Introduction

Noise, or unwanted sound, is one of the most common occupational hazards. The World Health Organization (WHO) estimates that at least one million healthy years of life are lost every year from traffic-related noise in the western part of Europe. Exposure to high levels of noise may cause hearing loss, create physical and psychological stress, reduce productivity, interfere with communication, and contribute to accidents or injuries. Sleep disturbances and annoyances, mostly related to road traffic noise, constitute the main burden of environmental noise.1

High levels of occupational noise present a further public health problem in all regions of the world. In the United States of America (USA), for example, more than 30 million workers are exposed to hazardous noise, and, in Germany, 4–5 million people (12%–15% of the workforce) are exposed to noise levels defined as hazardous by the WHO.2 Occupations at the highest risk for noise-induced hearing loss (NIHL) include those within manufacturing, transportation, mining, construction, agriculture and the military.3

Belgian legislation on well-being at work encompasses a set of provisions for prevention and the protection of the health and safety of workers within the workplace, including aspects pertaining to the hygiene of the workplace and psychosocial aspects at work (stress, violence, bullying and sexual harassment, among others). In principle, combating environmental noise is fully addressed in this country. However, other levels of policy-making also play an important role in this regard. For example, the federal government is in charge of product standards, and therefore also of noise emission standards for products. The interpretation and enforcement of Belgian legislation on well-being at work converts European directives and international agreements on well-being at work into Belgian law.
being at work, especially psychosocial aspects, ergonomics, occupational hygiene and prevention of occupational accidents and illnesses. Based on the currently available regulations, research publications, occupational health and consensus standards, this chapter aims to provide technical information and guidance for the evaluation of noise hazards in the workplace.

After a short summary of the basics of noise regulation and control, the current regulations for health at work in Belgium are discussed, particularly in regard to noise exposure. The third section offers investigative guidelines (including methods for planning the investigation set and workplace noise evaluations) and outlines a strategy for conducting noise evaluations. Finally, noise-induced events with induced hearing loss are described such as the first attitudes to adopt in case of noise overexposure.

Part I: Fundamentals of occupational noise exposure

Occupational noise can be any sound in any work environment. Sound is defined as “a rapid variation of atmospheric pressure caused by some disturbance of the air.” Sound propagates as a wave of positive pressure disturbances (compressions) and negative pressure disturbances (rarefactions). Sound can travel through any elastic medium (e.g., air, water, wood or metal). When air molecules vibrate, the ear perceives the variations in pressure as sound. These vibrations are converted into mechanical energy by the middle ear, subsequently moving microscopic hairs in the inner ear, which in turn convert the sound waves into nerve impulses. If the vibrations are too intense, over time these microscopic hairs can be damaged, causing noise-induced hearing loss (NIHL).

In the workplace, sound that is intense enough to damage hearing capacity is unwanted and is therefore considered to be noise. Several key terms describe the physical qualities of sound, and need to be understood for any effective occupational noise investigations.

1.1. Physical characteristics of sound in relation to occupational noise investigations

1.1.1. Wavelength

The wavelength (λ) is the distance travelled by a sound wave during one sound pressure cycle, and is usually measured in meters or feet (figure 1). Wavelength is an important parameter for designing engineering controls. For example, a sound absorbing material will perform most effectively if its thickness is at least one quarter of the wavelength.

![Figure 1](image-url)

Physical characteristics of sound
From occupational medicine to occupational event

1.1.2. Frequency
Frequency, \(f\), is a measure of the number of vibrations (i.e., sound pressure cycles) that occur per second (figure 1). It is measured in hertz (Hz), where one Hz is equal to one cycle per second. Sound frequency is perceived as pitch (i.e., how high or low a tone is). The frequency range sensed by the ear varies considerably among individuals. A young person with normal hearing can hear frequencies between approximately 20 Hz and 20,000 Hz. As a person gets older, the highest frequency that he or she can detect tends to decrease. Human speech frequencies are in the range of 250 to 4,000 Hz. This is significant because hearing loss in this range will interfere with conversational speech. The parts of the ear that detect frequencies between 3,000 and 6,000 Hz are the first to be affected by noise exposure. Audiograms often display a high-frequency “notch” in patients who are developing the beginning stages of sensorineural hearing loss.

1.1.3. Sound Pressure
The vibrations associated with sound are detected as slight variations in pressure. The range of sound pressures perceived as sound is extremely large, beginning with a very weak pressure causing faint sounds and increasing to noise so loud that it can cause pain.

The threshold of hearing is the quietest sound that can typically be heard by a young person with undamaged hearing. This varies somewhat between individuals, but is typically in the microPascal range. The reference sound pressure is the standardized threshold of hearing and is defined as 20 microPascals (0.0002 microbars) at 1,000 Hz. The threshold of pain, or the greatest sound pressure that can be perceived without pain, is approximately 10 million times greater than the threshold of hearing. It is, therefore, more convenient to use a relative (such as a logarithmic) scale of sound pressure rather than an absolute scale.\(^7\)

1.1.4. Decibels
Noise is measured in units of sound pressure called decibels (dB),\(^8\) named after Alexander Graham Bell. The decibel notation is implied any time a “sound level” or “sound pressure level” is mentioned. Decibels are measured on a logarithmic scale: a small change in the number of decibels indicates a huge change in the amount of noise and the potential damage to a person’s hearing. The decibel scale is convenient since it compresses the sound pressures important to human hearing into a manageable scale. By definition, 0 dB is set at the reference sound pressure (20 microPascals at 1,000 Hz, as stated earlier).

At the upper end of human hearing, noise causes pain, which occurs at sound pressures of about 10 million times that of the threshold of hearing. On the decibel scale, the threshold of pain occurs at 140 dB. This range of 0 dB to 140 dB is not the entire range of sound, but is the range relevant to human hearing (figure 2). Decibels are logarithmic values, so it is not appropriate to add them using normal algebraic addition. The decibel is a dimensionless unit; however, the concepts of distance and three dimensional space are important in understanding how noise spreads through an environment and how it can be controlled. Sound fields and sound power are terms used to describe these concepts.

