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Occupational noise as a health hazard

Physiological viewpoints

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Industrial noise can be a health hazard in mainly two ways. It can damage the ear and it can influence a number of other bodily functions. The latter effect is mediated through the sympathetic nervous system and the hypophyseal hormone system.

The presently accepted occupational noise standards and recommendations concern only permanent damage to the ear, i.e., that resulting in permanent hearing loss. Often effects, such as the acute effect of noise (temporary hearing loss), tinnitus, vertigo and fatigue, as well as the general effect on many vital bodily functions, are not considered therein.

EFFECT ON THE EAR

The first noticeable effect of exposure to a loud sound is an elevation of the hearing threshold, experienced immediately after the termination of the noise exposure. This hearing loss decreases gradually, and, if the noise is not too loud or the exposure

time too long, the hearing threshold will return to its previous value within hours or days, the time depending on the level of the noise. If the noise is louder than a certain level, however, the hearing threshold will not be fully restored and a residual hearing loss will take place. This latter effect is called a permanent threshold shift (PTS), whereas the nonresidual one is called a temporary threshold shift (TTS).

The degree of TTS, as well as that of PTS, is foremost a function of the intensity and the duration of the noise, but it is also dependent on other characteristics. The permanent hearing loss that a certain noise may induce is related to whether the noise has narrow peaks in its spectrum and to whether it is dominated by high frequency energy. Noise with narrow spectral peaks induces its greatest hearing loss in a frequency range slightly above that at which the noise has its highest energy. The precise relationship between noise spectrum and the distribution of hearing loss is, however, not fully known. The elevation in hearing threshold has generally been found to begin at high frequencies and to grow both in distribution over frequencies and in size (fig. 1).

It was previously assumed that the TTS and the PTS were similar in nature, the difference being only a matter of noise

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Fig. 1. Typical audiograms obtained from ears after various durations of noise exposure. [from Møller (8), modified from Taylor et al. (10).

level or exposure time. It was thus assumed that the TTS produced by a certain sound could be used to predict the PTS to which the noise would give rise if its intensity or its duration were increased. Recent studies have shed doubt upon that assumption. Consequently, the practice of basing estimations of risk for PTS in exposure to certain noises on experimentally determined TTSs can also be questioned.

Noise-induced hearing loss has previously been assumed to result from damage to the sensory epithelium in the inner ear only. To be sure, these sensory cells (hair cells) are damaged by noise, but part of the hearing impairment may be a result of damage to nerve cells in the ascending auditory pathways. Along the same line, recent research indicates that the TTS is not simply a fatigue of the sensory cells in the inner ear, but that it is likely to involve parts of the central auditory nervous system (5).

Thus the earlier accepted explanation that the effect of noise on the auditory system begins with fatigue (TTS) of the sensory cells upon exposure to moderate sound levels and proceeds into permanent damage (PTS) as the sound or exposure time is increased beyond a certain value now seems to be a great oversimplification.

The complex nature of noise-induced hearing loss is also apparent from the fact that loss in intelligibility of speech cannot be fully restored by a hearing aid that compensates for threshold elevation (7). This relationship may be attributable to

a partial loss of hair cells, the implication of which is not fully understood, but it may also result from damage to parts of the auditory nervous system.

There is a great individual spread in the amount of hearing loss brought about by a certain noise. Fig. 2 shows the threshold elevation at 4 kHz in industrial workers exposed to noise of different intensities and durations. The abscissa shows noise immersion levels, i.e., the duration and the intensity of the noise, combined into one figure according to the rule of equal energy. This rule assumes that it is the total energy of noise that is important, independently of how the noise is distributed in time. Accordingly, a rather short duration of a loud sound is as equally harmful to hearing as a long duration of a less loud sound.

The fundamental effect of noise on the ear is thus not fully understood. Only the results of basic auditory research can shed light upon such matters as the importance of the time structure of a sound to the damaging effect on the ear.

Damage risk criteria

As a part of hearing conservation programs most industrial countries apply recommendations or standards expressing the highest acceptable level of noise. The great spread in susceptibility of noise-induced hearing loss renders the standards

Fig. 2. Hearing loss at 4,000 Hz as a function of noise exposure level EA_2 . The dots show the individual values and the solid line shows the mean value. [from Møller (8), source: Burns and Robinson (3)]

and recommendations statistical in nature, i.e., they express the probability that a certain noise level will not induce more than a certain specified hearing loss in more than a few people in a large population.

In these standards the intensity of the noise is expressed in a single figure, i.e., decibels (A) [dB(A)], where A stands for a weighting of the noise spectrum in such a way as to place less emphasis on low frequencies than on high ones.

