

IMPULSE NOISE: A REVIEW OF THE HEALTH EFFECTS ON MAN AND THE EFFECTIVENESS OF HEARING PROTECTION DEVICES

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Abstract

This paper provides an overview of the health impacts of impulse noise on man as well as the effectiveness of Hearing Protection Devices.

Impulse noise usually results from an explosion, as in gunfire. Since the pressures involved are comparable to atmospheric pressure, the normal laws of acoustics, which assume that the acoustic pressures are much less than atmospheric pressure, do not always apply. One consequence of this is the formation of a shock wave, travelling supersonically, wherever a substantial increase in pressure occurs.

Damage to internal organs is microscopic and symptoms may take many years to show. Most information exists on the impact on the ears.

The myriad of parameters/factors, which influence human health make it very difficult to conduct epidemiological studies. Furthermore, the ethical requirements to conduct studies on humans complicate things considerably.

Although the human (epidemiological) studies conducted provides evidence that excessive long-term noise exposure is detrimental to human health the following questions are raised:

- What is excessive exposure?
- What is long-term exposure?

The accurate estimation of the attenuation that wearers of hearing protection devices (HPDs) receive under conditions of actual use (real-world conditions) has been a topic of substantial research and much debate. Although HPDs are useful for protection from **impulsive noise**, the noise reduction measurements are based on tests in **continuous noise** and may not be an accurate indicator of the device's performance for impulsive sounds such as gunfire.

It is necessary that suitable field tests are developed to measure attenuation and thereby determine the effectiveness of hearing protection devices.

Introduction

Impulse noise usually results from an explosion, as in gunfire. Since the pressures involved are comparable to atmospheric pressure, the normal laws of acoustics, which assume that the acoustic pressures are much less than atmospheric pressure, do not always apply. One consequence of this is the formation of a shock wave, travelling supersonically, wherever a substantial increase in pressure occurs.

Overpressure (ΔP) is usually measured in pounds per square inch (psi) and converted to kilo Pascal (kPa). 1psi = 6,8948kPa. The maximum value obtained, designated the peak pressure level (PPL) may then be converted to Decibels (dB).

The formula to convert ΔP (in kPa) to PPL (in decibels) is: $PPL = 20\log(\Delta P) + 153,98$

Impulse noise is expressed in Decibel. Decibel is a logarithmic scale and every 6 Decibel increase represents a doubling in sound pressure.

The **impulse** is defined as the integral over all time of the pressure, i.e., it might be considered to be the average level of the shock wave pressure multiplied by its duration.

The shock wave (over-pressure component) should be distinguished from “blast wind” which is the forced super-heated air flow.

Vibroacoustic disease (VAD)

According to Branco¹, vibroacoustic disease (VAD) is the clinical manifestation of a systematic disease that develops after long-term exposure to noise (≥ 10 yr), which is characterized by large pressure amplitude (≥ 90 dB PPL) within the lower frequency bands (≤ 500 Hz).

Clinical manifestations of VAD among the study population involve visual, auditory and balance disturbances, epileptic manifestations, stroke-like neurological deficiencies and psychological disturbances. The clinical progression is insidious, and lesions are found in many systems throughout the body. Some of the findings, such as extracellular matrix changes, appear to be specific to this disease.

Some of the first complaints of patients suffering from VAD are sore throat, coughing, bronchitis, and inflammation or infections of the oral cavity and upper respiratory pathways.

Internal organs

Many studies have been done on cadavers and animals to determine the health impacts of impulse noise. Damage to the internal organs of man is usually microscopic and symptoms take many years to show. Chest X-Ray tests and Lung Function tests will not show microscopic damage to the lungs².

Noise is an important etiological factor in hypertension, heart and neuropsychiatric disease¹. There are indications that exposure to impulse noise results in elevation of blood pressure and pulse rate. It is possible that noise might directly contribute to the risk of ischemic cardiopathy by causing spasms of the main coronary arteries due to a prevalence of alpha-adrenal tone in predisposed subjects³.

