11

PERSONAL MEASURES AND HEARING CONSERVATION

Professor Samir N.Y. Gerges
Federal University of Santa Catarina
Mechanical Engineering Department-Noise and Vibration Laboratory
Cx.P.476 - Florianópolis - SC
BRAZIL
gerges@mbox1.ufsc.br

Mr L. Vedsmand
Consultant, Work Environment
BAT-Kartellet, Kampmannsgade 4
Postboks 392
DK-1790 Copenhagen
DENMARK
lars.vedsmand@sid.dk

Mr H. Lester*
Health and Safety Executive, UK

11.1. WORK PRACTICES AND ADMINISTRATIVE CONTROLS

Evaluation of the workplace for noise exposure includes preliminary noise measurements, separation of the workplace into different noise risk areas - and development of both short and long term noise management plans. After evaluation of the workplace, it might be appropriate to evaluate possibilities which the individual employee has to control his or her own (noise) work environment and to evaluate simple measures which may result in a further reduction of the noise level.

Whatever noise levels are agreed upon in the workplace, or have been legally demanded, there will always for the individual employee and for a specific group of employees in definite sections of the workplace be a question of *what risk is acceptable - or "the acceptability of the noise level in the work environment".*

Every human has their own limit of acceptance - according to their attitude to their own life and health, their family and their colleaques. This limit of acceptance varies a lot from human to human, but even if the limit is exceeded one will back away from the risk. The limit is rather vague and is related to workers' traditions, possibilities of finding other less unhealthy jobs and the degree of influence at the workplace. The individual limit of acceptance thus might be either above or beneath what is considered healthy or legally justifiable.

---

*deceased. Contact: Keith Broughton, Technology Division 4, Health and Safety Executive
Magdalen House, Stanley Precinct
Bootle, Merseyside L20 3QZ UK
keith.broughton@hse.gsi.gov.uk

To get closer to the individual limit of acceptance in a workplace, it should be noted that:

- everybody will obtain updated information of health effects of noise,
- there is a high level of information about organizational, managerial and technical efforts of noise reduction,
- proper maintained personal hearing protection is available to a certain extent - and it is worn whenever necessary.

Employees can make their own noise reduction measures by:

- Avoiding unnecessary noise at transport and handling - "don't throw the things".
- Stopping machines and equipment that is not in use at the moment
- Securing loose machine parts that rattle.
- Reducing occupation and staying in high noise areas to an absolutely minimum
- Using appropriate technical equipment, for example encapsulation and noise shields.
- Making their own routines for maintenance, adjusting and oiling machinery and equipment.
- Taking part in development and evaluation of new noise efforts.
- If anything else is impossible, and hearing protectors must be used: **Use them all the time!**
- By taking any incipient hearing damage seriously, involve health personnel and have all damages properly investigated.

11.2. EDUCATION AND TRAINING

A very high level of information, training and education is definitely important for the understanding of the meaning of the health effects of noise and for understanding possibilities of hearing loss prevention in reducing the noise levels. It is also important for ensuring the effectiveness of the agreed noise policies and noise plans in the companies. So it is important to emphasise that instruction and education is not only aiming at teaching the employees how to use hearing protection devices, but the target groups for education and training are much broader:

- Employees
- Health and safety representatives
- Foremen, supervisors, engineers and designers
- Management and the company's buyers
- Professionals and managers
- Future engineers and machine inventors.

11.2.1. Training Within the Workplace

11.2.1.1. Content of training

The employer must provide instruction, supervision and training to all employees who work in unacceptable hearing risk areas so that they can perform their work in a safe manner and without risk to their health and safety.

The employer must ensure that all employees with potential for exposure to (hazardous) noise in the workplace are trained in relation to the noise, its sources and propagation paths.

The main content of the training should at least concern:

1) The known noise levels of different places in the workplace
2) Identification of risks to health and safety associated with working in the noisy areas, (for instance with the use of tapes with different noise levels and how it is experienced with different grades of hearing loss)
3) The control measurements and administrative procedures implemented to minimize exposure to noise (including demonstrations of measuring equipment).
4) The necessity of good work practice and periodical maintenance of machinery and equipment,
5) The duties of suppliers, management, supervisors, employees, work hygienists,
6) The availability and use of information, including noise declarations and noise estimation schemes ,
7) the proper selection, evaluation and maintenance of hearing protection and the importance of wearing hearing protection all the time. (including practical exercises)

11.2.1.2. Time of training

The employer must ensure that training is provided:

a) before an employee first begins work within a risky noise area.
b) whenever new machinery or equipment is planned to be installed.
c) when there is a change in the noise control measures used or a change in the managerial noise policy or plans.
d) when there is new information available on health and safety matters concerning noise.

11.2.1.3. Target groups of training within the workplace

1) All employees working in noisy areas and their health and safety representatives,
2) persons responsible for workplace layout, plant, buying and maintenance of machinery and equipment, i.e. internal engineers, supervisors, and designers,
3) persons responsible for control measures, including the acqusition and maintenance of hearing protective equipment.

11.2.1.4. Training methods

Training on the job should be undertaken by a competent operator familiar with noise effects, noise measuring and engineering controls and familiar with the company' s plans for noise reduction.

More consideration should be made in developing and providing training programmes, such as:

* how to be sure that the contents of the training are clearly understood by the participants,
* that employees and others being trained should not be required to carry out any procedure which after the training could cause health and safety risks to themselves and to other employees,
* any special needs of the participants in the training such as specific skills, work experience, ethnicity and first language, literacy and age.
* there might be a differentiated training for individuals or for mixed groups within the workplace; in many cases it would be appropriate to mix up different groups of employees, engineers and administrative staff to get more experience, good suggestions

for further noise reduction and by that also training the different groups co-operatively. The training should be carried out in a way that permits two-way communications - also to get new ideas for further training.

11.2.2. Training and Education Outside the Workplace

Training courses concerning noise, including all kinds of new information, should be provided for occupational hygienists and for health and safety executives. It is of special importance that education in the technical universities also includes work and environmental aspects of noise so that future designers of machinery and equipment in an early stage recognise the importance of noise reduction.

