Malchaire, J; 1987; Evaluation of the individual risk of hearing loss: prospective study; International Archives of Occupational and Environmental Health; Volume 59, Issue 4; Pages 355-362

Abstract

A method is proposed to predict the individual risk of hearing impairment according to age, duration of exposure to noise and daily noise equivalent level. This method is based on the model described in the ISO proposed standard 1999 "Determination of occupational noise exposure and estimation of noise-induced hearing impairment". The individual sensitivity to noise is defined as the percentage of the general population that would develop hearing losses lower than another person under the same conditions. This method is proposed in an attempt to upgrade industrial audiometric programs from hearing impairment detection programs to real hearing conservation programs. [Journal Article; In English; Germany, West]

Citation Subset Indicators: Index Medicus

MeSH Terms: Adult; Aging - physiology (PH); Automobiles; Hearing Loss, Noise-Induced - * diagnosis (DI); Hearing Tests; Human; Industry; Male; Middle Age; Occupational Diseases - * diagnosis (DI); Probability; Prospective Studies; Risk; Time Factors
Evaluation of the individual risk of hearing loss: prospective study

J. Malchaire

Work Physiology and Industrial Hygiene Unit, Catholic University of Louvain, BP 3038, B-1200 Brussels, Belgium

Summary. A method is proposed to predict the individual risk of hearing impairment according to age, duration of exposure to noise and daily noise equivalent level. This method is based on the model described in the ISO proposed standard 1999 “Determination of occupational noise exposure and estimation of noise-induced hearing impairment”. The individual sensitivity to noise is defined as the percentage of the general population that would develop hearing losses lower than another person under the same conditions. This method is proposed in an attempt to upgrade industrial audiometric programs from hearing impairment detection programs to real hearing conservation programs.

Key words: Acoustics – Audiometry – Hearing loss

Introduction

In several countries, yearly auditory examinations are mandatory for workers exposed to daily noise equivalent levels higher than 90 or 85 dB(A). These audiometric programs are often called “hearing conservation” programs. According to this title, these audiometric examinations should be aimed at the prevention of hearing impairments. One may question the reality of this, when, as it is usually done in industries, audiometric examinations are taken at any time during the day, regardless of the existence of temporary threshold shifts, and no attention is paid to hearing threshold unless they are higher than 30 to 40 dB.

In some cases, these programs might better be called “hearing handicap detection” programs, as their practical usefulness seems only to be the detection of deaf people and their declaration for compensation purposes.

The aim of auditory conservation programs is to observe the evolution of the hearing threshold levels (HTL) of each worker in order to predict his risk of hearing impairment in the future and possibly to avoid the development of this impairment by reassignment to a non-noisy job.

For this purpose, the program must include three sub-programs:

1. the somnometric program aimed at the evaluation of individual exposure to noise (the Dose);
2. the audiometric program where HTLs are evaluated (the Response); and
3. the interpretation program where the individual Dose-Response relationship is analyzed and the risk of hearing impairment is determined.

The methods of determination of the daily noise equivalent level are well known [1, 3, 5]. In many cases, however, such as in maintenance workers, the exposure to noise varies so greatly that it is simply impossible to quantify it. In these cases, “hearing conservation” programs cannot be developed and indeed should be replaced by a hearing handicap detection program.

The audiometric program is also completely different in the two cases. The main difference is that hearing conservation programs are devoted to prevention and thus concern mostly young or recently exposed people who might become impaired, while the latter programs try to detect those who are impaired and thus they are mainly concerned with older people or people exposed for a number of years. It is also clear that sound-proof rooms are required in the first case, while audiometry may be performed in almost any environment in the second.

It is also true that temporary threshold shifts (TTS) are more of a problem in the first case and that the evaluation of the exposure to noise prior to the examination is not needed as much in the second type of program.

The third subprogram is peculiar to hearing conservation programs. It consists of comparing the worker HTLs to the HTL distribution expected in the same exposure conditions in order to possibly detect how susceptible to noise this worker is.