1.1.5. Sound Fields
Many noise-control problems require a practical knowledge of the relationships between the following concepts:

- A sound field (a region in which sound is propagating);
- Sound pressure (influenced by the energy in terms of pressure emitted from the sound source, the distance from the sound source, and the surrounding environment);
- Sound power (sound energy emitted from a sound source and not influenced by the surrounding environment).

Sound fields are categorized as near field or far field, a distinction which is important to the reliability of measurements. The near field is the space immediately around the noise source, sometimes defined as within the wavelength of the lowest frequency component (e.g., a little more than 122 cm for a 25 Hz tone, about 30 cm for a 1,000 Hz tone, and less than 18 cm for a 2,000 Hz tone). Sound pressure measurements obtained with standard instruments within the near field are not reliable, because small changes in position can result in large differences in the readings.

The far field is the space outside the near field, meaning that the far field begins at a point at least one wavelength distance from the noise source. Standard sound level meters (i.e., Type I and Type II) are reliable within this field. However, measurements are influenced by whether the noise
is simply originating from a source (free field) or being reflected back from surrounding surfaces (reverberant field).

A free field is a region in which there are no reflected sound waves. In a free field, sound radiates into space uniformly in all directions from a source. The sound pressure produced by the source is the same in every direction at equal distances from the point source. As a principle of physics, the sound pressure level decreases 6 dB, on a Z-weighted (i.e., unweighted) scale, each time the distance from the point source is doubled. This is a common way of expressing the inverse square law in acoustics and is shown in figure 1.

Free field conditions are necessary for certain tests in which outdoor measurements are often impractical. Certain tests need to be performed in special rooms called free field or anechoic (echo-free) chambers, which have sound-absorbing walls, floors, and ceilings that reflect practically no sound. In the spaces defined by walls, however, sound fields are more complex. When sound-reflecting objects such as walls or machinery are introduced into the sound field, the wave picture changes completely. Sound reverberates, reflecting back into the room rather than continuing to spread away from the source. Most industrial operations and many construction tasks occur under these conditions.

Figure 3 illustrates sound radiating from a sound source and shows how reflected sound (dashed lines) complicates the situation.

The net result is a change in the intensity of the sound; the sound pressure does not decrease as rapidly as it would in a free field. In other words, it decreases by less than 6 dB each time the distance from the sound source doubles.

Far from the noise source, unless the boundaries are very absorbing, the reflected sound dominates. This region is called the reverberant field. If the sound pressure levels in a reverberant field are uniform throughout the room, and the sound waves travel in all directions with equal probability, the sound is said to be diffuse.

In practice, however, perfectly free fields and reverberant fields rarely exist, and most sound fields fall between these categories.

1.1.6. Sound Power

Up to this point, this discussion has focused on sound pressure. Sound power, however, is an equally important concept. Sound power, usually measured in watts, is the amount of energy per unit of time that radiates from a source in the form of
an acoustic wave. Generally, sound power cannot be measured directly; however, modern instruments make it possible to measure the output at a point that is a known distance from the source.

An understanding of the relationship between sound pressure and sound power is essential in predicting the noise problems that will be created when particular sound sources are placed in working environments. An important consideration might be how close workers will be to the source of sound. As a general rule, doubling the sound power increases the noise level by 3 dB.

As sound power radiates from a point source in free space, it is distributed over a spherical surface, so that at any given point there exists a certain sound power per unit area. This is defined as intensity, $I$, and is expressed in units of watts per square metre.

Sound intensity is heard as loudness, which is perceived differently depending on the individual, the distance from the source and the characteristics of the surrounding space. As the distance from the sound source increases, the sound intensity decreases. The sound power coming from the source remains constant, but the spherical surface over which the power is spread increases, and the power is therefore less intense. In other words, the sound power level of a source is independent of the environment. However, the sound pressure level at some distance, $r$, from the source depends on that distance and the sound-absorbing characteristics of the environment.  

1.1.7. Filtering

Most noise is not a pure tone, but rather consists of many frequencies simultaneously emitted from the source. To properly represent the total noise from a source, it is usually necessary to break it down into its frequency components. One reason for this is that individuals react differently to low-frequency and high-frequency sounds. Additionally, for the same sound pressure level, high-frequency noise is much more distressing and more likely to produce hearing loss than low-frequency noise. Engineering solutions to reduce or control noise are different for low-frequency and high-frequency noise. As a general rule, low-frequency noise is more difficult to control.

Certain instruments that measure sound level can determine the frequency distribution of a sound by passing the sound through various successive electronic filters, which separate the sound into nine octaves on a frequency scale. Two of the most common reasons for filtering a sound include 1) to determine its most prevalent frequencies (or octaves) to aid engineers in understanding how to control the sound, and 2) adjusting the sound level reading using one of several available weighting methods. These weighting methods (e.g., the A-weighted

![Figure 3](sound-pressure-levels-in-a-free-field-original-and-reflected-sound-waves.jpg)

**Figure 3**

Sound pressure levels in a free field; original and reflected sound waves
network or scale) are intended to indicate perceived loudness, and provide a rating of industrial noise that indicates the impact that the particular noise has on human hearing. The following paragraphs provide more detailed information.

1.1.8. Octave Bands (Frequency Bands)
Octave bands, a type of frequency band, are a convenient way to measure and describe the various frequencies that make up a sound. The centre, lower, and upper frequencies for the commonly used octave bands are listed in table 1. The width of a full octave band (its bandwidth) is equal to the upper band limit minus the lower band limit. For a more detailed frequency analysis, the octaves can be divided into bands of one third of an octave; however, this level of detail is not typically required for the evaluation and control of workplace noise.

Electronic instruments known as octave band analysers filter sound to measure the sound pressure (in dB) contributed by each octave band. These analysers either attach to a Type 1 sound level meter or are integral to the meter.