Ears

Exposure to high levels of noise causes hearing loss. The extent of damage depends primarily on the intensity of the noise and the duration of the exposure. Noise-induced hearing loss can be temporary or permanent. Temporary hearing loss results from short-term exposures to noise, with normal hearing returning after a period of rest. Generally, prolonged exposure to high noise levels over a period of time gradually causes permanent damage.

Many studies on animals and cadavers^{4,5} provide overwhelming evidence of hearing loss due to exposure to impulse noise.

The effect of excessive noise on hearing is nerve deafness. This occurs when the cilia, the tiny hair-capped cells that act as sensors within the inner ear (Fig. 1) become damaged. A number of energy transformations take place in the ear. Acoustic energy of the air is transformed to mechanical motion energy on the part of the eardrum and the chain of auditory bones. Hydro-mechanical motion of the inner ear is converted into bioelectrical energy in the hair cells and the auditory nerve³.

If the sound is not too loud or too prolonged, the fatigued cells may recover in a few hours. As the hair cells are repeatedly overstimulated however, they begin to deteriorate causing irreparable hearing damage.

Fast structural damage results from the mechanical overloading of the hair cells in the inner ear. Fast structural damage results from strong sound impulses⁴.

Noise Induced Hearing Loss (NIHL) is reported (as an occupational disease) to the Compensation Commissioner at an average of 2000 cases per year.

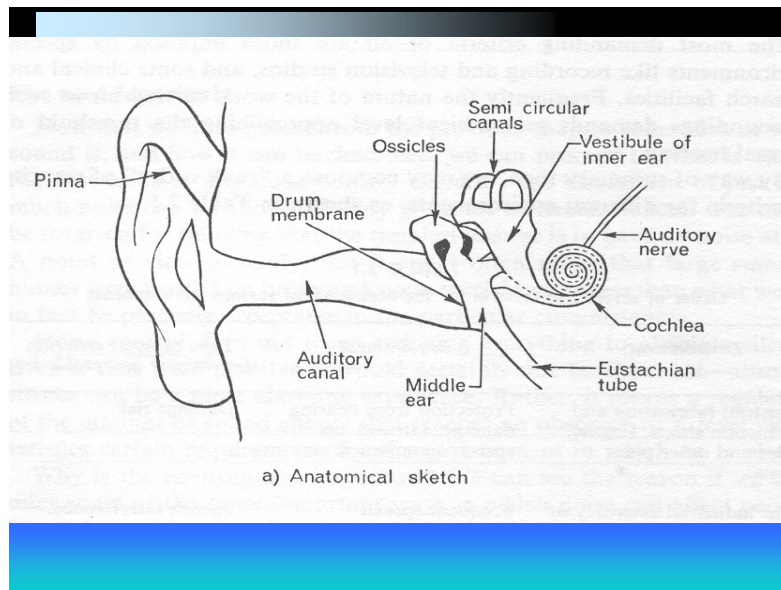


Figure 1: Dissection of the ear

Hearing protection devices

Because most weapon systems produce impulse noise above 170dB, double hearing protection is required.

According to Army Times⁶ studies in the USA Army found that even double hearing protection is insufficient. Army researchers measured the hearing of Special Forces troops before and after a three-day live-fire exercise. All the soldiers wore foam ear plugs, plus muff-style protectors. About 10% of the troops developed some hearing loss by the time the exercise was over.

Modern weapon systems get so loud that the skull vibrates, and the vibration causes the vibration of the ear fluid, which the ear reads as a very loud sound signal. A helmet on its own does not provide adequate protection either.

