Phonak Insight

Noise: Why should we care about it?

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Loud sounds or excessive noise exposure for any duration (short or long) causes fatigue to the ear's sensory hair cells. This may result in temporary hearing loss or tinnitus. When the exposure is too loud (above safe limits), it can lead to a permanent damage of the sensory cells and other neighbouring structures, resulting in an irreversible hearing loss. Furthermore, prolonged and continuous exposure will cause a progressive hearing loss, ultimately affecting speech comprehension which results in a negative impact on an individual's quality of life. Here we throw light on the basic aspects of noise with its influence on the natural human hearing process and the necessity to protect it.

Key highlights

- Sound pressure level (SPL) is a commonly used pointer to measure a wide range of sound pressures. It uses a logarithmic scale to represent the sound pressure of a sound relative to a reference pressure.

- ISO standardized Equal-Loudness Contours signify an essential descriptor for loudness perception. Phons are the unit of measure for perceived loudness.

- Excessive noise usually damages about 10 to 25 mm from the round window of the Cochlea where frequencies between 3 to 6 kHz are mostly perceived.

Considerations for practice

- When deciding on using a hearing protection device two important factors should be considered: the level of noise and the length of exposure time.
- Noise level measurements and assessments require trained persons and use of specialist equipment.
- Noise levels are generally measured in units known as decibels dB(A) by standard Noise Dosimeters.
- Different standards and guidelines per region regulate the daily noise exposure limits. Guidelines for which are as follows:
  - European directive 2003/10/EC, the daily noise exposure limit value is $LA_{EX,8h}$ = 87 dB.
  - OSHA standards: 85 dBA measured as 8-hour TWA (time weighted average)

Why should we care about noise?

Noise is generally considered an unrecognized topic which is a hidden threat that might cause a number of short- and long-term health issues. Noise can interfere with communication, cause sleep problems, cardiovascular effects, voice problems and concentration issues at work and school, in turn affecting the performance. It can also cause hearing insufficiency, neurological diseases, cardiovascular effects, hearing damage etc. At sufficiently high noise levels (above 80 dB) hearing can be impaired. In children, it affects their ability to learn. Hearing loss currently affects more than 1.5 billion people or 20% of the global population; the majority of these (1.16 billion) have mild hearing loss. However, a substantial portion, or 430 million people (i.e. 5.5% of the global population) experience moderate or higher levels of hearing loss (hearing thresholds higher than 35 dB in the better hearing ear) which, if unaddressed, will most likely impact their daily activities and quality of life (WHO, 2021; GBD, 2019). When the hearing loss caused by excessive noise exposure is not treated, it may lead to a series of negative physical, mental and social consequences. As per EU figures, about 40% of the EU population is exposed to road traffic noise at levels exceeding 55 dB(A), and 20% is exposed to levels exceeding 65 dB(A) during daytime. During night-time more than 30% is exposed to levels exceeding 55 dB(A). When hearing protection is neglected, noise generated by various sources such as by traffic, at work, listening to loud music results in so-called noise-induced hearing loss (NIHL). NIHL is often accompanied by tinnitus, or ringing in the ears. This type of hearing loss is still one of the most prominent and important topics regarding health concerns which is recognised among the occupational diseases in the Member States of the European Union. Noise levels in general regularly exceed the prescribed limit values in many sectors, such as agriculture, construction engineering, foods and drink industry, woodworking, foundries or entertainment. The exposure to loud noise seems to be affecting more and more younger workers (Schneider, et al., 2005). Noise exposure and their health effects, especially occupational hearing loss, is often overlooked or not dealt with properly, because of the fact that the increasing noise overexposure, and the exposures that damage hearing (short and long term) are not necessarily painful or even annoying in order to deal seriously with them. It usually occurs in a subtle manner, without any dramatic consequences such as bleeding, deformity, or death.