1.1.9. Loudness and Weighting Networks
Loudness is the subjective human response to sound. It depends primarily on sound pressure, but is also influenced by frequency.

Three different internationally standardized characteristics are used for sound measurement: the weighting scales A, C, and Z (or “zero” weighting). The A and C weighting scales allow the sound level meter’s response to be set higher for some frequencies than others. The very low frequencies are reduced (attenuated) quite severely by the A-scale and hardly attenuated at all by the C-scale. Sound levels (dB) measured using these weighting scales are designated by the respective letter (i.e., dBA or dBC).

The A-weighted sound level measurement is thought to provide a rating of industrial noise that indicates the injurious effects such noise has on human hearing, and has been adopted by OSHA in its noise standards. In contrast, the Z-weighted measurement is an unweighted scale (introduced as an international standard in 2003), which provides a flat response across the entire frequency spectrum from 10 Hz to 20,000 Hz. The C-weighted scale is used as an alternative to the Z-weighted measurement (on older sound level meters on which Z-weighting is not an option), particularly for characterizing low-frequency sounds capable of inducing vibrations in buildings or other structures. A previous B-weighted scale is no longer used.

These scales evolved from experiments designed to determine the response of the human ear to sound, carried out in 1933 by a pair of investigators named Fletcher and Munson. Their study alternately presented a 1,000 Hz reference tone and a test tone to the test subjects (young men), who were asked to adjust the level of the test tone until it sounded as loud as the reference tone. The results of these experiments yielded the frequently cited Fletcher-Munson or “equal loudness” contours, which are

### Table 1
Octave band filters and frequency range

<table>
<thead>
<tr>
<th>Lower Band Limit (Hz)</th>
<th>Band Centre Frequency (Geometric Mean in Hz)</th>
<th>Upper Band Limit (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>31.5</td>
<td>44</td>
</tr>
<tr>
<td>44</td>
<td>63</td>
<td>88</td>
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<td>88</td>
<td>125</td>
<td>177</td>
</tr>
<tr>
<td>177</td>
<td>250</td>
<td>354</td>
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<tr>
<td>354</td>
<td>500</td>
<td>707</td>
</tr>
<tr>
<td>707</td>
<td>1,000</td>
<td>1,414</td>
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<tr>
<td>1,414</td>
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<tr>
<td>2,828</td>
<td>4,000</td>
<td>5,656</td>
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<tr>
<td>5,656</td>
<td>8,000</td>
<td>11,312</td>
</tr>
<tr>
<td>11,312</td>
<td>16,000</td>
<td>22,624</td>
</tr>
</tbody>
</table>

Each octave band is named for its centre frequency.
displayed in figure 4. These contours represent the sound pressure level necessary at each frequency to produce the same loudness response in the average listener. The changing contour shapes represent the nonlinearity of the ear’s response as the sound pressure level is increased (a phenomenon that is particularly noticeable at low frequencies). The lower, dashed curve indicates the threshold of hearing and represents the level of sound pressure necessary to trigger the sensation of hearing in the average listener. Among healthy individuals, the actual threshold may vary by as much as 10 decibels in either direction. Ultrasound is not listed in figure 4 since it has a frequency that is too high to be audible to the human ear.

1.2. How we hear

The ear is the organ that makes hearing possible. It can be divided into three sections: the external or outer ear, the middle ear, and the inner ear. The function of the ear is to gather, transmit, and perceive sounds from the environment. This involves three stages:

- Stage 1: *Modification (transfer function)* of the acoustic wave by the outer ear, which receives the wave and directs it to the eardrum. Sound reaches the eardrum as variations in air pressure.
- Stage 2: *Conversion and amplification* of the modified acoustic wave to a vibration of the eardrum. These vibrations are amplified by the ossicles, small bones located in the middle ear that transmit sound pressure to the inner ear. The vibrations are then transmitted as wave energy through the liquid of the inner ear (the cochlea).
- Stage 3: *Transformation (transduction)* of the mechanical movement of the wave into nerve impulses that will travel to the brain, which then perceives and interprets the impulse as sound. The cilia of the nerve cells in the inner ear, known as hair cells, respond to the location of movement of the basilar membrane and, depending on their position in the decreasing radius of the spiral-shaped cochlea, activate the auditory nerve to transmit information that the brain can interpret as pitch and loudness. Impaired function at any of these stages will affect hearing.
1.3. Hearing loss

To categorize different types of hearing loss,\textsuperscript{17} the impairment is often described as either conductive, sensorineural, or a combination of the two.\textsuperscript{18}

Conductive hearing loss results from any condition in the outer or middle ear that interferes with sound passing to the inner ear.

Sensorineural hearing loss is generally (cave TTS/PTS) a permanent condition; it usually cannot be treated medically or surgically, and is associated with irreversible damage to the inner ear. The normal aging process and excessive noise exposure are both notable causes of sensorineural hearing loss. Studies show that exposure to noise damages the sensory hair cells that line the cochlea. Even moderate noise can cause twisting and swelling of the hair cells and biochemical changes that reduce the sensitivity of the hair cell to mechanical motion, resulting in auditory fatigue. As the severity of the noise exposure increases, hair cells and supporting cells disintegrate, and the associated nerve fibres eventually disappear. Occupational noise exposure is a significant cause of sensorineural hearing loss,\textsuperscript{19} which appears on sequential audiograms as declining sensitivity to sound, typically first at high frequencies (above 2,000 Hz), and then at lower frequencies as damage progresses.\textsuperscript{20} Often, the audiogram of a person with sensorineural hearing loss will show a “notch” at 4,000 or 6,000 Hz.\textsuperscript{21} This dip in the individual’s hearing level is an early indicator of sensorineural hearing loss. In particular, impulse noise results in higher frequency losses than continuous noise, and 6KHz is also often affected by this form of noise.\textsuperscript{21,22} However, in most clinical ENT environments, only octave measurements are performed, omitting 3,000 and 6,000 Hz. The results are the same for hearing tests on the ear and bone conduction testing. Sensorineural hearing loss can also result from other causes, such as viruses (e.g., mumps), congenital defects, and certain medications.