This paper describes how this distribution can be computed, based on the ISO draft international proposal 1999 [4] and how this interpretation can be conducted. It describes also the first results of a prospective study aimed at testing the applicability of this technique in industry.

The model and its use in predicting the risk of hearing impairment

ISO/DIS 1999 makes it possible to draw the distribution of HTL as a function of age (A in years), duration of exposure (T in years) and daily noise equivalent level $[\text{Leq in dB(A)}]$.

Due to the complexity of the mathematical model, calculations need to be made by a computer. They can be simplified and illustrated using diagrams prepared by the author. This procedure is illustrated for the average HTL at 1000, 2000 and 3000 Hz as this mean threshold has been adopted in some countries as the criterion to appreciate whether or not the ability of understanding conversational speech in low levels of background noise can be affected. Other interpretation schemes may also be adopted.

The proposed simplification of the model (for male subjects) can be written:

\[
\text{HTL} = F_1 \cdot F_2 + F_3
\]
where HTL is the hearing level (mean value at 1, 2, and 3 kHz) that would be exceeded by (100−p)% of the population aged A and exposed for T years to an A-weighted continuous level Leq. F₁ is a function of the duration of exposure (T) and the percentile of the population p%. F₂ is a function of the Leq level, and F₃ is a function of age A and percentile p%.

The mathematical expressions of F₁, F₂, and F₃ are derived for the average hearing level at 1–2–3 kHz from the data presented in the ISO document.

\[ F_1 = (-1.1 + 4.65 \log T) + Z (a + b \log T), \]

where Z is the value in the normal (Gaussian) distribution for which the cumulative probability (from minus infinity to Z) is equal to the percentile p%; a is equal to 2.17 for p less than 50% and 1.58 for p above 50%, and b is equal to 0.51 and 0.84, respectively. This factor may be estimated using Fig. 1.

\[ F_2 = (\text{Leq} - 80.4)^2 / 100 \]

F₃ gives the distribution of the age-related hearing threshold levels. The ISO document presents two data bases for the calculation of this level: data base I applies for otologically normal persons. Data base II was chosen as it applies for an unscreened occupationally non noise-exposed population.

\[ F_3 = 0.00713 (A - 18)^2 + 2.97 + Z (c (A - 18)^2 + d), \]

where c is equal to 0.0029 for p less than 50% and 0.0070 above 50% and d equals 5.1 and 9.0, respectively. This factor may be estimated using Fig. 2.

Figure 3 (curve 1) shows an example of the cumulative distribution of HTL expected in a population aged 30 years and exposed to 95 dB(A) for ten years. Curve II shows the distribution for A = 60 years, T = 40 years and Leq = 95 dB (A).

According to curve 1, a mean HTL of 20 dB or less is expected for 70% of a population in these exposure and age conditions. A subject belonging to this population and having 20 dB HTL thus appears to have developed a higher than normal HTL and can be said to have a "sensitivity" of 70%. If this were true, one could expect that, if his conditions of exposure remained the same for the rest of his professional life, he would develop an average HTL of 42 dB at age 60.
Prospective study

This study includes 96 male workers of a car assembly plant. Rejected from the study were individuals who were exposed to unknown but a-priori significant noise levels in other factories before working in this plant. Subjects with hearing level changes clearly due to other causes than exposure to noise were also excluded. However, data base II was used, as the sample was not “highly screened” as defined in the ISO document [4].

The Leq levels were carefully recorded every year using calibrated B & K 4431 dosimeters and modifications were taken into account in the prediction model.

The HTLs were recorded each year using a calibrated audiometer. The audiometer examinations were performed in a sound-proof room 16 h after the last exposure to noise for workers exposed to 95 dB(A) or less and a period of 3 days for those exposed to Leq above 95 dB(A).

Sixty subjects were exposed for less than 10 years, while three were exposed for more than 20 years. The exposure duration was in most cases equal to the age minus 20. 30 subjects were exposed to a Leq level between 85 and 90 dB(A), and 33 to more than 95 dB(A).