Sound Pressure Level (SPL)

In the atmosphere we generally encounter pressure variations. These variations of pressure when overlaid on the atmospheric pressure within the audible range is called the sound pressure. It is expressed as force per unit area, and its unit is Pascal (Pa). Here we have to be aware that sound pressure is the mere "effect" of a disturbance in the environment. The actual "cause" of the disturbance, and the resulting reaction effect, is due to the driving force (sound power). For calculation convenience, the sound power output of a source is expressed in terms of its sound power level (PWL or Lw) which is represented as:

$$L_w = 10 \log\left(\frac{W}{W_o}\right)\ dB\ re\ 10^{-12}\ watt$$

where W is the sound power of the source in watts and W_o is the reference sound power defined as $10^{-12}\ watt$.
The sound pressure level (SPL) is a measure of the air vibrations that make up a particular sound. All measured sound pressures are referenced to a standard pressure that corresponds roughly to the threshold of hearing at 1000 Hz. Thus, the sound pressure level indicates how much greater the measured sound is than this threshold of hearing. Because the human ear can detect a wide range of sound pressure levels (20 µPa –102 Pascal (Pa)), they are measured on a logarithmic scale with units of decibels (dB). In most of the noise cases SPL varies with time. Consequently, in calculating some measures of noise, the instantaneous pressure fluctuations must be integrated over some time interval. To approximate the integration time of our hearing system, sound pressure meters or sound level meters (SLM's) have a standard Fast response time, which corresponds to a time constant of 0.125s. Thus, all measurements of sound pressure levels and their variation over time should be made using the Fast response time, to provide sound pressure measurements more representative of human hearing. Sound pressure meters may also include a Slow response time with a time constant of 1s, but its sole purpose is that one can more easily estimate the average value of rapidly fluctuating levels. Many modern meters can integrate sound pressures over specified periods and provide average values. These average values can be used to generate equivalent continuous sound pressure levels. This level, often given as Leq,T is equivalent to the total sound energy measured over a stated period of time. An 8-hour equivalent Leq is also known as $L_{EX,8h}$. The readings obtained using such SLM's represent the sound pressure levels (abbreviated as SPL), in decibels (dB) relative to a reference sound pressure, which for measurements in air is 20 µPa (micro-pascals) or 20 $\mu N/m^2$ (Berger, 2003). The equation for SPL is:

$$SPL = 20 \log\left(\frac{p}{p_o}\right)\ dB\ re\ 20\ \mu Pa$$

where, p is the measured root-mean-square (rms) sound pressure and p_o is the reference rms sound pressure. Here the multiplier is 20, because sound power and intensity are proportional to the square of the pressure under normal conditions and

$$10\log p^2 = 20\log\ p$$

As mentioned earlier, sound pressure levels are measured on a logarithmic scale, therefore they cannot be added or averaged arithmetically. For example, adding two sounds of equal pressure levels results in a total pressure level that is only 3 dB greater than each individual sound pressure level. Consequently, when two sounds are combined, the resulting sound pressure level will be significantly greater than the individual sound levels only if the two sounds have similar pressure levels.

