to communicate with his environment, and exposing him to certain risky situations. Hearing loss is said to occur when the "Stage I", also called "latent deafness", is reached or exceeded. The hearing loss level is characterized by irreversible auditory scotoma on the frequency of 4 KHz exceeding 30 dB.

« *Users suffer from hearing loss due to noise or age*

There are two choices: *Yes/No*
If "Yes": If σ_f > 4dB, then the HPD cannot be included in the choice of "ideal" HPDs

if σ_f > 10dB, then the HPD will not be included in the choice of "acceptable" HPDs

4.2.4 Physical aspects and the environment

4.2.4.1 Beards, spectacles, or long hair

Beards, long hair, or spectacles can be detrimental in the case of earmuff type personal hearing protectors with headbands. Thus, larger or smaller acoustic leaks can be caused by the spacing of the ear pads, which must ensure a perfect seal around the periphery of the ear of the wearer.

"The user has a beard, long hair, and wears glasses"

There are two choices: "*Yes/No*"
If "***Yes***": Exclude ear muffs with headband

4.2.4.2 Wearing of other PPE

Wearing some HPD, mainly ear muffs with headbands, is not compatible with the wearing of another type of personal protective equipment.

One can easily imagine the difficulties of adjustment of a headband when the subject must also protect himself by using a mask, a helmet, or a hood.

"The user has another personal protective equipment in addition to hearing protection, such as a hood, a protective helmet, respirator, goggles, face shields"

There are two choices: *"Yes/No"*
If "***Yes***": Exclude ear muff with headband and canal cap HPDs

Note that there are ear muff models designed to fit with helmets, as well as ear muffs with headbands integrated into the helmet. These models were not analyzed, nor were they included in the SAPAN software.

4.2.4.3 Exposure to heat, humidity

Physical labor or a hot or humid environment may cause significant and unpleasant sweating at the portion covered by a headband. In this case, an earplug-type HPD is recommended.

Some headband models offer absorbent pads for protection; it should be noted that these devices can alter the effectiveness of the HPD.

"The user operates in a hot environment (T > 25 ° C), humidity (RH > 80%) or a significant physical activity."

There are two choices: "*Yes/No*"
If "***Yes***": Exclude headband type HPDs

4.2.4.4 Messy tasks

If the user is equipped with earplugs to be molded, make sure his hands are clean, allowing him to shape his earplugs without risk of infection.

"Should the user remove/put on his protectors with dirty hands?"

There are two choices: *"Yes/No"*
If "***Yes***": Exclude earplugs to be molded

4.2.4.5 Discretion

Certain trades or activities may require both the wearing of hearing protectors, as well as user discretion, lifeguards for example. Under these conditions, the headband type HPD are excluded from selection.

"The function of the user requires a discrete HPD"

There are two choices: *"Yes/No"*
If "***Yes***": Exclude headband type HPDs

4.2.4.6 Short and repeated exposure

In the case of repeated exposures to noise for a short term, it is best to remove the earplugs to be molded in favor of a headband type HPD or preformed or molded earplugs that allow quick and simple implementation and removal.

"The user is subject to short and repeated exposure"

There are two choices: *"Yes/No"*
If "***Yes***": Exclude earplugs to be molded

5 The performance of the hearing protector can be lower than that measured in standard testing and published by the manufacturer.

Many studies have shown that differences exist between certification laboratory measurements and actual measurements (in situ measurements) for all HPD.

These differences depend on the type of HPD and training received by the user to help in the implementation of the protector.
Without repeating all of these studies, the literature review of Alain Kusy INRS (Kusy, 2008) offers an interesting summary, indicating that a reduction will be applied to each protector to determine its index of actual attenuation. It is therefore appropriate to apply this reduction before comparison, for the selection of the HPD.

A summary of different reductions (NEXER Choosing a personal hearing protector, 2011) is given in Table 5. This table highlights the simplified and general values in some countries; please follow the recommendations of the occupational risk prevention organization in your country for more details.

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***	
Ear muffs	- 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	*Note **
Customized earplugs	- 5 dB	- 10 dB	- 3 dB	**	*Note **

Table 5: Discounts recommended by occupational risk prevention agencies
** Note: Not documented*

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

The SAPAN method will take these recommendations into account in the selection of the hearing protector. The safest values between German and French recommendations have been taken into account; the recommendations of NIOH are not taken into account. The concept of training recommended by the INRS (France) is retained.