It is important to note that some hearing loss occurs over time as a normal condition of aging. Termed \textit{presbycusis}, this gradual sensorineural loss decreases a person’s ability to hear high frequencies. Presbycusis can make it difficult to diagnose noise-related hearing loss in older people, since both of these affect the upper range of an audiogram. An 8,000 Hz “notch” in an audiogram often indicates that the hearing loss is age-related as opposed to noise-induced. As humans begin to lose their hearing, they often first lose the ability to detect quiet sounds in this pitch range.

1.4. Effects of excessive occupational noise exposure

Workplace noise affects the human body in various ways. The most well-known is hearing loss, but working in a noisy environment can also have other effects.\textsuperscript{23}

1.4.1. Auditory Effects / Audiological Characteristics

Although noise-induced hearing loss is one of the most common occupational illnesses, it is often ignored since there are no visible effects. It usually develops over a long period of time, and, except in very rare cases, there is no pain.\textsuperscript{24} What occurs is a progressive loss of directional hearing, resulting in loss of communication, socialization, and responsiveness to the environment. In its early stages (when hearing loss is above 2,000 Hz), it affects the ability to understand or discriminate speech. As it progresses to the lower frequencies, it begins to affect the ability to hear sounds in general.

The primary effects of workplace noise exposure include a noise-induced temporary threshold shift, a noise-induced permanent threshold shift, acoustic trauma, and tinnitus. A noise-induced \textit{temporary threshold shift} is a short-term decrease in hearing sensitivity that displays as a downward shift in the audiogram output. It returns to the pre-exposed level in a matter of hours or days, as long as there is no continued exposure to excessive noise.

If noise exposure continues, the shift can become a noise-induced permanent threshold shift, that is, a decrease in hearing sensitivity that is not expected to improve over time. A \textit{standard threshold shift} is a change in hearing thresholds of an average of 10 dB or more at 2,000, 3,000, 4,000 and 6,000 Hz in either ear when compared to a baseline audiogram. Employers can conduct a follow-up audiogram within 30 days to confirm whether the standard threshold shift is permanent.

The effects of excessive noise exposure are made worse when workers have extended shifts (longer than 8 hours). With extended shifts, the duration of the noise exposure is longer and the amount of time between shifts is shorter. This means that the ears have less time to recover between noisy shifts. As a result, short-term effects, such as temporary threshold shifts, can become permanent more
quickly than would occur with standard 8-hour workdays.

Tinnitus, or “ringing in the ears,” can occur after long-term exposure to high sound levels, or sometimes from short-term exposure to very high sound levels, such as gunshots.25 Many other physical and physiological conditions also cause tinnitus. Regardless of the cause, this condition is actually a disturbance produced by the inner ear and interpreted by the brain as sound. Individuals with tinnitus describe it as a hum, buzz, roar, ring, or whistle, which can be short-term or permanent. Hyperacusis is characterized by an increased sensitivity to certain frequencies and volume ranges of sound (in other words, a collapsed tolerance to normal environmental sounds). A person with severe hyperacusis has difficulty tolerating everyday sounds, some of which may seem unpleasantly or painfully loud to that person but not to others.26

Acoustic trauma refers to a temporary or permanent hearing loss due to a sudden, intense acoustic or noise event, such as an explosion.

1.4.2. Worker Illness and Injury Reports27

The burden of occupational noise-induced hearing loss has influenced many recent political decisions and medical procedures.28 The World Health Organization assessed the burden of disease from work-related hearing impairment at national and local levels and confirmed that high levels of occupational noise remain a problem in all regions of the world.29 The U.S. Bureau of Labor Statistics (BLS) publishes annual statistics for occupational injuries (including hearing loss) reported by employers as part of required recordkeeping. Illnesses represented 5.1% of non-fatal occupational cases in private industry in 2010. The BLS data show that hearing loss represented 12% of the occupational illnesses reported in 2010.30 This means that more than 18,000 workers experienced significant loss of hearing due to workplace noise exposure.

1.4.3. Other Effects31

Other consequences of excessive workplace noise exposure include dizziness32 and interference with communication33,34 and performance.35 Workers may find it difficult to understand speech or auditory signals in areas with high noise levels. Noisy environments also lead to a sense of isolation, annoyance, fatigue, difficulty concentrating, lowered morale, reduced efficiency, absenteeism, and accidents.

In some individuals, excessive noise exposure can contribute to other physical effects. These can include muscle tension and increased blood pressure (hypertension). Noise exposure can also cause a stress reaction and fatigue, and can interfere with sleep.

1.5. Ultrasonics

Ultrasound is high-frequency sound that is inaudible (i.e., cannot be heard) by the human ear. However, it may still affect hearing and produce other health effects. Factors to consider regarding ultrasound include:

- The upper frequency audible by humans is approximately 15 to 20 kilohertz (kHz). This is not a set limit: some individuals may have higher or lower (usually lower) limits. This frequency limit normally declines with age.

- Most of the audible noise associated with ultrasonic sources such as ultrasonic welders or ultrasonic cleaners consists of subharmonics of the machine’s major ultrasonic frequencies. Finally, low-frequency noises are defined as about 100 to 150 Hz, and infrasound as frequencies below about 20 Hz.36

1.6. Interactions between noise and solvents or other damaging agents

Many animal experiments have indicated that a combined exposure to noise and solvents induces synergistically adverse effects on hearing.37 Experimental studies have explored specific substances, including toluene,38 styrene, ethylbenzene, and trichloroethylene.39

A number of epidemiological studies have investigated the noise–solvent relationship in humans. Overall, the evidence strongly suggests that combined exposure to noise and organic solvents can have interactive effects (either additive or synergistic), in which solvents exacerbate noise-induced impairments, even though the noise intensity is below the permissible limit value. In addition to the synergistic effects with solvents, noise may also have additive, potentiating, or synergistic ototoxicity with asphyxiants (such as carbon monoxide) and metals (such as lead). Finally, mechanical vibration associated with noise exposure increases cochlear damage.40
Part II: Belgian health regulations at work

2.1. General Legal Context

The Belgian legislation encompasses a set of provisions on prevention and the protection of the health and safety of workers in the workplace, including aspects pertaining to hygiene in the workplace and the psychosocial aspects of work (stress, violence, bullying and sexual harassment, among others).