Noise and equal-loudness contours

From the medical science perspective, noise can be defined as an extremely intense sound which is capable of producing considerable damage to the inner ear (cochlea). Noise is basically a form of energy. This energy is transmitted through the air in the form of pressure waves. A healthy human ear is capable of detecting these pressure waves, which it recognizes as a sound or noise. Noise can be explained in terms of intensity or amplitude (perceived as loudness) and frequency (perceived as pitch). Both the intensity and the noise duration exposure are seen as the potentials for bringing damage to cochlea. High-frequency noise is much more damaging than low-frequency noise; therefore, intensity alone cannot be used to predict the risk to hearing. By simply measuring the physical intensity of the stimulus as a sound pressure level, one cannot assess the potential damage caused by excessive noise. The human ear does not respond in the same manner to all the frequencies available in a typical sound spectrum. The response of the human ear to sound or noise depends on the frequency and the sound pressure level (SPL). Under a sufficient sound pressure level, a healthy, young human ear is able to detect sounds with frequencies between 20 Hz to 20,000 Hz. However, it is a relatively small percentage of the population that can truly detect sounds at the outer edges of this range. The human ear has different sensitivities to different frequencies, being least sensitive to extremely high and extremely low frequencies. For example, a pure-tone of 1000 Hz with intensity level of 40 dB would strike the human ear as being louder than a pure-tone of 80 Hz with 50 dB, and a 1000 Hz tone at 70 dB would give the same subjective impression of loudness as a 50 Hz tone at 85 dB. A noise, at the threshold of hearing is just loud enough to be detected by a healthy human ear. Above that threshold, the degree of loudness is a subjective interpretation of SPL or intensity of the sound. The concept of loudness is important for the evaluation of exposure to noise. The loudness level of a sound is determined by adjusting the SPL of a pure tone of a specific frequency until it is judged by normal hearing observers to be equal in loudness compared to a reference tone. Loudness level is expressed in phons, which have the same numerical value as the SPL at 1000 Hz. (Goelzer et al.).

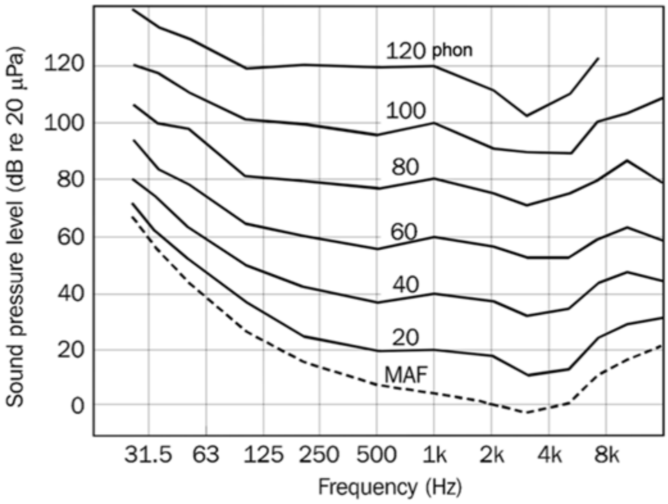

Figure 1 Equal-loudness contours for pure tones for field heard under standard conditions (as per ISO 226). These curves are determined relative to the reference level at 1 kHz. The numbers indicate the loudness level, in phons, of the tones that fall on each contour (Goelzer et al.).

The loudness of sounds is graded by "equal-loudness contours". As these curves involve subjective reactions, they have been determined through psycho-acoustical experiments. Figure 1 here represents these contours for free-field conditions, with the minimum audible field (MAF) representing the average threshold of hearing, shown by the dashed line. Inspection of the curves clearly shows that the human sensitivity is greatest from 2kHz to 5kHz and they tend to become more flattened with an increase in the loudness level. These curves also demonstrate how typical human hearing is a function of frequency and amplitude of the sound wave. So, a sound at one frequency may seem louder (or softer) than a sound of equal pressure and amplitude at a different frequency. The lines are constructed so that all tones of the same number of phons sound equally loud (Goelzer et al.).

The equal loudness curves are the reason that many sound level meters include a function called frequency weighting. In order to correct the SPL's (measured by the SLM) for the loudness as experienced by the human ear, different weighting curves are applied. At levels below 100 dB, A weighting is usually applied which filters out a lot of the low frequency content of the noise. At levels above 100 dB, the response of the human ear becomes flatter (refer Figure 1), so it becomes more sensitive to low frequencies. In such a case, C weighting can be applied which filters out less low frequency content compared to A weighting. When a weighting curve has been applied to a sound level measurement, it is indicated by adding the capital A or C to the unit used. For example LAeq,8h is the single number denoting the A weighted, 8-hour equivalent continuous sound level.