We then get the following values:

Values to be removed from the attenuation displayed by the manufacturer		
Parameters / **Type of HPD**	***SAPAN recommendations***	
	With training	***Without training***
Ear muffs	- 5 dB	- 10 dB
Earplug to be molded	- 9 dB	- 15 dB
Preformed earplug	- 5 dB	- 15 dB
Customized earplugs	- 5 dB	- 10 dB

Table 6: Reductions taken into account in the method SAPAN

The reduction will then be applied to the actual level in the ear.

Example: the actual A-weighted sound pressure level in the ear when wearing earplug to be molded type of hearing protector is 76dB. In theory the HPD could be considered "ideal."

The reduction will be integrated directly at the actual level in the ear, thus avoiding the "complication" of calculation in the four methods. Taking the example of HPD for which no training is provided, it will be given a reduction of 15 decibels on its attenuation, we will have 76dB + 15dB = 91dB of actual level in the ear. This residual level exceeds the recommendations, and the HPD will be declared "unsuitable".

This reduction will be applied on L'_A and L'_{pc}.

The efficiency test (HPD monitoring on its wearer) produced by some manufacturers predicts the attenuation level required as per the SAPAN method. This test will help verify retrospectively that the hearing protector is compliant and that the actual attenuation corresponds to the needs of the user.

6 Training/awareness

We saw in the previous chapter that training in the implementation of the HPD and awareness of the noise risk are important and influence the effectiveness of the HPD.

The SAPAN method takes this parameter into account, and based on whether the user receives training or not, the attenuation values of the proposed HPD will deteriorate or not deteriorate according to Table 6 of the previous chapter.

*"Is a training **session** on the wearing and implementation of the HPD ensured?"*

There are two choices: “*Yes/No*”
If “*Yes*”: No additional reduction
If “*No*”: Reduction based on Table 6

7 The selection method

Eight steps will be taken to determine the HPD best suited to a given situation.

7.1 Filtering the HPDs

Incompatible HPD are excluded.

7.2 Selection of the calculation method

According to noise exposure parameters, which have been described by country, the calculation method will be selected.

7.3 Calculation of the effective level in the ear

The actual level at the ear L'_A is calculated with the method defined in 7.2 for each HPD.

7.4 Reductions based on the recommendations

A reduction will be applied to attenuation of HPD, according to Table 6. It therefore depends on the type of HPD and the presence or absence of training. After applying reductions, the HPD does not provide an adequate level of protection where L'A < Lact will be excluded.

7.5 Management of impulse noise

In case of impulse noise, L'_{pc} is calculated. HPD that does not allow an adequate level of protection ($L'_{pc} < L_{act,\,pc}$) are excluded.

7.6 Attenuation at uniform response across all frequencies

A filter will be applied to all HPD previously retained in the case where a uniform response to attenuation would be required.

7.7 Setting the "ideal" pressure level

The value of the "ideal" A-weighted pressure level required by the hearing protector is defined.

In the absence of recommendations from other countries, those of the European Community will be used. According to Table 2 of the standard (EN 458, 2005) the three ranges are:

"Ideal" range: $L'_A > (L_{act} - 10)$ AND $L'_A \leq (L_{act} - 5)$

"Acceptable" range: $L'_A \geq (L_{act} - 15)$ AND $L'_A \leq (L_{act} - 10)$ OR

$L'_A > (L_{act} - 5)$ AND $L'_A \leq L_{act}$

"Unsuitable" range: $L'_A > L_{act}$ OR $L'_A < (L_{act} - 15)$

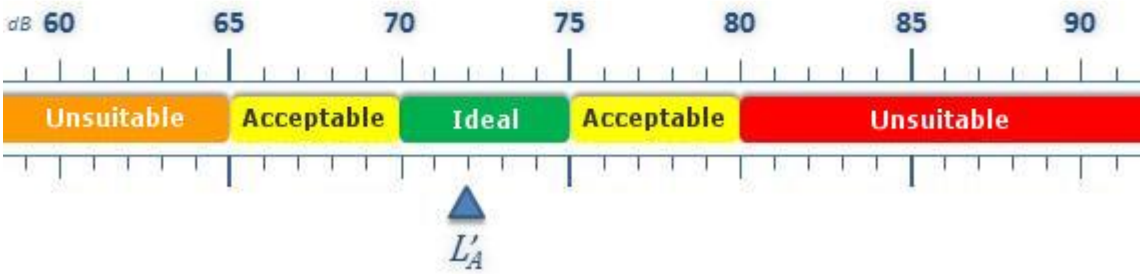


Figure 6: Qualification of ranges based on L'A (A-weighted pressure level of the hearing protector) taking into account the recommendations of Table A2 of the EN458 standard. The example that we used is that of the European Community, which defines Lact = 80dB according to (DIRECTIVE ON "NOISE" 2003/10 / EC OF THE EUROPEAN PARLIAMENT, 2003). L'Ai is the "ideal" residual level.

The "ideal" - A-weighted pressure level required by the hearing protector we call L'_{Ai} would therefore be in the middle of the range:
$L'_A > (L_{act} - 10)$ AND $L'_A \leq (L_{act} - 5)$

If $L_{act} = 80dB$ this level will be: 72.5 dB

We round off this value to the nearest lower whole number which is $L'_{Ai} = 72\ dB$

For other countries $L'_{Ai} = 72\ dB$ remains at this level even if the $Lact$ is higher.

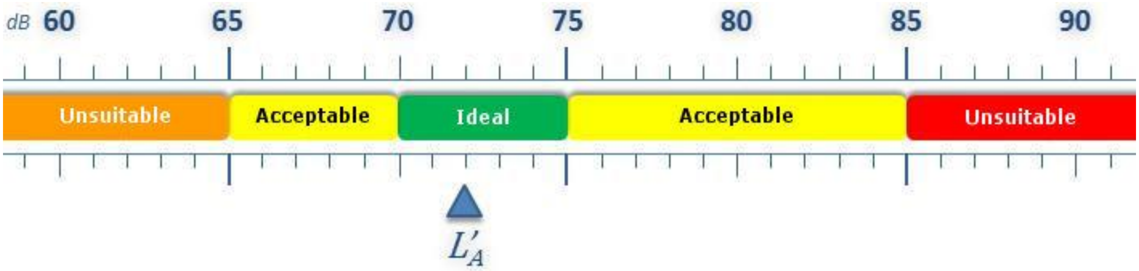


Figure 7: Here we see that the L'_A does not change for other countries - except the European community. However, the acceptable range located at the right of the ideal range expands to reach 85dB (A).

The "ideal" type HPD will be the same HPDs offered regardless of the country. Employees in countries outside the European Community will be offered a wider choice of HPD deemed "acceptable", while some of them will be considered dangerous in Europe.

We then apply the specific weighting to the user, defined by the variable "V". This variable takes into account the integration of constraints and special characteristics of the user. The result will indicate the "ideal" A-weighted pressure level desired in the hearing protector, taking into account the weighting of "V". We will call it L'_{AiV} .
We thus have $L'_{AiV} = L'_{Ai} - V$

7.8 Final classification

The final classification will establish a sorting in each of the two "ideal" and "acceptable" categories. We replace L'_A (A-weighted pressure level of the protector) with L_A (A-weighted sound pressure level). When the result is equal to L'_{viv} the HPD is considered the best suited, and it takes rank "1"; when the difference between L_A and L'_A is equal to 1 in absolute value, the HPDs concerned shall take up rank "2"; and so on. The aim is to reach as close to the ideal level as possible: L'_{AiV}.

For example, the HPD of the "ideal" category would be classified as follows:

Rank 1 - HPD model A as $L_A - L'_A = |L'_{AiV}|$
Rank 1 - HPD model B as $L_A - L'_A = |L'_{AiV}|$
Rank 2 - HPD model C as $L_A - L'_A = |L'_{AiV}+1|$
Rank 2 -HPD model D as $L_A - L'_A =$
$|L'_{AiV}-1|$

Rank 3 - HPD model E as $L_A - L'_A = | L'_{AiV} - 2|$

Rank 3 - HPD model ...