Figure 4 shows the sample cumulative distributions of the HTL observed during the last three years and of the HTL predicted at age 60 for each subject. HTL changes from one year to another were rather small (2 dB in average), except as expected, for those exposed to the higher Leq levels. While, presently, one worker exceeds the level of 35 dB and no one exceeds the level of 50 dB, it can be expected that, at age 60, with the exposure remaining the same, five and one persons will present HTL above these two levels respectively.

Figure 5 shows the sample cumulative distributions of sensitivities for the three years of the study. Since HTL changes were small, the successive estimations of sensitivities give concordant results. These distributions, however, do not appear to agree with the model. Indeed, the sensitivity distribution should be normal (Gaussian) with a mean of 50%. In this study, the distribution is clearly positively skewed (mean value 35.3, SD = 16.2, coefficient of skewness = 2.1). This indicates that sensitivities have been systematically underestimated.

Discussion

Previous attempts to determine individual sensitivities to noise have failed [6, 7, 8, 9]. A method has been described, based on the draft standard ISO 1999. In this context, the “sensitivity” to hearing loss of a person has been defined as the percentage of people whose HTL would be lower than those of the person, in a population of the same age and exposed for the same length of time to the same noise conditions.

This interpretation postulates that the sensitivity, as defined, does not vary during the life of the person. At present, this postulate seems to be acceptable. It must be emphasized that it does not imply that the rate of increase of HTLs is independent of time: indeed the prediction model assumes that these levels increase as a function of the logarithm of exposure duration and of the square of age.

This method might appear in contradiction with the statement made in the ISO document that the model does not apply “for a single individual since it is not possible to determine precisely which changes in HTL are caused by noise and which are caused by other factors”. Although the reasons advocated are true, this does not preclude the use of the model to compare individual data to the normality, taking into consideration the characteristics of the person and attempting to foresee his HTL in the future.
It is obvious that the validity of the estimated sensitivity and of the long-term predicted hearing risk depends upon the accuracy of the input parameters, i.e. exposure duration, exposure conditions and hearing levels. For this reason, the interpretation is very strictly conditioned by rigorous sonometric and audiometric programs.

The effect of hearing protectors has not been taken into consideration. This is actually impossible to do as it depends not only on the attenuation of the protectors but also mainly on the regularity of their use. These cannot be measured, as the attenuation in real situations is almost uncorrelated to the theoretical attenuation [2]. This does not make the sonometric program or the interpretation program meaningless, but simply leads to the underestimation of the apparent sensitivity. This is the explanation of the bias of the sensitivity distribution that is observed in the ongoing prospective study. Indeed, other assumptions or errors would lead to overestimations.

It was assumed that the workers were exposed from the beginning of their professional life to the Leq level measured three years ago. It is likely that, as recent technological improvements were brought to the working environment, the Leq levels were higher in the past. Therefore hearing impairments should be higher than expected, based on present Leq levels and sensitivities should be overestimated. The same holds true for audiometric errors that usually overestimate the recorded hearing levels and thus also lead to overestimation of the apparent sensitivity. The same applies to errors such as aggravated hearing impairments due to temporary threshold shifts.

In any case, the estimation and the prediction will not be reliable for reallocation of the person to a non-noisy job, until applications of the model, repeated year after year, have confirmed the results. As the present study was undertaken only three years ago, it appears too early to draw conclusions about the validity of the approach.

As mentioned already, in many industrial situations it might be quite impossible to assess the degree of noise exposure. When this is the case, it must be stressed that it is rather useless to conduct systematic (such as yearly) audiometric examinations of young workers and that time and effort could better be used in educating workers in the selection and use of the most adequate protection equipments.

Finally the point must be stressed that, at the present time, occupational physicians do not have any reference data to discriminate between people with the same HTLs and different exposure conditions. Even if the risk of hearing impairment predicted as described above proves to be inaccurate, the ISO model will at least have the merit of providing these reference data.

References

5. Johnson DL, Farina ER (1976) Continuous measurement of an individual's 24 h noise exposure for 31 consecutive days. Paper given at the Acoustical Society Meeting, 5-10 April

Received June 30, 1986 / Accepted January 5, 1987