How does noise affect human hearing?

The hearing process in human beings is one of the critical human senses. Hearing helps in communicating with each other and our environment. The inclusion of sound adds productivity to life, be it for the language details and humour, the emotions introduced by music, or the connection felt to our surroundings or with nature. The inner ear ("cochlea") of humans, with its irreplaceable and complex anatomical and functional design allows for the existence, clearness, and quality of sound to be experienced in all the situations. This extremely complex cochlea (Figure 2) and the peripheral auditory system is delicate, yet rugged; vulnerable yet remarkably resilient.

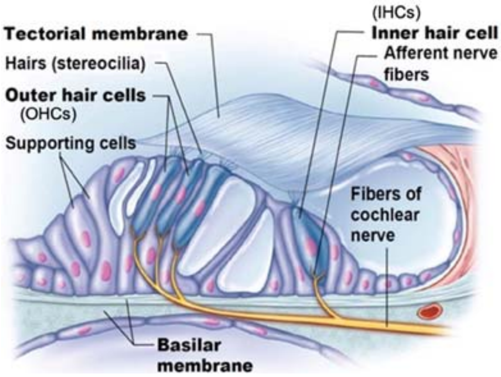

Figure 2 Cross-section of cochlea's spiral organ (organ of corti) with other components (Basilar membrane, Tectorial membrane, OHCs and IHCs) (Marieb and Hoehn, 2012).

The cochlea, when exposed to excessive noise, sustains adverse and irreversible damage resulting in permanent hearing loss. This has generally been termed as Noise induced hearing loss (NIHL) and is found on the internal sensory components of the cochlea. It's also referred to as Sensorineural hearing loss (SNHL). The effect of excessive noise on hearing depends on factors like: level of noise and exposure duration, sound frequency, individual hearing sensitivity, and vulnerability in environmental and biological factors etc. In the normal healthy cochlea, a single row of inner hair cells (IHCs) and three rows of outer hair cells (OHCs) are present (Figure 3a). They are termed as "hair" cells due to the fact that they look like clusters of hair. The IHCs and OHCs have totally different functions. The row of IHCs is responsible for conversion of mechanical movement or vibrations into an electrical neural signal, whereas the three rows of OHCs play a supporting role serving two functions: amplifying the motion of the basilar membrane and protecting the inner hair cells from getting damaged. Excessive noise (> 85dB) mainly causes damage to these hair cells. In the initial stages the damage may be limited to the OHCs but if the noise exposure continues for a longer duration the damage may also extend to the IHCs. This is clearly visible from the image (Figure 3b) representing the damaged IHCs and OHCs leading to NIHL. Damage in OHCs results in reduced sensitivity for quiet sounds, loss in frequency resolution (ability to distinguish between two frequencies especially in situations of background noise), over-reaction to particular sounds ('hyperacusis') and "Loudness recruitment" (Moore, 2007). In certain cases, the severity of the noise is so high that it might also cause a fatal destruction to the cells in the organ of Corti (refer Figure 2).

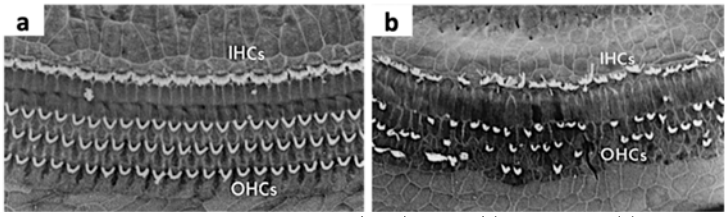

Figure 3 Scanning electron micrographs (SEM) of the (a) normal and (b) damaged cochlear hair cells (Ryan, 2000).