The clarification and enforcement of the Belgian laws regarding well-being at work come under the remit of the Federal Public Service Employment, Labour and Social Dialogue, which converts European directives and international agreements on well-being at work into Belgian law.

The Act of 4 August 1996 and the Royal Decree of 27 March 1998 on the well-being of workers in carrying out their work is the primary law on this issue in Belgium; it concerns not only safety and health at work, but also every other field related to well-being at work, especially psychosocial aspects, ergonomics, occupational hygiene and prevention of occupational accidents and illnesses.41

This Act, also known as the “Act on Well-Being”, is the translation of the framework Directive 89/391/EEC on the introduction of measures to encourage improvements in health and safety at work. The contents make provision for the enforcement of most decrees in the Act on Well-Being, which are mainly a translation of special European directives on the health and safety of workers, and have been introduced in the Code on Well-Being at Work.

The decrees in this Code are inspired by an innovative philosophy, compared to the one that inspired the “General regulations concerning protection at work” (Algemeen Reglement voor de arbeidsbescherming (ARAB), Règlement Général pour la Protection au Travail (RGPT)), that is, the former codification of the rules related to health and safety at work. The current regulations on well-being are based on guidelines aiming to reach specific objectives, whereas the ARAB/RGPT principally contained detailed instructions about methods of implementation. The Act on Well-Being and the Code thus contain fewer detailed technical instructions. A large part of the ARAB/RGPT has now been abrogated and replaced by the Royal Decrees that partly make up the Code. The ARAB/RGPT will therefore soon be completely replaced, since the remaining provisions will also be integrated in the Code or, if this is impossible, removed.

At European level, the European Commission has since 1978 developed multi-annual action programmes regarding health and safety at work. Initially, these action programmes focused mainly on legislative work. Today, however, the programmes focus more on the emergence of new risks linked to changes in the working environment and society. In February 2007, the Commission published a Communication entitled: “Improving quality and productivity at work: Community strategy 2007-2012 on health and safety at work”. The Commission has invited the member states to develop and adopt national strategies linked to the Community Strategy and, within this framework, to set quantitative objectives to be achieved. The Commission and the Council of the European Union aim to reduce the incidence rate of accidents at work within Europe by 25%. To this end, they have established a series of ambitious objectives included in the new European strategy. Finally, the European Agency for Safety and Health at Work coordinates the European network and information exchanges between member states.

2.2. Specific Legal Context Dealing with Noise Exposure

The Royal Decree of 16th January 2006 on the protection of the health and safety of workers from the risks of noise at work has been transposed into the Belgian law arising from Directive 2003/10/EC of the European Parliament and the Council of 6th February 2003, which concerns the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (Seventeenth individual Directive within the meaning of Article 16, Paragraph 1 of Council Directive 89/391/EEC).42

2.2.1. Risk Assessment

Employers are obliged to assess the risks to the safety and health of workers arising from exposure to noise at work, and to take the necessary preventive measures. For this purpose, the employer should pay greater attention to:

- the level, type and duration of exposure;
- the values of limits and exposure action;
- those workers who are particularly sensitive to risk;
- interactions between noise and work-related ototoxic substances (such as carbon monoxide, certain aromatic solvents and certain antibiotics);
- interactions between noise and vibrations;
- interactions between noise and warning signals or other sounds that need to be given to reduce the risk of accidents;
- information provided by the manufacturers on noise emissions from the machines;
- the existence of alternative work equipment designed to reduce noise emissions;
- the extension of exposure to noise beyond normal working hours under the employer’s responsibility;
- relevant information obtained from health surveillance; and
- the availability of hearing protectors with adequate attenuation characteristics.

2.2.2. Action Values and Occupational Exposure Limits

In this Royal Decree, the following action limits (AL) and permissible limit values (PEL) are defined:

- lower exposure action values: \(LEX, 8h = 80 \text{ dB(A)}\) and \(p_{\text{peak}} = 112 \text{ Pa} (135 \text{ dB(C)} \text{ at } 20 \text{ Pa})\);
- upper exposure action values: \(LEX, 8h = 85 \text{ dB(A)}\) and \(p_{\text{peak}} = 140 \text{ Pa} (137 \text{ dB(C)} \text{ at } 20 \text{ Pa})\);
- permissible maximal exposure limit values (with hearing protectors): \(LEX, 8h = 87 \text{ dB(A)}\) and \(p_{\text{peak}} = 200 \text{ Pa} (140 \text{ dB(C)} \text{ at } 20 \text{ Pa})\).

When applying the exposure limit values for the determination of the effective exposure of the worker, the attenuation provided by individual hearing protectors worn by the worker should be taken into account.

When applying the exposure action values, the preventive measures are designed not to take into account the damping effect of hearing protectors.

Table 2 shows the measures to be taken in regard to the values for daily exposure to noise, according to the former and current regulations.

2.2.3. Derogations

If the use of individual hearing protectors may result in a greater risk to health or safety because of the nature of the work than not using such protectors, a

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**Table 2**

<table>
<thead>
<tr>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>90 dB(A)</strong> (not taking into account dampening effect of hearing protection)</td>
</tr>
<tr>
<td><strong>85 dB(A)</strong> (not taking into account dampening effect of hearing protection)</td>
</tr>
<tr>
<td><strong>87 dB(A)</strong> (taking into account the effect of hearing protection)</td>
</tr>
</tbody>
</table>

**lower exposure action values:**
- Provide PPE
- Information and training of employees
- Medical health surveillance

**upper action value:**
- Information and training of employees
- Measures to reduce noise
- Signaling / demarcation of danger zones
- Use of PPE required
- Medical health surveillance

**limit must not be exceeded in case of exceeded limit:**
- Take immediate action to bring exposure below threshold
- Identify the cause of overshoot
- Adapt protective and prevention measures to avoid a new overshoot.
derogation of the obligatory wearing of these can be granted. In addition, in exceptional circumstances, exemptions may be granted for exceeding the upper action value. For activities where daily noise exposure varies markedly from day to day, the daily level of exposure to noise for the application of limit values and exposure action values shall be replaced by the weekly level. However, this level of weekly noise exposure may not exceed the PEL value of 87 dB(A).