> **RECOMMENDATIONS FROM THE WHO CONSULTATION ON NOISE**
> ***(see Background)***
> Education as to the dangers of overexposure to noise should aim not only at managers, workers and all professionals related to workplaces, but should start with school children and also include the general public.
>
> Educational campaigns should follow adequate strategies and utilise materials appropriate to each target group. Mass media, for example, is an excellent tool to educate the general public.

11.3. PERSONAL HEARING PROTECTORS

11.3.1. Introduction

Despite the great progress in noise control technology, there are many noise situations where engineering noise reduction is neither economically nor technically feasible. Also in many practical situations, it may be many years before noisy machines and processes can be modified or replaced. Therefore, in these cases, or during the period in which noise control actions are being undertaken, personal hearing protection should be used as an interim solution. The use of personal hearing protectors is an ideal solution in many situations where a worker is exposed to high noise levels for short periods of time, particularly if communication is not necessary such as cutting a sheet of wood, in the circular saw room. In this case, the worker can go into the room in which the saw is enclosed, shut the door, put the hearing protector on, switch on the noisy circular saw, cut the sheet, switch off the saw, take off the protector and hang it on the inside side of the door, and then get out of the room. During the cutting period, which may last for minutes, there is no need to communicate with any other person, and the operator can withstand the disconfort of the protectors. Therefore the use of hearing protectors in this case, and similar cases, is the ideal solution.

11.3.2. Selecting Hearing Protection

A correctly selected hearing protector should provide enough noise reduction to remove the risk of hearing damage, and at the same time allow communication with the surroundings while ensuring the best available level of comfort. The acceptance of hearing protection is strongly linked to the likelihood of it being used. To get a 100 % use the noise reduction, the communication and the comfort should be considered.

High noise reduction requires heavy hearing protectors located very close to the head with a large pressure. But great weight and high pressure result in high discomfort which may be even so bad that nobody could stand to use the protector for a long period. High noise reduction protects against hazardous noise while at the same time allowing the user to hear desirable sounds (eg. conversation, warning sounds.

It should be emphasised that the hearing protector should be used in all the time that one is in a noise area. If one take off the protector even for a few percent of the time, maybe 5-10 minutes in a whole working-day, the protection could be reduced to half (see Figure 11.1).

If the protector is not used all the time, its nominal noise reduction will be unimportant. So it is very important that the protector should be accepted by the user. The selection of a hearing protector must be from a total point of view (including comfort) and not only on the basis of the noise reduction curve.

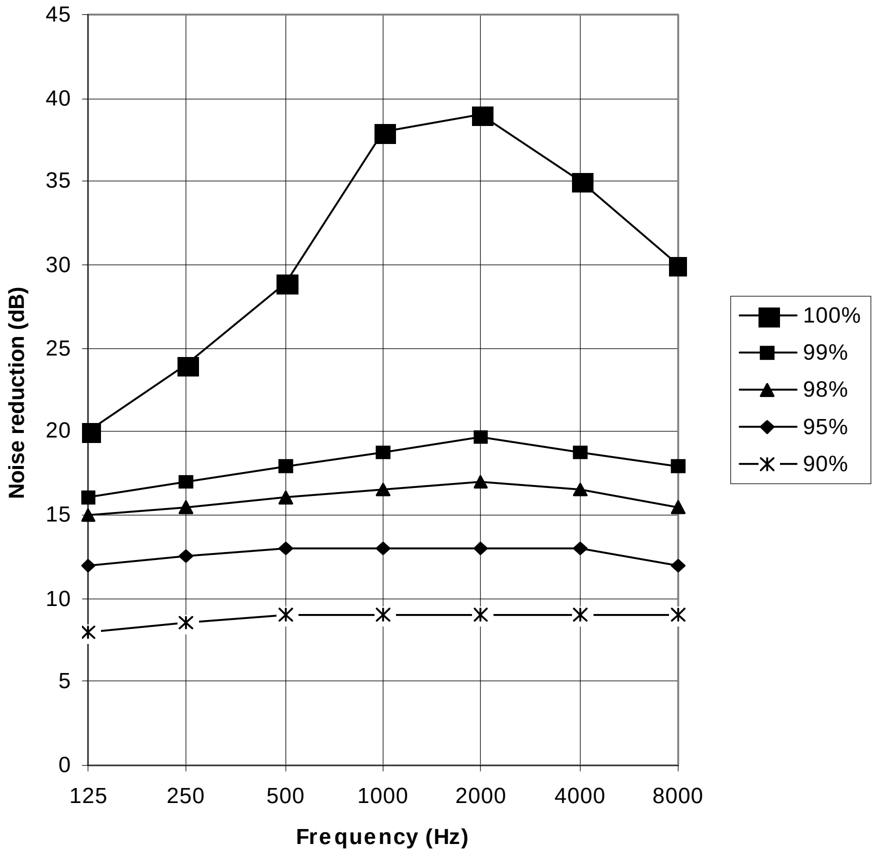


Figure 11.1. Effect of percentage of time typical hearing protection is worn on the effective noise reduction experienced by the wearer.

It has not yet been possible to find a method of measuring the comfort of the protectors. The comfort could vary significantly from person to person. The shape of the user's head and the ears and head dimensions vary greatly between individuals. Only the user can determine whether a specific protector gives enough comfort. So the user should always be provided with a number of different protectors to ensure that the protector is acceptable and thus it is used as intended.

11.3.3. Types of Protectors

Hearing protection devices may be broadly divided into three basic types: (1) earmuffs which cover the outer ear and act as an acoustic barrier sealing it against the head (2) earplugs which can be inserted into the outer ear canal, thereby blocking the propagation of airborne sound to the middle ear. (3) Canal caps (semi-aural) which are basically earplugs connected by flexible headband. Canal caps generally seal the ear canal at its opening and they are used extensively in the food industries. (4) Other special types are available such as helmets with circumaural, cups or muffs with communication. Other brands are also now available with electronic amplification or with active noise reducing digital circuits.

There are many varieties of hearing protection devices available on the market and several factors have to be considered in addition to the noise attenuation provided; such as selecting the most suitable type for each situation, comfort, cost, durability, chemical stability, safety, wearer acceptability and hygiene. No particular brand is obviously the best choice for all.