Mechanisms of HPD attenuation

In the unoccluded ear, the dominant sound path for external sounds is through the ear canal to the eardrum. However, in the occluded ear, four distinct sound paths are:

- **Ear Leaks.** For maximum protection, HPDs must essentially make an airtight seal with the walls of the ear canal or circumaural regions surrounding the pinna.
- **Hearing Protector Vibration.** Due to the flexibility of the ear canal flesh, earplugs can vibrate in a piston-like manner, thus limiting their low-frequency attenuation. Earmuffs too, vibrate as a mass/spring system, the stiffness of the spring depending on the dynamic characteristics of the earmuff cushion and the circumaural flesh, as well as the volume of the air entrapped inside the earcup;
- **Structural Transmission.** The exterior surfaces of an HPD will vibrate in response to the forces applied by impinging sound waves. This vibration is transmitted by the protector material to its inner surface where the resultant motion radiates sound, of diminished intensity, into the enclosed volume between the HPD and the wearer's eardrum; and
- **Bone and Tissue Conduction.** The concept of bone conduction implies that sound is transmitted via any pathway other than that of conventional air conduction (ear canal). For the absolute maximum in attenuation; the head must be acoustically shielded in addition to

wearing double protection. Shielding with a lightweight acoustically leaky barrier such as a safety helmet has no effect. What is required is a tight fitting helmet, like a standard military flight helmet, that encloses the entire skull and face. Even the best of helmets provide little attenuation at frequencies below 1000 Hz.

Damage-Risk Criteria

In the United Kingdom and the USA, the CHABA impulse-noise damage-risk criteria (DRC) are generally referred to for assessment of the danger of auditory damage from exposure to impulse noise. The objective is to protect 95% of the exposed population from permanent auditory damage⁸. According to the Committee on Hearing, Bioacoustics and Biomechanics (CHABA)- criteria, the maximum permissible shots per day are determined.

Real-World (field conditions) testing

The accurate estimation of the attenuation that wearers of hearing protection devices (HPDs) receive under conditions of actual use (real-world conditions) has been a topic of substantial research and much debate. There has never been a field study conducted in which currently labelled values of HPD attenuation have been achieved for groups of users under real-world conditions. Although HPDs are useful for protection from **impulsive noise**, the noise reduction measurements are based on tests in **continuous noise** and may not be an accurate indicator of the device's performance for impulsive sounds such as gunfire⁹.

The methods for measuring attenuation of HPDs include: real-ear attenuation at threshold (REAT); microphone in real ear (MIRE); and acoustical test fixture (ATF).

The prescribed hearing protection is based on assumptions (MIL-STD 1474 for impulse noise) and laboratory testing of hearing protectors (SANS 1451). No realistic practical testing has been performed. Noise damage through bone conduction (neck and skull) is possible.

Legal requirements

According to the Noise-Induced Hearing Loss Regulations¹⁰ an employer shall ensure that the exposure of a person to noise is either prevented or, where it is not reasonably practicable, adequately controlled:

- a) Engineering control measures to eliminate or reduce noise at its source or of the routes;
- b) Administrative controls to limit the number of persons exposed and the duration of exposure;
- c) The use of hearing protective equipment if engineering and administrative control measures fail to reduce exposure below the 85dB noise-rating limit.

Conclusion

The myriad of parameters/factors, which influence human health make it very difficult to conduct epidemiological studies. For instance, the factors that might have an impact on blood pressure are alcohol consumption, smoking, coronary disease, medications, etc.

Furthermore, the ethical requirements to conduct studies on humans complicate things considerably.

Because there are no easy and affordable tests available to determine the possible injury (on a micro scale) of the internal organs, we are obliged to rely on information obtained from other studies with regards to effects to internal organs.

Although the human (epidemiological) studies conducted provides evidence that excessive long-term noise exposure is detrimental to human health the following questions are raised:

- What is excessive exposure?
- What is long-term exposure?

The only guideline is that exposure to explosions (impulsive noise) above 194dB (100kPa) results in definite organ damage.

It is necessary that suitable field tests are developed to measure attenuation and thereby determine the effectiveness of hearing protection devices.

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