2.3. Fund for Occupational Diseases

2.3.1. Legal Fundamentals

The Belgian Royal Decree of December 24th 1963, regarding damage compensation for occupational diseases and prevention of these, established the Belgian Fund for Occupational Diseases (BFOD) (Fonds pour les Maladies Professionnelles/Fonds voor Beroepsziekten), as a complement to the Royal Decree of 16th April 1965, which extended the role of occupational medicine in Belgium.

These decrees aimed to position the law more effectively in terms of the existing and future challenges in occupational medicine, with a particular interest in the protection of all workers exposed to occupational diseases and the improvement of social efficacy in their prevention and management, through a system of traceability of exposure throughout an individual’s entire working life and, finally, the conservation of medical expertise in this field.

In February 2007, a Royal Decree established a list of industries, occupations or enterprises in which the workers are presumed to be exposed to a potential occupational risk. Concerning the specific risk of noise exposure, the Belgian Code 1.603 in regard to noise-induced hearing losses or deafness considers the following industry categories to be at risk: boiler making, sheet metal working industries, car body work, coating, nail factories, wood or stone sawmills, weaving or sewing enterprises, and discotheques.

To this already long list can be added all industries working with pneumatic or rotating hammers, extraction industries in mines, activities involving the grinding, cutting, rolling or polishing of metals, all types of coating, polishing or riveting metal sheets, glassware washing, engine or turbine testing, and the use of pressers, shredders and bottling or filling machines.

2.3.2. Processes

Although the BFOD gave positive answers in 2012 to 361 of 1163 occupational cases of noise-induced hearing loss, only 109 invalidities were recognized in 2013, and of these only 4 were permanent.43 Claims for hearing loss or deafness as occupational disease (n=802) closely followed the group of claims which had the highest number of negative decisions; that is, back pain (n=1250).

Again in 2012, the number of requests for revision of claims linked to occupational hearing losses was 107, the fourth largest cause of requests for revision. These aspects affect both the public and private economic sector. In addition to demands for compensation for NIHL, there has been an increase in claims for occupation-linked tinnitus.44 Ultimately, only eleven of the 24 revision procedures submitted to the court received a positive outcome. If these features seem impressive at first sight, it is possible that the on-place reality is underestimated.

Part III: Investigation guidelines

3.1. Noise Exposure Controls

Noise controls should minimize or eliminate sources of noise, prevent the propagation, amplification, and reverberation of noise and protect workers from excessive noise exposure. Ideally, the use of engineering controls should reduce noise exposure to the point where the risk to hearing is significantly reduced or eliminated.45,46

Engineering and administrative controls are essential for an effective hearing loss prevention program. They are technologically feasible for most noise sources; however, their economic feasibility must be determined on an individual basis. In some instances, the application of a relatively simple noise-control solution reduces the hazard to the extent that the other elements of the program such as audiometric testing and the use of hearing protection devices are no longer necessary. In other cases, the noise reduction process may be more complex, and must be accomplished in stages over a period of time. Even so, with each reduction of a few decibels, the risk of hearing loss is reduced, communication is improved, and noise-related annoyance is reduced.

The first step in noise control is to identify the sources of noise and their relative importance. This
can be difficult in an industrial setting with many sources of noise. It can be accomplished through several methods used simultaneously, such as obtaining a frequency spectrum from an octave band analyser, turning various components in the factory on or off, or using temporary mufflers or enclosures to isolate noise sources, and probing areas close to equipment with a sound level meter, to pinpoint the areas where the sound is dominant. These measures will aid in identifying the sound sources that affect workers the most and should be prioritized when implementing noise controls. Once the noise sources have been identified, it is possible to proceed with choosing an engineering solution, administrative controls, or a form of personal protective equipment to reduce the noise level if noise exposure is too high.\(^6\)

3.1.1. Hierarchy of Controls for Noise
The hierarchy of controls for noise can be summarized as:

1) preventing or containing the escape of the hazardous workplace agent at its source (engineering controls);

2) controlling exposure by changing work schedules to reduce the amount of time any one worker spends in the hazard area (administrative controls); and

3) controlling the exposure with barriers between the worker and the hazard (personal protective equipment). This hierarchy highlights the principle that the best prevention strategy is to eliminate exposure to hazards that can lead to hearing loss. Corporations that have started buy-quiet programs are moving toward workplaces where no harmful noise will exist. Many companies are automating equipment or setting up procedures that can be managed by workers from a quiet control room, free from harmful noise. When it is not possible to eliminate the noise hazard or relocate the worker to a safe area, the worker must be protected with personal protective equipment.

3.1.2. Personal Protective Equipment (Hearing Protection)
Hearing protection devices (HPDs) are considered the option of last resort for controlling noise exposures. HPDs are generally used during the time it takes to implement engineering or administrative controls, or when such controls are not feasible. Unless great care is taken in establishing a hearing conservation program, workers will often receive very little benefit from HPDs. The best hearing protector, when fitted correctly, is one that is accepted by the worker and worn properly. If the worker’s exposure is above 80 dBA (8-hour TWA), hearing protection must be made available. If the worker exposure is above 85 dBA (8-hour TWA), the wearing of a HPD is obligatory, along with the other requirements of the hearing protection program. All hearing protectors are provided with a noise reduction rating (NRR). However, one should not rely on the NRR uncritically, particularly if the protection is based on A-weighted measurements, and the employer must remember that calculated attenuation values reflect realistic values only to the extent that the protectors are properly fitted and permanently worn.