RECOMMENDATIONS FROM THE WHO CONSULTATION ON NOISE
(See Background)

As any personal protective equipment, hearing protection devices should be regarded as "last resource" measures, or for sporadic or temporary use. All efforts should be made to reduce noise levels in the work environment.

The provision of hearing protection of dubious or unknown effectiveness is unacceptable. In order to ensure effectiveness of hearing protection devices, it is imperative that their quality be assessed, for each type and manufacturer; national institutions should carry out or request such evaluations.

Furthermore, even protectors of proven quality need to be assessed for individual workers.

Protectors should have labels that are representative of their performance at the workplace.

Research on the development of open-back head-sets and ear plugs that use active noise control for broad-band noise reduction should be promoted. There is also scope for improvement of the classical passive types of ear protectors.

..

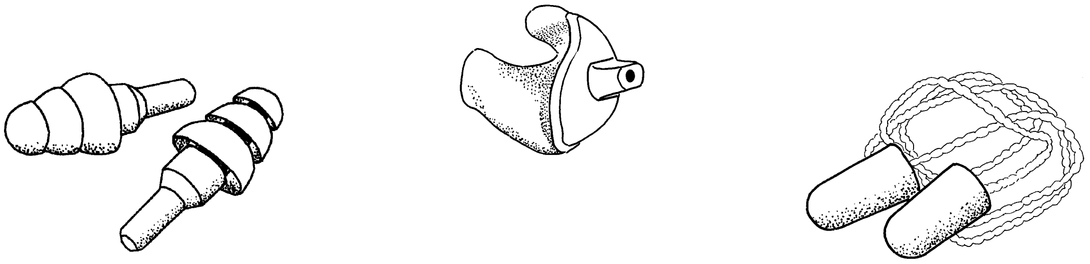
11.3.3.1. Earplugs

Earplugs can be classified by size, shape and construction materials such as; custom molded, premolded and expandable.

Premolded earplugs are generally made of soft plastic or silicone rubber and are available in different sizes (see Figure 11.2(a)). Generally they are available with an attached cord to prevent loss. The characteristics of these plugs depend on the fitting and maintenance. The wearer of these types can experience a feeling of pressure or discomfort due to their semi-solid construction.

Custom molded ear plugs are made of a soft rubber material which is molded into the individual's outer ear canal (see Figure 11.2(b)). In these case, a high degree of attenuation is obtained depending on each wearer.

Expandable earplugs are considered the most comfortable (see Figure 11.2(c)). Since they are porous and soft. They are made from slow recovery closed cell foam. They offer high attenuation since they expand against the outer ear canal and seal it with less pressure.



(a) **(b)** **(c)**

Figure 11.2. Earplugs.

11.3.3.2. Earmuffs

Ear muffs are made from rigid cups, are mostly oval shaped, and are designed to cover the external ear completely. They are held in place by a preformed or spring-loaded adjustable band and are sealed round the rim of each cup, with a soft foam-filled or liquid-filled circumaural cushion, to achieve a continuous seal contact.

The effectiveness of ear muffs depends mainly on the pressure exerted by the headband and the cushion to head sealing. The attenuation provided by ear muffs can be greatly reduced when the muff seal is displaced by the side arms of spectacles or long hair. Ear muffs fit most people, are easy to put on and remove in a hygienic way, and are therefore recommend for use in dirty areas and for workers who suffer from external ear canal problems.

11.3.3.3. Canal caps (semi-aurals or banded ear plugs)

They consist of flexible tips, made from silicone, vinyl or foam in mushroom, hollow bullet or conical shape, atached to a lightweight plastic headband. They are easily removed and replaced. They can be used under the chin and behind the head.

11.3.3.4. Special types of hearing protectors

There are a number of hearing protectors designed for special purposes. Ear muffs can be fitted with phones and wired-up or connected by radio in order to provide communication and/or entertainment. Also they can be fitted with acoustic frequency band-pass filters to provide speech communication between wearers, providing that the noise is out of the speech frequency band.

Ear muffs are also available which can reproduce music or messages from external units. These muffs have a peak limiting circuit (to about 80 dB(A)) to avoid hazard.

Active noise control ear muffs are now available which cancel the low frequency band noise inside the cups by out-of-phase generated sound. They provide good attenuation at low frequencies (up to 20 dB) and also serve as classical passive earmuffs with good attenuation at high frequencies. They are still expensive and have the possibility of electronic failure (see Figure 11.3).

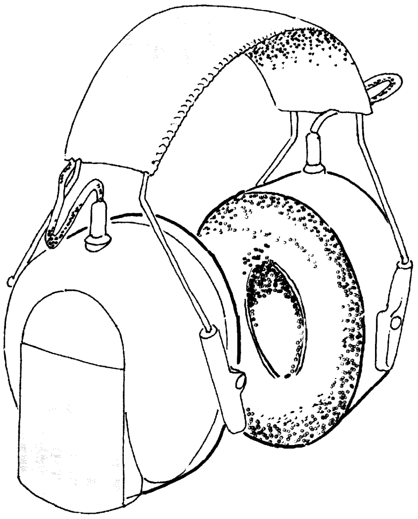


Figure 11.3. Active control muffs

11.3.4. Hearing Protector Attenuation

The maximum possible protection is dependent on the frequency of the noise and the noise attenuation is limited, especially at low frequencies. Noise can reach the inner ears of the person wearing the hearing protector by one or more of the following pathways (see Figure 11.4);

1- Leakage around the protector contact with the head (for muffs) or ear canal (for earplug)
2 - Vibration of the protector causing sound generation in the outer ear canal;
3 - Sound transmission through protector materials;
4 - Bone and tissue conduction through parts of the head not enclosed by the protector;

The four leakage pathways set practical limits to the noise attenuation provided by any ear protector. The maximum possible attenuation of the protector is unlikely to be achieved for various reasons e.g. protector-wearer coupling, but approximate values for wearers of both plugs and muffs are between 40 to 60 dB depending on the frequency bands (see Table 11.1). This maximum possible attenuation is unlikely to be achieved in practice.