The HPD of the "acceptable" category would be classified as follows:

Rank 6 - HPD model R as $L_A - L'_A = | L'_{AiV} - 3|$
Rank 6 - HPD model S as $L_A - L'_A = | L'_{AiV} + 3|$
Rank 6 - HPD model T as $L_A - L'_A = | L'_{AiV} + 3|$
Rank 7 - HPD model U as $L_A - L'_A = | L'_{AiV} + 4|$
Rank 8 - HPD model V as $L_A - L'_A = | L'_{AiV} - 5|$
Rank 8 - HPD model ...

Reminder: No "unsuitable" HPD will be included in this classification. This is only done with HPD recognized as "ideal" or "acceptable".

Example 1:

$L_A = 92dB\ (A)$ - A-weighted sound exposure level of the user
$L'_{Ai} = 72dB\ (A)$ - A-weighted "ideal" pressure level of the personal hearing protector
As a reminder, the median of the "ideal" range defined by the standard (EN 458, 2005)
$V = -3dB$ - A-weighting to be applied taking into account the constraints and specific features of the user
$L'_{AiV} = L'_{Ai} - V$ - "Ideal" A-weighted pressure level desired for the hearing protector by taking into account the weighting of
$L'_{AiV} = 72 - (-3)$
$L'_{AiV} = 75\ dB(A)$

The "ideal" range will be between:

$L'_A > (L'_{AiV} - 2.5)$ AND $L'_A \leq (L'_{AiV} + 2.5)$

The "acceptable" range will be between:

$L'_A \geq (L_{act} - 15)$ AND $L'_A \leq (L'_{AiV} - 2.5)$ OR
$L'_A > (L'_{AiV} + 2.5)$ AND $L'_A \leq L_{act}$

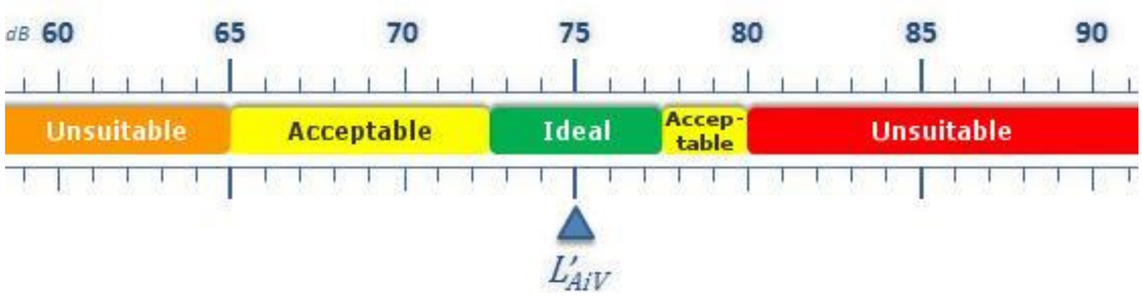


Figure 8: As given in Example 1, always taking the example of the ranges defined by EU standards, the ranges are shifted by + 3 dB to the right to meet the needs of the user, and the ideal level becomes 75 dB (A). The "acceptable" range, located to the right of the "ideal" range not exceeding the value of 80dB (A), was reduced to 2.5dB.

8 Conclusion

To determine the best-suited hearing protector for a user, two main parameters are taken into account:

1 - The attenuation level should be chosen to protect the hearing of the wearer of the device, but take care to avoid overprotection.

2 - This level must then be adapted, respecting parameter #1, to ensure continuous wearing meeting the constraints and special characteristics of the user.

The SAPAN method, through the software of the same name, collects all the information and parameters for a future user of the HPD, to offer products in the market that meet the specifications described in a better way.

Bibliography

Order of 19 July 2006. (2006). *by application of Articles R. 231-126, R. 231-128 and R. 231-129 of the labor code*.

Casali J. G., Robinson G. S. (2000). *Speech communications and signal detection in noise*. Auditory Systems Laboratory.

DIRECTIVE on "NOISE" 2003/10 / EC OF THE EUROPEAN PARLIAMENT. (2003, février 6). *concerns the minimum safety and health requirements for workers' exposure to noise*. Official Journal of the European Union.

Ehmer, R. (1958). *Masking Patterns of Tones.* Journal of the Acoustical Society of America. 31, 1115 .

EN 458. (2005). *Personal Hearing Protectors - Recommendations for selection, use, care and maintenance*.

EN 352. (2003). *Hearing protectors - General requirements*.

EN352-1. (2003). *Hearing protectors - General requirements - Part 1: ear muffs*.