The drawbacks of specifying the noise level by a single figure, dB(A), are not limited to the previously mentioned lack of information about spectral distribution. The commonly used dB(A) measure of noise level does not include any information about whether or not the noise contains sharp transients, a factor that increases the hazard of the noise to a great extent. In fact, the commonly used noise level meter integrates energy over about 100 ms. This value corresponds to the integration time of the auditory system as it has emerged from psychoacoustic experiments, but this integration time is a property of the central auditory nervous system. The cochlea, where noise causes its primary damage, has an integration time far below that, its value ranging in tenths of milliseconds. While sound level meters may give a reasonably correct reading with regard to sound perception, they have by far too long a temporal integration to give a correct reading with regard to the damaging effect of noise on the ear (2).

The presently adopted standards and recommendations on tolerable noise levels in most western countries are a more or less significant modification of ISO recommendation 1999 (6), by virtue of which the upper limit of tolerable noise is 85 or 90 dB(A). The recommendation assumes the validity of the equal energy principle, a matter that is presently being questioned by more and more researchers.

Acceptable hearing loss

The recommendations available give the noise levels that are assumed to bring about a hearing loss in terms of elevation of threshold over a certain point in only

a few people. The definition of this acceptable hearing loss originates from the *Guidelines for Conservation of Hearing* of the American Academy of Ophthalmology and Otolaryngology (4), wherein it is assumed that the ability to understand normal everyday speech in quiet at a distance of about 1.5 m is not noticeably deteriorated as long as hearing loss does not exceed an average of 25 dB (re. ISO audiometric zero) at 500, 1,000 and 2,000 Hz. This extent of hearing loss was originally set in the United States as the definition of the size of a handicap justifying workmen's compensation for loss in earning power. It is somewhat of a mystery how this degree of hearing loss can be designated as acceptable nowadays. It should be emphasized that the hearing loss being discussed is that induced by noise. The total acceptable hearing loss is thus that induced by noise plus whatever is assumed to be the result of other causes, such as presbycusis.

Medical prophylaxis

Noise-induced hearing loss usually begins in the high frequency range of hearing that is of little importance for speech perception. Such a hearing loss may remain unnoticed by the person himself until it has spread to the frequency range of importance for speech perception. It is therefore crucial that the hearing of industrial workers exposed to noise be checked frequently with careful audiometry. Noise susceptible people may then be identified before their hearing loss has reached a level that is a social handicap.

The aim of hearing examinations of people exposed to heavy noise in industry has previously been focused totally upon determining the permanent damage that the ear has suffered. Great care has been exerted to arrange the measurements of hearing (audiometric tests) to keep the results from being influenced by the temporary threshold shift that also evolves from noise exposure. More than 60 h of rest from noise during the weekend has been held insufficient to exclude the effect of this TTS.

The adverse effects which a person suffers from hearing loss are the same

regardless of whether they are permanent or temporary. To the person involved, it is of little interest that this TTS disappears after he has been away from work for 60 h. It is only on vacations or long holidays that such a person has the benefit of hearing without the interference of the TTS. In fact, any TTS remaining after 12 h affects most of a person's leisure time.

Instead of disputing how many hours should elapse after the last noise exposure before an audiometric test can be made, the degree of noise-induced hearing loss (TTS + PTS) to be accepted at a given time after the termination of noise exposure should be agreed upon and incorporated into noise standards. In other words, one should decide for what purpose hearing is to be conserved. If the intention is to preserve hearing for the entire leisure time, including evenings, the hearing loss should be based on the hearing threshold as it is immediately after the end of the work hours. If the intent is less ambitious and met by preserving hearing for the weekends, the hearing loss should then be measured some time after the termination of work, e.g., after 12 h. The present routines whereby audiograms are taken 48 h or longer after the end of noise exposure imply that the goal of hearing conservation programs is solely to preserve hearing for vacations and retirement.

Even though one might accept that a modern hearing conservation program is satisfactory if it succeeds in preserving enough hearing to render perception of everyday speech under quiet circumstances, it is doubtful whether a person with an average hearing loss of 25 dB at 500, 1,000 and 2,000 Hz can do so (7). It thus seems obvious that even a much smaller hearing loss than that accepted in the present recommendation results in a significant reduction in the quality of life.

Future noise standards

Revision of the noise standards and recommendations can by all rights be considered an immediate need. Hearing impairment which prevents a person from

experiencing health according to the present definition of the World Health Organization² should not be regarded as acceptable.