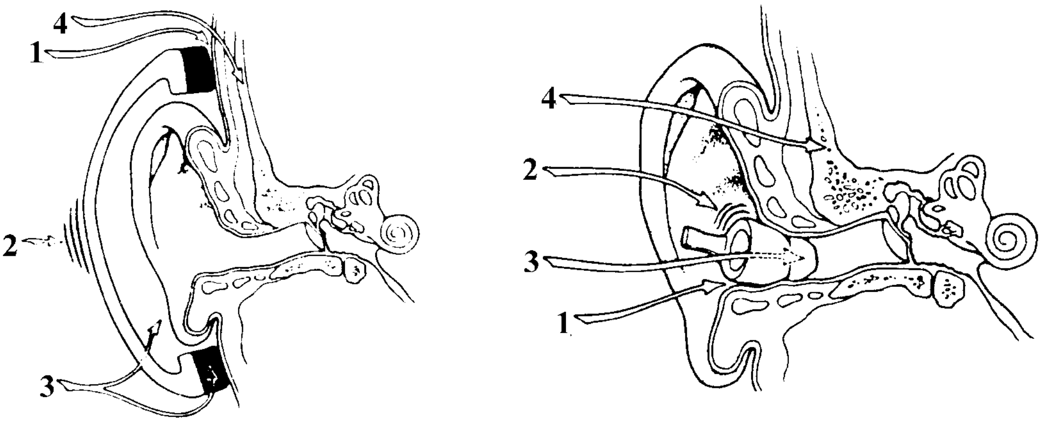


Figure 11.4. Sound pathways leakage (Berger et al. 1996)

The noise attenuation of a hearing protector is best represented by the "Insertion Loss (IL)" which is the difference between the sound pressure level at the outer ear canal with and without the hearing protector.

Working environments are generally reverberant fields characterised by broad or narrow band frequencies. Therefore any test method for measurement of hearing protector attenuation must reasonably represent this situation.

Table 11.1: Bone conduction limitation to hearing protector attenuation (Berger et al. 1996).

Frequency band Hz	125	250	500	1k	2k	3.15k	4k	6.3k	8k
Maximum Protection, dB	47	50	58	48	40	47	49	48	48

11.3.5. Hearing Protector Measurements (Franks et al. 1994)

Several national and international standards are available for the laboratory determination of hearing protector noise attenuation, mainly the ANSI standard used in the USA and ISO & EN standards (see list at end of this chapter)used in Europe.

The method specified by the Environmental Protection Agency "EPA" in the USA for determining the amount of noise attenuation that a hearing protector provides is based on subjective tests of protectors as worn by listeners rather than objective tests from an electromechanical device. The actual test method is called real-ear-attenuation-at-threshold (REAT), and the techniques for measuring REAT are specified in ANSI S3.19-1974. ANSI S3.19 - 1974 requires that auditory thresholds be obtained from a panel of 10 normal -hearing listeners sitting in a diffuse random-incidence sound field. The test signals are pulsed one-third-octave bands of noise which have centre frequencies of 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz. Thresholds are determined with the listeners' ears open and with their ears occluded by the hearing protector under test. The difference between the open-ear threshold and the occluded-ear threshold at each frequency is the REAT for that frequency. Each listener is tested three times with their ears open and three times with their ears occluded. The REATs for all 10 listeners are arithmetically summed and the mean attenuation is calculated for each test frequency. Since there are three REATs at each test frequency for 10 listeners, the average is calculated by dividing the grand total by 30 to get the grand mean. The standard deviation is also calculated for each test frequency using the number 29 (n-1 from the formula for the standard deviation of a sample, where n is the number of samples) as the denominator, as if 30 separate subjects had provided one REAT each per test frequency.

When a REAT is being determined for the purpose of labelling hearing protectors according to EPA labelling requirements, the protector is fitted into the ear or placed on the head by the experimenter in order to obtain maximum protector performance. Technically, the experimenter fit described in ANSI S3.19 - 1974 and adopted by the EPA does in fact permit the test subjects to fit the protector themselves (using a fitting noise to adjust the device for maximum attenuation) provided that the experimenter personally checks each installation for good fit and acoustic seal and reinserts or readjusts the protectors as necessary. In practice, however, the EPA has determined that "experimenter-fit" shall mean that the experimenter always personally fits the device under the test.

The current American National Standards Institute's method for determining REATs for hearing protectors is ANSI S12.6-1984. This standard, which replaced ANSI S3.19 - 1974, allows more freedom in setting up a diffuse sound field, defines sound-field noise-burst audiometry with greater precision, and is more explicit in its details about how audiograms are to be read and analysed (particularly in the areas of pairing open and occluded thresholds). S12.6 - 1984 requires an experimenter-supervised fit in which the listener fits the hearing protector while listening to a fitting noise and while gaining insight from the experimenter on optimum fitting techniques. The experimenter does not physically touch the protector or the listener after the final fitting. Calculations of mean REAT and standard deviations are identical to the earlier standard. Since ANSI 12.6 -1984 was adopted after the EPA hearing protector labelling laws were written, and since the EPA regulations made no provision for adopting newer standards, the older S3.19 method must be used when testing hearing protectors for EPA labelling purposes even though S12.6 is the most current methodology.

The European community also relies upon the REAT for determining hearing protector attenuation (ISO 4869-pt.1 - 1992). However, there are differences in methods. The number of subjects required is 16 rather than 10 and each subject is tested only once with ears open and once with ears occluded to produce one REAT at each test frequency. In addition, 4869-1 relies upon a subject-fit in which the listeners fit the hearing protectors using a fitting noise to adjust the protectors for best perceived attenuation, but without feedback from the experimenter. Because of the lack of coaching by the experimenter, when hearing protectors are tested for European markets, the reported REATs are usually lower than when they are tested for distribution in the United States.

In 1997 an ANSI new standard was approved -ANSI S12.6 -1997 (methods A and B). The method B, subject fit qualified subjects who are trained and experienced in audiometric test but naive with respect to use of hearing protectors. This subject fit the protector himself or herself using the manufacturer instruction with no assistance from the experimenter at all. This method provides data results that approximate the protection that can be attained by a group of informed users in the workplaces within a well managed and well supervised hearing conservation program (Berger et al. 19xx). The octave band results measured using the new standard can be converted to a single number called Norse. This number is the SNR for 84% (See ISO 4869-2) less 5 dB. The NRRsf may be subtracted from the A-weighted sound pressure level (or Leq) exposure to give directly the protected level for most users (84%).