EN352-2. (2003). *Hearing protectors - General requirements - Part 2: earplugs*.

EPA. (1974). ANSI S3.19.

ISO 4869-2. (2006, September 15). *Acoustics - Hearing protectors - Part 2 Estimate of A-weighted sound pressure levels in casing of using hearing protectors*.

Kusy, A. (2008). *In situ sound attenuation of personal hearing protectors.* INRS.

NEXER, G. (2011). *Selecting a personal hearing protector* TheHearingProtection. NEXER, G. (2011). *Select a personal hearing protection device with uniform response attenuation uniform*. TheHearingProtection.

NF S 31-084. (2002, October). *Measurement method of noise exposure levels in the workplace*.

NIEL, & NEXER. (2013). The effect of using personal hearing protection devices on communication in a noisy environment. TheHearingProtection.

Pearsons, Bennett & Fidel. (1977). Speech Noise Levels in Various Environments.

Appendix 1

(Order of 19 July 2006, 2006)

Measurement of noise related to the exposure of employees

Article 1 - Definition of physical parameters that are risk indicators

1 - The level of daily exposure to noise, $L_{ex,8h}$ is the value of the A-weighted continuous equivalent sound pressure level during the actual total duration of the working day "TE", standardized by the reference time "TO" of 8 hours. It is given in dB (A) by the

$$L_{ex,8h} = L_{Aeq'}Te + 10 \, . \log(\frac{Te}{To})$$

where:

➜ is the actual total duration of the working day;

➜ is the reference duration, set at 8 hours;

➜ $L_{Aeq'}$ is the A- weighted continuous equivalent sound pressure level.

2 - The peak sound pressure level L_{PC} is given in C-weighted decibels

by the formula:

$$L_{pc} = 10 \, . \log(\frac{Pc}{Po})^2$$

where:

➜ Pc is the maximum value of the instantaneous sound pressure during the working day, measured with C-weighted frequency at the worker's ear regardless of the wearing of personal protection.

3 - The weekly noise exposure level, $L_{ex,40h}$, is evaluated using the daily noise exposure levels. It is given in dB (A) by the formula:

$$L_{ex,40h} = 10 \, . \log(\frac{1}{5} . \sum_{i=1}^{S} 10^{0,1.(L_{ex,8h})i})$$

where:

➜ S is the number of working days during the week;

➜ $L_{ex,8h}$ is the level of daily noise exposure of yet another working day.

Article 2 - Definition of physical parameters that are risk indicators

1 - To assess the possibility of exceeding values and requiring preventive action, the peak sound pressure level, the level of daily exposure to noise and, where appropriate, the level of weekly noise exposure

are determined whenever a measurement is required, in accordance with the requirements of the standard (NF S 31-084, 2002).

The methods and apparatus used are adapted to existing conditions, taking into account the characteristics of the noise to be measured, the length of exposure, ambient factors, and the characteristics of the measuring apparatus.

The methods used may include sampling, which is representative of worker exposure.

The evaluation of the measurement results takes into account the measurement inaccuracies determined in accordance with metrological practice.

2 - To assess compliance with the limit values, where the worker wears hearing protectors, the effective exposure of the worker is determined in accordance with the requirements of the standard (ISO 4869-2, 2006).

Appendix 2

Example No. 1

The subject on whom we will base our example works in Germany. He is exposed to sound levels of 91 dB (A) and works in a glass factory; the frequencies are rather average and high in nature. The subject works in the morning on machine A and the afternoon on machine B. Machine A generates a sound intensity of 93 dB (A) near the operator, the machine B, an intensity of 89dB (A), which gives us a $L_{EX,8h}$[1] of 91 dB (A). The subject has a beard and myopia that requires him to wear glasses to watch the screens of Machine A.

Apart from safety shoes, he does not wear other personal protective equipment. He has been using disposable earplugs for years; he has no problem in using them. The occupational physician found no decreases in hearing for the 6 years that the subject has worked in this business. The subject works alone on his computer; he sees few people in the day.

1. Control of the actual sound pressure level in the ear when wearing HPD

The method used to predict the actual A-weighted sound pressure level at the ear when wearing personal hearing protectors will be the HML method since:
- We have sound level in dB (A): 91 dB (A)
- We have a notion of the type of noise: medium and high
- We calculate for each HPD the value L'_A

2. Reduction of attenuation values of HPD

The L'_A is recalculated for each HPD, taking into account the reductions in attenuation, according to Table 3.