Earplugs come in a variety of sizes, shapes, and materials and can be reusable and/or disposable. They are designed to occlude the ear canal when worn. Although earplugs can offer protection against the harmful effects of impulse noise, and some earplugs are designed specifically to reduce this type of noise, the NRR is based on the attenuation of continuous noise and may not be an accurate indicator of the protection attainable against impulse noise. Earplugs are better suited for warm and/or humid environments, such as foundries, smelters, glass works, and outdoor construction in the summer.

Earmuffs are another type of hearing protector. They come in a variety of sizes, shapes, and materials and are relatively easy to dispense, as they are one-size devices designed to fit nearly all adult users. Earmuffs are designed to cover the external ear and thus reduce the amount of sound reaching the inner ear. Care must be taken to ensure that safety glasses, facial hair, respirators, or other equipment does not break the seal of the earmuff, as even a very small leak in the seal can destroy the effectiveness of the earmuff. Earmuffs should be chosen based on the frequency that needs to be reduced, referring to the EPA label on the manufacturer’s product. Earmuffs are a good choice for intermittent exposure, given how easy they are to put on and take off. Additionally, in cold environments, their warming effect is appreciated.\(^7\)

Hearing bands are a third type of HPD and are similar to earplugs, but have a stiff band that connects the parts that are inserted into a worker’s ears. The band typically wraps around the back of
the wearer’s neck, though variations are available. Hearing bands come in a variety of sizes, shapes, and materials and are popular due to their convenience. They may not provide the same degree of noise attenuation as properly fitting earplugs, since the parts that fit into the ears are stationary and cannot be twisted into place like earplugs.

Earplugs, earmuffs, or hearing bands alone may not provide sufficient protection from significantly high noise levels. In this case, workers should wear double hearing protection, such as earmuffs with earplugs. Corded earplugs should be avoided, as the cord interferes with the seal of the earmuffs. Additionally, hearing bands cannot be worn with earplugs or earmuffs, since the connected band would interfere with the seal, and there is no room to insert earplugs at the same time.

HPDs are rated to indicate the extent to which they reduce worker noise exposure. New technologies are being developed to test the effectiveness of earplugs and may eventually change the way that hearing protection is rated.

It should be stressed that education, teaching and supervision of the adequate use of HPDs (especially custom-fitted HPDs) should be done on a very regular basis; this is the only way to gain some benefit from these efforts towards hearing protection.

3.1.3. Collective Protective Equipment

Various systems are available for collective noise protection. Two different strategies are possible: containment of the noise source, or the use of sound isolators.

A. Containment of the Noise Source

Where possible, the sound-producing material is placed in an isolated box. This equipment can attenuate the sound intensity up to 30 dB(A). By extension, the isolation of walls, doors, soils and windows can be carried out by preferentially choosing solid material such as concrete or brick, which has minor vibration potential. These systems should be distinguished from isolation cabins for workers where the containment of the noise source is impossible.

B. Sound Isolators

The advantage of this system is that it can be directly applied where necessary: for example, at the surface of a machine, pipes, tubes, or ventilators. Isolating glass is used increasing often in modern buildings. Other material can also be included in all constructions containing a noise source: metal sheet, foam, mineral wool, and panels of expanded woods. Finally, if the source is also responsible for generating vibration, the material should be mounted on felt, cork, rubber isolators or on springs.

Frequently, several systems must be carried out simultaneously to obtain an optimal result.

3.2. Noise Investigation

A workplace noise investigation typically involves:

- Advanced planning, including determining whether sound levels at the site might be hazardous
- Reviewing employer records.
- Reviewing the audiograms.
- Reviewing previous hearing loss cases.
- Determining whether workers have hearing loss.
- Conducting a walk-around evaluation.
- Identifying the sources of noise.
- Documenting noise levels.
- Conducting follow-up monitoring
- Determining the potential effect of the noise on workers.
- Evaluating the employer’s efforts to protect workers’ hearing (hazard abatement and control).

In some workplaces, this will be the first time a thorough investigation has been performed. Frequently, however, at least some aspects of a noise investigation will have been completed previously through the employer’s workplace health and safety measures or sometimes as part of seemingly unrelated activities, such as expanding operations or upgrading equipment. To conduct an investigation, the information already available through employer or industry records needs to be determined and confirmed, and gaps filled in. To ensure that the investigation is efficient, however, both of these steps should be carried out simultaneously, which requires a certain amount of advance planning.

3.2.1. Planning the Investigation

An effective noise investigation begins before arrival on site. Firstly, a little research should be conducted to determine whether noise hazards are likely. If so, noise measurements and monitoring should be planned. Confirm that the instruments’ annual calibrations are current (i.e., have not expired), ensure that the batteries are fresh, and calibrate the sound level meter and noise dosimeters before the opening conference. This will permit sound level
measurements to be obtained during the initial walk-around at the site. After these preparations, you will also be ready to start obtaining personal noise dosimetry samples early in the visit, while you have an opportunity to collect samples of significant duration. The resulting noise dosimetry might not be full shift, but it will provide valuable information regarding worker noise exposure during that first day on site.

Sources of information about whether you are likely to encounter noise hazards at an establishment include:
- Previous inspection records for the establishment, employer, or other facilities in the same or similar industries.
- Information summarizing state or national data regarding hearing loss (Fund for Occupational Diseases).
- Potential records of noise-related citations from previous inspections.
- NIOSH reports on the industry, including Health Hazard Evaluations (HHEs).
- Your own knowledge of or experience with the industry and its processes.

3.2.2. Equipment Needed for Workplace Noise Evaluations
You will need a sound level meter (Type 2 or Type 1) and, depending on the extent of the evaluation, an octave band analyser that is compatible with your sound level meter and noise dosimeters. A noise instrument calibrator also will be required.