11.3.6. Rating Systems (Franks et al. 1994)

The mean attenuation and standard deviations as reported by hearing protector suppliers were used to calculate all ratings of protector performance according to the various methods.

The *NRR* is a single-number rating method which attempts to describe a hearing protector based on how much the overall noise level is reduced by the hearing protector. The *NRR* is described in 40 CFR Part 211 EPA Product Noise Labeling Law, Subpart B Hearing Protective Devices (EPA 1979), and was adapted by the EPA from Method 2 in the first NIOSH Compendium (Kroes et al., 1975). The formula for calculating the *NRR* is

$$NRR = 107.9(\mathrm{dB(C)}) - 3 - 10\log_{10}\left[\sum_{f=125}^{8k} 10^{0.1(L_{af} - APV_{f98})}\right]$$

where L_{af} is the A-weighted octave band level at centre frequency f of a pink noise spectrum with 100 dB at each frequency band and an overall level of 107.9 dB(C); and APV_{f98} is the mean attenuation value minus 2 standard deviations at centre frequency *f* (two standard deviations accounts for 98% of the variance in a normal distribution).

The equation can be broken down into the steps shown in reference (Franks et al. 1994). The *NRR* assumes a background of pink noise with octave-band levels of 100 dB. The corrections for the C-weighting scale are then subtracted to compute unprotected C-weighted octave-band levels at the ear. These octave-band levels are logarithmically summed to obtain the overall sound level in dB(C) at the unprotected ear; this value is the first term of the equation and is always 107.9. The corrections for the A-weighting scale are then subtracted from the pink-noise octave-band levels to compute the A-weighted octave-band levels at the ear. The average attenuation minus twice the standard deviations are subtracted from the A-weighted octave-band levels to compute the protected A-weighted octave-band level at the ear. The adjustment of 2 standard deviations theoretically provides an *NRR* that 98% of the subjects will meet or exceed, provided that the wearers use the hearing protection device the way laboratory subjects did and that the subjects were a reasonable sample of the user population anatomically. The protected A-weighted octave-band levels at the ear is then logarithmically summed to calculate the overall protected A level. The *NRR* is computed by subtracting 3 dB from the difference between the unprotected C-weighted (107,9 dB(C)) and the protected A-weighted levels at the ear. The 3 dB factor is a correction for spectral uncertainty to account for whether the pink noise used in the computation really matches the noise in which the hearing protection devices is worn.

The *NRR* is intended to be used for calculating the exposure under the hearing protector by subtracting it from the C-weighted environmental noise exposure level. Thus, if a protector has an *NRR* of 17 dB and it is used in an environmental noise level of 95 dB(C), the noise level entering the ear could be expected to be 78 dB(A) or lower in 98% of the cases. An alternative use of the *NRR* is with dB(A) measurements, the *NRR* can be applied if 7 dB is subtracted from its value. Thus for the same protector above, if it is used at an environmental noise level of 90 dB(A), then the noise level entering the ear is 90 - (17-7) = 80 dB(A).

In Europe, new rating systems (ISO/DIS 4869 - 1992) have been adopted which may have as wide a use there as the *NRR* has in the United States. The systems are the Single-Number Rating (*SNR*), the High-Middle-Low (*HML*) rating, and the Assumed Protection Value (*APV*). These methods are based on REATs measured according to ISO 4869-pt.1 - 1992 (discussed above) for one-third octave bands in octave steps from 63 to 8000 Hz (when data for 63 Hz are not present, the summation occurs from 125 to 8000 Hz). All of these methods provide the user with the option of selecting a protection performance value which is an indication of the percentage of test subjects who achieved the specified level of noise reduction. The protection performance is computed by subtracting a multiple of the standard deviation from the mean attenuation values. The most commonly utilized protection performance value in Europe is 80%, which is computed by using a multiplier of 0.84 with the standard deviation values. However, in this document, a protection performance value of 98% (computed by multiplying 2.0 times the standard deviation) is utilized for all *SNR* , *HML*, and *APV* calculations in order to make them more directly comparable to the *NRR* values. It should be stressed, though, that these methods allow the user to select a protection performance level other than 98%, and that the ratings can be recalculated from the data provided.

The *SNR* is calculated much like the *NRR*, except that the values used may vary with the selected protection performance value and that there is no 3 dB spectral correction factor. The method for calculating the *SNR* is presented in (Franks et al. 1994). The *SNR* differs from the *NRR* further in that the base spectrum for calculations is made-up of octave-band noise levels which sum to 100 dB(C), rather than pink noise octave-band noise levels of 100 dB which sum to 107.9 dB(C). The *SNR* considers attenuation only at the octave centre frequencies and does not include the third-octave center frequencies of 3150 and 6300 Hz. The octave band levels are also adjusted by the A-weighting correction factors and summed to a value of 98.5 dB(A). The mean attenuation value for each octave-band, minus the standard deviation for that octave band, multiplied by a protection-performance value, is subtracted from the A-weighted corrected octave-band levels in order to calculate the *APV* for each band. The sum of the *APV* s is subtracted from 100 dB(C) to calculate the *SNR* . The *SNR* may be subtracted from the environmental noise level in dB(C) to predict the effective A-weighted sound pressure level under the hearing protector. Thus, if a hearing protector had an *SNR* of 16 dB and was used in a noise level of 95 dB(C), the effective A-weighted sound pressure level under the hearing protector would be assumed to be 79 dB(A).

The *HML* - method is a different rating system altogether, in that it provides three numbers to describe hearing protector attenuation. Which number will be used in a given instance depends upon the noise from which protection is sought. The *HML* - method has a number which describes the low-frequency attenuation (L value), the mid-frequency attenuation (M values), and the high-frequency attenuation (H value) of a protector. These numbers are calculated by taking into account typical industrial noise spectra. In the early 1970s, NIOSH collected noise spectra from a variety of industrial locations and developed the NIOSH 100 noises (Johnson and Nixon 1974). The noise-spectra array was reduced to 8 spectra for calculation of the *HML* based on the difference between the calculated dB(C) and dB(A) level for each noise.