A reduction of the accepted noise level in industries to 75 dB(A) should improve the situation considerably. Such levels have been suggested before (7), but rejected because of the expected economic implications. In addition, earlier studies on noise-induced hearing loss were interpreted as not fully supporting such low values. The foregoing review of present knowledge on the effect of noise on hearing, plus the awareness of the drawbacks of personal protective devices, should serve to disprove the claim that such low values are not defensible from the medical standpoint. As far as the economic issue is concerned, the expected high costs of implementing such a standard have been put forth as a basis for rejecting it, but practically no information about the actual costs of noise reduction is available. Recently, the results of a project in the paper industry in Sweden have shown that, if noise reduction is implemented at the construction stage of factories and machinery, the costs are much lower than previously estimated. In the construction of a new, fast paper machine, a noise reduction from more than 110 dB in old machinery at many work places to about 85 dB(A) and, in many places, not more than about 82 dB(A) was achieved (13). The total cost was given to be 1.1 % of the total cost of the plant (0.45 % on machinery alone, 4.4 % on ventilation systems and 3.0 % on buildings). Undeniably, there are several industries in which the costs for noise reduction are greater than in the example given, but it is equally obvious that there are many branches of industry in which the costs are less. They may even be negligible in some.

It may not be necessary, and not even desirable, to choose a noise standard that can be implemented in all possible cases,

² "Health is a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity. The enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being without distinction of race, religion, political belief, economic or social condition." (12).

Fig. 3. Simplified scheme to indicate the effect of noise on different bodily functions via the sympathetic nervous system (black). The motor system is indicated (gray). [from Borg and Møller (1)]

nor is such the case with the present standards. No doubt, some situations exist in which it is impossible to achieve such a reduction in noise level with present technology; in other situations, the economic implications may indeed be greater than can be accepted. Such cases should be given the possibility of being exempted from the standard.

It therefore seems reasonable to suggest that the present standards be modified in such a way as to reduce the noise level of new equipment substantially. Present knowledge indicates that an upper limit

of 75 dB(A) (for continuous noise without spectral peaks, 8 h per day, 40 h per week) would considerably reduce the risk for noise-induced hearing loss, as well as other adverse affects of noise (such as difficulty in verbal communication, etc.), to an acceptable value.

EFFECT OF NOISE ON OTHER BODILY FUNCTIONS

The effect of noise on other bodily functions is much less known than is its effect

on hearing. The various bodily reactions to loud sounds are mediated by the vegetative (autonomous) nervous system, which receives its auditory input from the ascending auditory pathways at a much lower level than the auditory cortex. These reactions therefore are usually not under conscious control and are probably independent of our interpretation of the sound.

Above a certain level, noise may activate the sympathetic nervous system and therefore give rise to, among other things, an increased secretion of hormones from the adrenal medulla (adrenalin and noradrenalin) and a change in blood circulation (fig. 3).

The effect on circulation is measurable in short-time exposure in the intensity range of 60–90 dB SPL.³ Thus the systolic blood pressure of rats has been shown to increase during noise exposure. (After 10 weeks of 4 h of exposure daily to 100 dB, it rose to 150 mm Hg from an initial value of 120 mm Hg.) A combination of noise and other stress factors resulted in a further increase in blood pressure (9).

Although it emerges from a few studies that the effect of noise on these autonomic reactions increases as noise intensity increases, it is at present practically unknown how these reactions are influenced by other characteristics of noise and how they are related to the time pattern of exposure. The combined effect of noise and other stressors is practically unknown, as are the effects of long-term exposure.

Sounds of somewhat higher intensity (80–90 dB SPL) have been shown to increase the secretion of many of the hypothyseal hormones, for example ACTH, which controls the secretion of cortisol from the adrenal cortex. Cortisol is in turn important for the action of adrenalin and noradrenalin. It also affects a great many other functions such as blood glucose levels, the immunodefensive system, etc. The secretion of ADH (antidiuretic hormone) and oxytocin also becomes heightened upon exposure to sounds of 80–90 dB SPL. In addition, the secretion of several of the hormones involved in reproduction is affected by noise. The

size of the ovaries has been shown to change in rats exposed to loud noise during pregnancy (11). Since the hormone systems are coupled to each other in a highly intricate way, the effect of noise on them is difficult to survey. These bodily reactions remain to be studied more than superficially. They are assumed to be part of the flight-fight reaction initiated by sound and very important for survival throughout evolution.

A few reports indicate that long-time exposure to loud noise may affect general health, but these reports are yet too few and the results too unreliable to permit definite conclusions. The fact that noise exposure often exists in combination with other pollutants and stressors in modern industry makes it difficult to isolate its effect. This circumstance does not in any way render the problem less crucial. Published results are indeed sufficiently alarming to call for intensified research in these fields. With present knowledge it is not possible to estimate the health effects of the hormonal reactions to noise nor to recommend tolerable noise levels with regard to these effects.

Subjective annoyance evoked by exposure to noise is well documented but difficult to evaluate objectively. It has to do with a person's attitude toward the information carried in the sound.

Lastly, another important question is how noise interferes with a person's work in as much as it renders speech communication difficult or impossible.

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³ SPL: sound pressure level, re 20 μ Pa.

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