It has been observed by research that the area of maximum destruction is usually about 10 to 25 mm from the round window. This is normally where the frequencies between 3 and 6 kHz are perceived, which may explain the existence of the 4 kHz dip that is one of the common features of NIHL. This dip in hearing is usually referred to as a 'notch' in the audiogram which is as shown in Figure 4. As clearly seen the notch lies between 3 and 6 kHz. Further exposure to noise results in deterioration in hearing levels and also the widening of the frequency range. In general, NIHL (SNHL) is a relatively rapid process with its rate having a gradual progressive nature. As observed from Figure 4, the loss of hearing occurs more prominently in the high frequency zone rather than the low ones. This is mostly above 3 kHz where most people can still manage to hear quite well in quiet environments. On the other hand, in a noisy situation, understanding speech becomes challenging and also difficult to distinguish. The age factor is also connected to NIHL. It actually is an additive feature which further worsens the hearing process in most individuals as they grow older. In many NIHL cases, there is an element of presbycusis present and it is hard to separate them, although experts have drawn reference tables in order to estimate the extent of hearing loss occurring due to age or noise (Maltby, 2005).

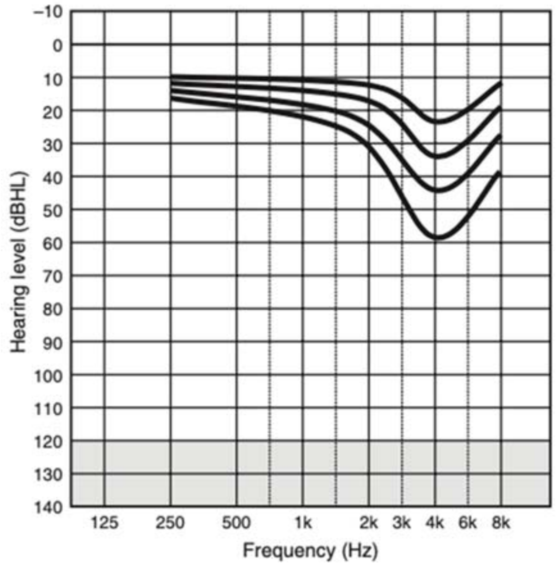

Figure 4 Plot showing the damage progression in NIHL (Maltby, 2005).

A need to protect hearing?

In our everyday life we all are exposed to different types of sounds which can be eligible as to be "noise", even if we don't really notice it. At school or work, in traffic, mowing your lawn – or even hearing the neighbour's dog barking – there is noise all around us. It all depends on the noise level, but that's not so easy to predict. Thus, in general loud noise can be categorized under occupational, recreational and environmental noise.