Additional equipment includes spare batteries for all instruments; check that you have the correct batteries. Calibrators frequently require a different size of battery than sound level meters or noise dosimeters.

Pack so that you have the following readily accessible: tape measure, preferably a 3 m length; pens and paper for sketching the workplace layout; and standard noise measurement forms.

While conducting noise evaluations, you should wear protective equipment appropriate for the site, including hearing protection. Keep earplugs or muffins with you at all times and wear them whenever you are in an area that the employer has designated as a noise-hazardous zone (e.g., by posting signs or if your escort tells you hearing protection is required), when you find that measured noise levels approach 85 dBA, and any other time that you suspect that noise levels are elevated. Use hearing protection anywhere it is noisy enough that you would have to raise your voice to carry on a conversation with someone 1 metre away. In some situations, double hearing protection might be necessary.

3.2.3. Reviewing Employer Records
Review employer records to determine whether hazardous noise levels have been found in the past and to evaluate the employer’s medical records. These records can also show the steps the employer has taken to reduce any excessive noise exposure and whether there is evidence that workers are experiencing noise-induced hearing loss. In addition, ask the employer for noise questionnaires that may be in use. If you can conduct the walk-around inspection before the records review, review the employer’s records while noise dosimeters are operating (return to the work area periodically to confirm that the equipment is still operating properly and to collect sound level measurements to compare with the dosimeter data).

Request copies of previous noise surveys or evaluations that included measurements of sound levels. Note noise levels that exceed the action limit (AL), along with the associated location, equipment, and activities. Enquire about the duration of exposure and determine which workers might be exposed to the noise by using the equation for calculating the time-weighted average (TWA) for the percentage dose. Use noise dosimetry data to determine whether workers were exposed over the AL or the permissible exposure limit (PEL). If the measurements will be used to show compliance, check that the equipment used to make the measurements was at least a Type 2 sound level meter (or dosimeter) with fully documented periodic and daily calibration.

3.2.4. Conducting the Walk-Around Evaluation
The walk-around inspection is a chance for you to see the employees’ working conditions at first hand and to measure noise levels using the sound level meter or noise dosimeter (set to operate as a sound level meter). Use your senses to identify areas that might have hazardous noise, and then use the sound level meter to document the noise levels.

For each noise level, include a description of the noise source (including a photograph), record the distance from the source at which the measurement was made, and note how many and which workers are potentially exposed. Also note that if a noise is intermittent, the frequency and duration of the noise,
Where noise levels exceed the PEL, an octave band analyser can help determine the frequency profile of the sound. This information can aid in pinpointing the cause of the sound (e.g., a slipping belt or vibrating supports) and will be useful for planning control measures.

The sound level meter is also useful for confirming the extent to which the employer’s noise reduction measures have reduced workers’ noise exposure. In this case, octave band analysis can help confirm that the materials used are appropriate for controlling the particular noise.

When monitoring is complete at the end of the day, follow standard procedures for recording results from the instruments. Dosimeter output usually includes the TWA (normalized to 8 hours), the $L_{eq}$ or $L_{10}$ representing the average dose for the period monitored, the percentage dose, and the maximum or peak reading. Do not neglect to perform the post-use calibration check on each instrument.

3.2.5. Follow-Up Monitoring

If noise levels documented by sound level meter or dosimetry on the first day indicate that additional sampling is required, you will need to return to conduct follow-up monitoring. This additional monitoring may be necessary to confirm that workers are adequately protected or that an overexposure exists, or you may need to monitor another operation which was not being carried out on the first day. Since the follow-up monitoring will focus on noise dosimetry, prepare to arrive in time to start monitoring with calibrated equipment just as the shift begins. The goal is to sample for a full 8 hours (or 8 hours plus the lunch break period if the break is not included in the dosimetry).

Part IV: Events inducing hearing loss

After an event inducing hearing loss or deafness, various declarations must be made to the insurance company and the regional inspectorate for control of well-being at work.

1. Declaration to the Insurance Company

After the employer is informed about an incident at work, a notification must be made by at least the tenth day following the day on which the accident occurred. This must be done using a form provided by the insurance company, and a medical certificate...
may be included. If the incident is critical, the insurance company should be informed as soon as possible.

2. Declaration of a Work Incident to the Regional Well-Being at Work Inspectorate

The notification should be carried out using the appropriate paper-based or online form, giving the name of the victim, name and address of the employer, date and place of the incident, physical consequences and a short summary of the circumstances.

The following types of incidents are considered to be serious:

1) a work event leading to death;
2) a work incident where the occurrence can be linked to a faulty process such as:
- electrical dysfunction, blast or fire
- flow or overflow, spilling, vaporization, gas emission
- rupture, break, blowout, slipping, or collapse of material
- loss of control of a machine (such as transportation or maintenance), tool or object
- falling of an employee
- trapping by an object, a machine or their movement.

Noise-induced hearing loss or deafness can occur in some of these situations.

Situations involving numerous instruments or materials (such as scaffolding or elevated constructions or buildings, excavations, trenches, wells, underground, galleries or underwater environments) are also considered to be severe, and may cause noise-induced events; these may include vehicles, explosive substances, toxic agents (chemical, biological or radioactive), weapons or security systems. However, to be definitively recognized as severe, the use of these items must be associated with permanent health damage. If this damage is temporary (e.g., post-trauma fractures or burn wounds), they are required to have led to an incapacity to work for at least several days.

Take-home messages for ent specialists

1. Well-being at work has become a major public health theme within politics around the world. In Belgium, several Royal Decrees and Acts have implemented international recommendations into Belgian law.

2. The importance of prevention is illustrated by the numerous rules imposed on employers to protect employees from noise exposure.

3. Despite the diversity, extensiveness and interrelatedness of these regulations, noise-induced hearing loss or deafness unfortunately remains frequent. This can be due to continuous exposure to high-intensity sounds or to accidents such as blasts.

4. In addition to providing hearing protection devices, employee education and monitoring with regard to the proper use of HPDs is crucial.

References


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