3. Peak pressure

Our subject is not subjected to any peak pressure.

4. Oral or telephone communication

The subject communicates very little: *V* = *V*

5. Undistorted perception, perception of warning signals

No requirement: *V* = *V*

6. Desire for isolation

No, the subject already has it in sufficient amounts: *V* = *V*

7. Current level of protection

The subject used disposable earplugs: *V* = *V*

8. Noise sensitivity
Low or medium: $V = V$

9. Medical conditions
None: $V = V$

10. Physical aspects
We have seen that the subject has a beard and wears glasses.
We therefore exclude ear muff type HPD

Result
No variable will be applied ($V = V$).

All of the HPD are given in three lists:
HPD that ideally match the needs described: *n* "acceptable" HPD
Model(s) with regard to the requirement described: *n*
"Unacceptable" HPD with regard to the requirement described: *n*
model(s)

Example 2

The second subject works at a printing press in the United States. He coordinates the various printing lines; he is somewhat responsible by nature. No noise survey was ever performed, our subject was never even really protected. He never managed to use the foam plugs in his ears, as the helmet was too heavy, too hot. He could not do it. The occupational physician has yet again explained to him how important it is to protect himself from noise. The last audiometric testing, which shows a decrease in hearing, convinced our subject to do so soon, if he finds a hearing protection device that suits him.

Using the SUVA database (available in the SAPAN software), we select the profession of the subject "Printing of bills". He prints millions of currency notes all day long.
The system tells us that the $L_{EX,8h}$ is 86 dB(A).

1. Control of the actual sound pressure level in the ear when wearing HPD
No specific method is used to determine the residual level, for each HPD we calculate the value L'_A using the following formula:
$(L'_A = L_A - NRS_A^{LV})$
L_A is equal to 86dB(A)

2. Reduction of attenuation values of HPD
The L'_A is recalculated for each HPD, taking into account the reductions in attenuation, according to Table 3.

3. Peak pressure

Our subject is not subjected to any peak pressure.

4. Oral or telephone communication

The subject communicates all day, either orally or on the telephone. Only HPDs that permit good intelligibility will be offered to him.

5. Undistorted perception, perception of warning signals

No requirement: $V = V$

6. Desire for isolation

No: $V = V$

7. Current level of protection

The subject is not protected: $V < 2$ $\quad V = V - 3dB$

8. Noise sensitivity

Average: $V = V$

9. Medical conditions

Mild hearing loss: $V = V$

10. Physical aspects

Nothing in particular

Result

$V = -3dB$

The HPD will be classified by rank by percentage of intelligibility that it offers.

Models offering a percentage of intelligibility < 60% will be marked as "unsuitable".

[1] A calculator to assess the $L_{ex,8h}$ is available free of charge on the site HearingProTech.com

Appendix 3

The SAPAN method is available both as software and online.

As mentioned in the introduction to Chapter 3, the database used in the SAPAN application was entirely collected and composed of the data displayed by manufacturers/distributors. This data has been checked for consistency, but HearingProTech shall in no case be held liable with regard to the actual attenuations displayed for each HPD.

If we take the case of the German Manufacturer Egger, all attenuation data displayed are on the average attenuation and not on the VPA (average at which the standard deviation was deducted). For this manufacturer, who used other manufacturers' certifications to highlight his own products, when it comes to Clearsound filters, it was sufficient for this manufacturer to take up the certification data displayed by others. Egger has its own filters, but since we do not have VPA certification for these filters, they have not been integrated into the database.

We have just mentioned that there are various manufacturers who use a certification obtained by other manufacturers to market the same filter but in another protector that they themselves manufacture. We can assume that the attenuations are thus different. We will let each user of the SAPAN application make his own judgment on this. Before choosing a manufacturer, ensure that he does have "CE" certification in his name for the products he offers. The best-known example today is the case of Jrenum, whose filters are available in all European countries by manufacturers whose manufacturing methods are certainly different from those used by Jrenum during certification of its products over 20 years.

In cases where the same product (a single certification) would be sold/distributed by several distributors/manufacturers, a single model will be displayed. The details of distributors/manufacturers who sell it will be displayed at the time of selection of the said model.