As with the *NRR* and *SNR* values, the mean attenuation and the standard deviations for calculation of the *H*, *M* and *L* values are provided by the manufacturer. To use the values, the environmental noise level in dB(A) is subtracted from the environmental noise level in dB(C) to see which rating is appropriate. If the difference between the dB(C) and dB(A) levels is equal to or greater than 2 dB, the mean of the *M* and *L* values is used according to the equation:

$$M - \frac{(M - L)}{8}.(\mathrm{dB(C)} - \mathrm{dB(A)} - 2\mathrm{dB})$$

If the difference is between 2 dB and - 2 dB, the mean of the *M* and *H* values is used according to the equation.

$$M - \frac{(H - M)}{8}.(\mathrm{dB(C)} - \mathrm{dB(A)} - 2\mathrm{dB})$$

The *HML* method allows selection of a hearing protector so that it can be effective at the frequency range where it is needed most. For example, suppose an earplug had an H rating of 25 dB, and an M rating of 18 dB, and L rating of 13 dB. If the environmental noise level were 95 dB(C) and 92 dB(A), the dB(C)-dB(A) value would be calculated from the M and L values, 18 - (18-13)/8* (94-92-2) = 11.25. So the exposure level at the ear from the protector would be 95.0 - 11.25=80.75, which rounds to 81 dB(A). The method for calculating the *HML* is presented in (Franks et al. 1994).

The Assumed Protection Values (*APV*) are calculated for each test frequency by subtracting a coefficient multiplied by the standard deviation from the averaged attenuation. The coefficient varies depending upon the protection performance desired. For a protection performance of 84%, the coefficient is 1.0; for 80% , the coefficient is 0.84; and for 98% the coefficient is 2.0. The *APV* s are used in the calculation of the *SNR* and *HML* , and they may also be used frequency-by-frequency for a direct calculation of octave -band noise reduction. In a typical application, one would examine the noise spectrum to find the frequency regions with the most energy and then find a hearing protector with adequate *APV* s for those frequency bands so that the resultant overall dB(A) level at the ear would be safe. The method for calculating the *APV* is presented in (Franks et al. 1994).

The long-method calculation of hearing protector noise reduction is probably the most accurate method for rating. Considering that the protector user is wearing the device in the same manner as the listener during the laboratory test (which is not necessarily true), then the most detailed and accurate method is to use the noise floor level in frequency bands together with laboratory test data to calculate the user's exposure level. Table 11.2 gives a numerical example of how to carry-out this calculation.

Table 11.2. Calculated protection for 98% confidence

1- Center frequency octave band (Hz)	125	250	500	1 k	2 k	4 k	8 k	Total dB(A)
2- A-weighting SPL	83.9	93.4	101.8	106.0	102.2	97.0	88.9	109.0
3- Average attenuation	14	19	31	36	37	48*	40**	
4- Standard deviation x 2	10	12	12	14	14	14*	16**	
5- Estimated noise after protection = (step2 - step3 + step4)	79.9	86.4	82.8	84.0	79.2	63.0	64.9	90.3

* Arithmetic average of 3150 and 4000 Hz, ** Arithmetic average of 6300 and 8000 Hz

...

The estimated protection for 98% of the users exposed to the environment levels of step 2, assuming that they wear the protector in the same manner as the listener during the laboratory test, is : **109.0 - 90.3 = 18.7 dB(A)**

11.3.7. Variability of Attenuation Data between Laboratories

Berger et al. (1996), reported the results from a round robin test of eight laboratories' data. The comparison is shown in Figure 11.5 for the *NRR*'s values. These results show great variation between different laboratories in both the average attenuation and the standard deviation, leading to great differences in the *NRR*'s values. Three main factors are responsible for these differences; the fitting , subject selection and training. Even repeatability of results from the same laboratory for the same protector may also vary. That is why the use of two standard deviations when calculating the protection is recommended. Therefore any changes less than 3 to 5 dB(A) in *NRR* should not be considered of any practical importance.

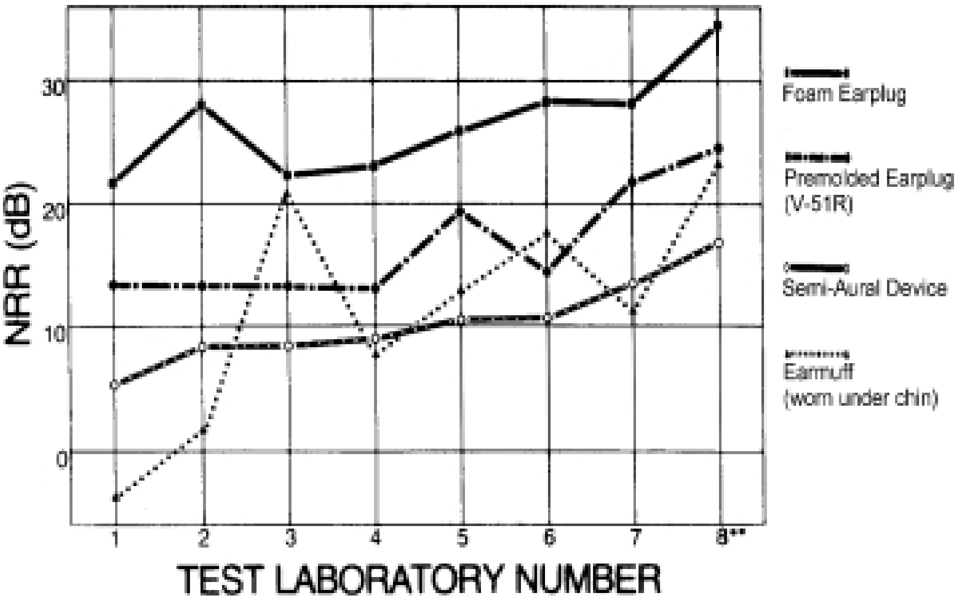


Figure 11.5. Comparison of 8 laboratory results for *NRR* (after Berger et al. 1996)