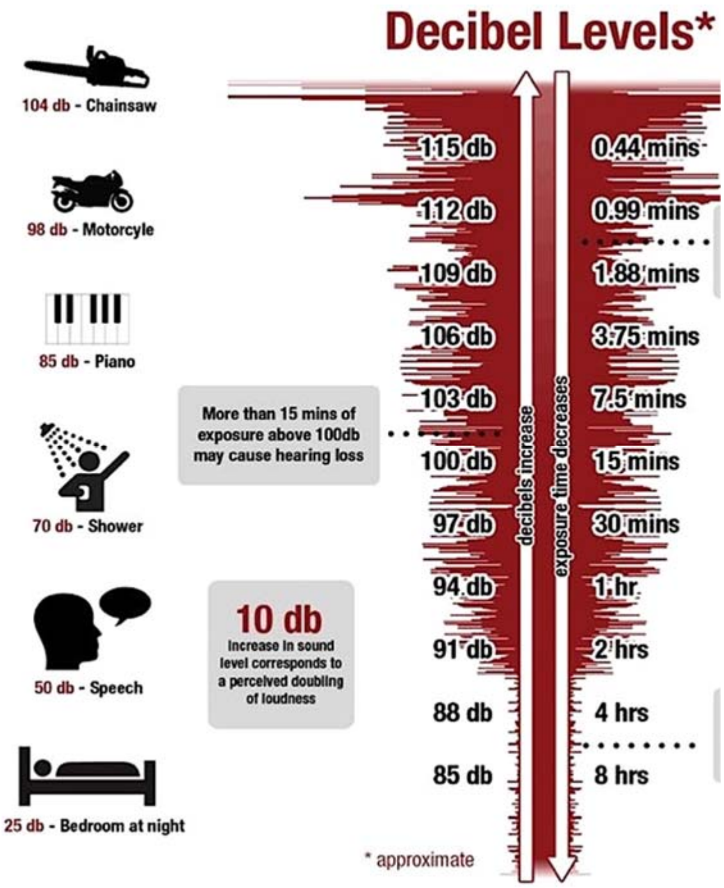

Figure 5 A sound chart showing the loudness level [8].

Standard human speech and conversation takes place at around 50 dB on average. A jet plane during take-off can reach a maximum level 140 dB (Figure 5). The danger is when the loud sound continues for a longer duration of time or happens repeatedly for a long time. Many countries have authorized regulations concerning noise limits that workers are allowed to be exposed to during a working day (standard 8-hour shift). The aim is to protect workers from getting any kind of hearing reduction or impairment due to the noisy work environment. As per the OSHA (Occupational Safety and Health Administration) industry guidelines the employers must provide adequate hearing protectors to all workers exposed to noise levels of 85 dBA or above, measured as 8-hour TWA (time weighted average) (OSHA, 2002). According to the European directive 2003/10/EC, the daily noise exposure limit value is $LA_{EX,8h}$ = 87 dB. When these values are exceeded, measures should be taken to protect against hearing damage. It is always preferable to limit the production of noise at the source. If that is not sufficient, proper hearing protection should be selected. Although it is tempting to choose hearing protection with very high attenuation values, care should be taken to avoid overprotection. The European guidance document EN-458 recommends a hearing protector which provides an effective sound level at the ear ($L'_{p,A}$) of between 70 and 80 dB. If excessive attenuation is used, the wearer is at risk of failing to recognize warning signals and understand essential communications. The wearer may also feel isolated from their environment. Even if someone doesn't work in a noisy environment, then situations to be considered are those including going to live music concerts, watching fireworks from close distance, flying, or listening to music or podcasts with earphones at too high a volume etc. Apart from the mentioned reasons in the earlier sections, other reasons why we need to protect our ears are: human ear structure especially the inner ear ("cochlea") is fragile (as see in earlier sections above), living with tinnitus is not a pleasant experience and the damage once done to the inner ear is irreversible and cannot be repaired. Human eardrums and cochlea don't heal themselves, which means that if we do not preserve our hearing by adequate usage of hearing protection devices then we are already set on the path of causing damage to our hearing.

Conclusion

Human beings, in their daily lives, encounter many different types of noise in their profession and in their personal sphere. Any type of sound exposure above a certain threshold, whether its work-related or leisure, in most instances is expected to cause hearing damage. In general sounds up to 85 dBA are considered to be safe for humans. Within this limit, hearing damage is unlikely to occur.

However, as soon as this limit is crossed in combination with a longer exposure duration, it will result in severe permanent destruction to the hearing process and the ear itself. Some people such as pregnant women, persons sensible to noise changes, individuals with a pre-existing hearing problem and who work with chemicals etc. may be more susceptible to noise damage and therefore require special attention. To diagnose NIHL, a 4 kHz notch in an audiogram is a first indication which mostly presents with tinnitus. NIHL deprives the victim of optimal communication and the notification of warning signals at work. Nevertheless, one should not be prohibited from their usual work in a noisy environment because of a hearing disability, except when there are huge health and safety risks and adjustments cannot be made that reduce the risks to a satisfactory level. Noise is one of the inevitable elements of our environment where we work or live. We cannot avoid noise completely, but with adequate hearing protection devices we can make substantial efforts to supress the noise to a level which is safe for our ears.

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