11.3.8. Head band force and Pressure of muffs

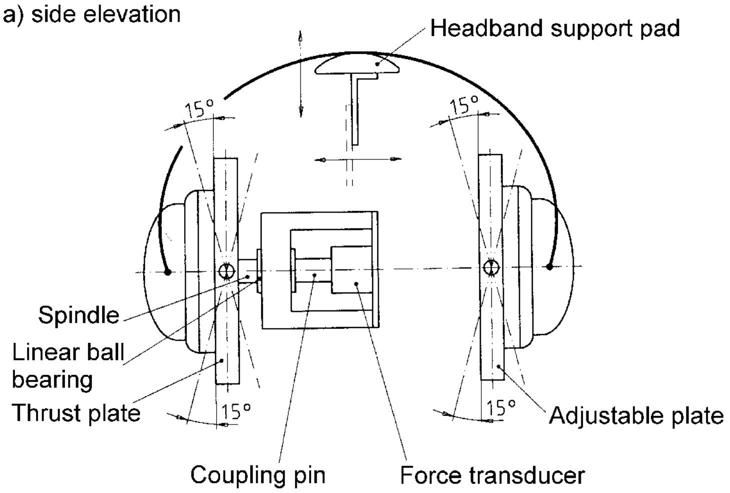
Comfort can be reduced if the head band force increases. However sufficient force is necessary for a close fit of the hearing protector which is in turn needed for the required sound attenuation. Therefore it is necessary to measure the headband force and also to use the measured force for quality control and life assessment. ANSI S3.19 - 1974 shows a mechanical device for head band force measurements. An alternative, and more accurate, mechanical /electric device is shown in Figures 11.6. There is between 2% and 5% variation in the measured force. The maximum mean force acceptable for reasonable comfort must not exceed 12 N. The applied pressure is more important than the headband force for acceptability comfort. Hearing protectors with broad cushions will give less pressure with the same force. Maximum acceptable pressure is about $4000 N/m^2$.

11.3.9. Simultaneous Use of Double Hearing Protection

Many situations exist where the use of a single protector is not sufficient. In these cases the use of "combined" protection (ear plug + Earmuff) should be considered, however extreme care is required and the performance of the "combination" should be known before use. Tests have shown that the performance of "combination"protection is not the sum of the protectors in use but something in the order of 5 to 15 dB more than the performance of the best of the combination (EN 458).

Berger et al. (1996, page 353) show that at and above 2 kHz most ear plug - plus - muff combinations provided attenuation that was approximately limited by the bone-conduction flanking (see Figure 10.20 in Berger et al. 1996). At frequencies below 2 kHz, it can be shown that the ear plug is the critical element. The extra attenuation gained, varied between 0 and 15 dB for the best of the individual devices. The increase in *NRR* is between 3 and 10 dB when compared with the higher of the two individual protectors.

a) side elevation



b) plan view

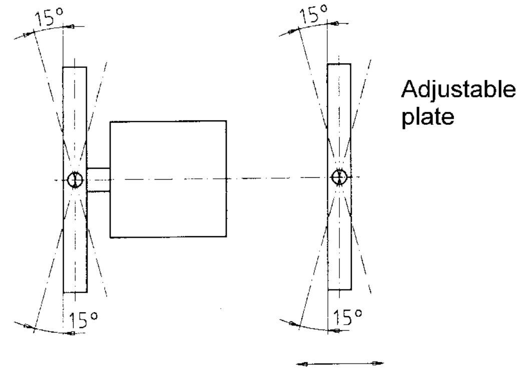


Figure 11.6. Band force measurement system (EN 352, part 1)

NOTE: The pinna simulators shown are fitted to the plates of the fixture so that the holes at the center of the simulators lie on the horizontal axis through the force transducer

11.3.10. Considerations in the Selection and Use of Hearing Protectors (Franks et al. 1994)

Although calculated noise-reduction capabilities are important factors to consider in the selection of hearing protection devices, several other points should also be considered. Studies by Casali (1992) and Riko and Alberti (1982) on the effectiveness of hearing protectors suggest that workers are most likely to demonstrate consistent wearing of devices which are comfortable and quick to insert regardless of the amount of attenuation they provide. Additional thought must be given to the worker's physical limitations including concurrent use of safety glasses or eyeglasses, the need for the worker to hear warning signals, and the need to communicate verbally. The environmental conditions of the workplace, such as temperature, confined working spaces, or the wearing of additional protective devices, also warrant consideration. The durability (shelf life or useful life) and sanitary-hygienic characteristics of each device, as well as the length of time it will be worn, are also factors that should not be overlooked. If custom-molded hearing protectors are to be used, it is important to ensure both the expertise of those who will prepare the impression and of those who will form the final earplug.

In order to ensure that a worker receives the most effective attenuation from the use of a hearing protector the worker should be trained in the use, care and maintenance of the protection. This training should be updated on a regular basis and should be provided by appropriately trained personnel.

Comfort is a personal matter. Ear protectors are generally uncomfortable. Some people find one brand more uncomfortable than the others. Therefore a chance should be given for a choice to be made between different types.

Ear protectors do not offer protection unless they are worn adequately and properly throughout the time of exposure. Small ear plugs or ear muffs with weak springs, may be more comfortable but offer low noise attenuation.

11.3.11. Real World Attenuation (Franks, et al., 1994)

Standard laboratory methods (ANSI S3.19 - 1974, ANSI S12.6 - 1984 and ISO 4869 pt. 1 - 1992) were developed to produce a measurement of attenuation for an "optimum fit" condition. Since the 1970's, researchers in various laboratories around the world (Franks et al. 1994) have been investigating the amount of attenuation workers typically receive. They found workers generally received much less attenuation than the optimum-fit laboratory methods predict. The magnitude of the difference was from 22% to 84% less attenuation for the real-world setting than for the laboratory setting. Researchers at NIOSH have worked with researchers from other laboratories as part of an ANSI working group to develop and test laboratory methods that give measurements of hearing protector attenuation which are more reflective of real-world performance and remain consistent from laboratory to laboratory. The new method, called the NIOSH/ANSI method (Franks et al. 1994) provides very consistent inter-laboratory results, much more consistent than those possible using the methods of ANSI S3.19 - 1974. The method also provides mean attenuations which are much lower than the optimum-fit attenuation and more in accord with real-world results, while maintaining a reasonable standard deviation. At the time of writing, the NIOSH/ANSI method was being prepared as an alternate procedure in a revision of ANSI-S12.6 - 1984.

It is also important that the hearing protector is worn 100% of the time. Figure 11.1 shows the effect of the percentage of time worn on the noise attenuation gained. For example, if a hearing protector has an effective attenuation of 20 dB(A), and it is worn in an ambient noise of 100 dB(A) for 8 hours daily exposure, then the worker will be exposed to 80 dB(A) (simple calculation). If the same hearing protector is not used for 50 minutes out of the 8 hour day, that means 90 % of the time the protector is worn, the worker will be exposed to 92 dB(A), i.e. despite the use of hearing protection there is still the risk of hearing loss. Additional calculations show also that if the worker uses any protector for only 4 hours, then the effective protection will be only 3 dB(A), and the worker will be exposed to a daily average of 97 dB(A) see also EN 458 (1993). Even in case of the 5 dB trading relation given in some regions by statutory rules there will be only 5 dB effective protection and therefore also the risk of hearing loss.

11.3.12. Problems with Hearing Protectors

Comfort, wearability and durability are more important than a few decibels more of attenuation. Provided that the attenuation is reasonable, human factors are more important. Some of the factors which should be considered when hearing protectors are implanted are; hygiene (especially for earplugs), discomfort, effects on communication, effect on directional localization of warning sounds and safety in general.

11.3.13. Costs of Hearing Protectors

The cost of hearing conservation by means of personal hearing protection should consider the following factors:

(1) Initial cost of muffs and/or plugs;
(2) Management and administrative costs of ordering, documentation, stores, issuing, fitting, training, etc.
(3) Replacements of the worn parts;
(4) Education in and encouragement towards the use of hearing protectors, correctly and consistently, using films, talks, posters, audiometry, etc.

These costs can be compared with other methods of engineering noise reduction, say for the period of a 5 or 10 year program.

11.4. REPORTING PROTECTIVE FAILURES

Every employee is responsible of reporting protective failures which include:

- damaged protectors
- changes in maintenance of machinery and equipment because of wear
- any change in noise perception due to moving of machines, altered working methods and work practices.

Responsibility for reporting should be given to the health and safety representatives, to foremen and supervisors and to the management aiming at direct action to be taken or to prioritise the protective failure within the company's noise plans. Reporting protective failures must not affect the worker’s social status in the workplace.

11.5. HEALTH SURVEILLANCE

Health surveillance programmes should be instituted and periodic audiometry upon commencement of work and according to national regulations should be carried out to ensure hearing conservation programmes are effective.

The employer must ensure that audiometric records are retained as confidential. Workers shall have access to their own medical records, either personally or through their own physicians. The results should be used to determine health status with respect to noise exposure and should not be used to discriminate against the worker. Suitable alternative work should be provided to persons with recognised hearing damage.

Records resulting from medical surveillance of workers should be kept for at least 30 years, in a form and by persons designated by the regulatory authority.

REFERENCES

Abel, S.M., Alberti, P.W. and Rick, K. (1982). User fitting of hearing protectors: Attenuation results. Personal Hearing Protection in Industry, Albert, P.W. (ed.), Raven Press, New York, 315-222, USA.

ANSI S 3.19 - 1974, Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Earmuffs.

ANSI S 12.6 - 1984, Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Earmuffs.

ANSI S12.6 - 1997, Methods for Measurement the Real -Ear Attenuation of Hearing Protectors .

Berger, E.H. and Royster, L.H. (19xx); In search of meaningful measures of hearing protector effectiveness. 21st Annual Conference of the NHCA, San Francisco, CA. ??

Berger, E. H., Word W.D., Morrill J.C. and Royster L.H. (1996). *Noise & Hearing Conservation Manual,* Fourth Edition, American Industrial Hygiene Association.

Casali, J.G. (1992). Comfort: The "Other" Criterion for hearing protector design and selection. Proceedings of the 1992 Hearing Conservation Conference, pp.47-53, ISBN 0-899779-080-4, held 1-4 April, Cincinnati, OH, USA.

Environmental Protection Agency (1979). 40 CFR Part 211 - Product Noise Labeling, Subpart B - Hearing Protective Devices. 44 Federal Register 56139-56147.

EN 24969 Pt 1, "Sound Attenuation of Hearing Protectors - Part 1 - Subjective methos of measurement"

EN 24869 Pt 2, "Estimation of Effective A-Weighted Sound Level of Hearing Protectors when Worn".

EN 24869 Pt 3, "Measurement of Insertion Loss"

EN 24869 Pt 4, "Measurement of the Sound Attenuation of Amplitude Sensitive Muffs"-

EN 352 Pt 1, "Hearing Protectors - Safety Requirements & Testing" - Part 1 : Ear Muffs.

EN 352 Pt 2, "Hearing Protectors - Safety Requirements & Testing - Part 2 : Ear Plugs".

EN 352 Pt 3, "Hearing Protectors - Safety Requirements & Testing - Part 3 : Helmet Mounted Muffs".

EN 352 Pt 4, "Hearing Protectors - Safety Requirements & Testing - Part 4 : Level Dependent Ear Muffs".

EN 458, "Hearing Protectors - Recommendation for the selection, Use, Care and Maintenance - Guidance Document".

Franks J.R., Themann C.R. and Sherris C. (1994). *The NIOSH Compendium of Hearing Protection Devices*. U.S. Department of Health and Human Services, Public Health Service, Centres for Disease Control and Prevention,

Johnson, D.L. and Nixon, C.W. (1974). Simplified Methods for Estimating Hearing Protector Performance. Sound and Vibration, 8(6):20-27.

Kroes P., Fleming, R., and Lempert, B. (1975). List of Personal Hearing Protectors and Attenuation Data, NIOSH Technical Report, HEW Publication No. (NIOSH) 76-120.

INTERNATIONAL STANDARDS

Titles of the following standards referred to in this chapter one will find together with information on availability in chapter 12:

ISO 4869-1, -2;

Other relevant standards included in the list of general references, see above

..