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AN OPTIMAL METHOD OF ASSESSMENT THE INDIVIDUAL SUSCEPTIBILITY TO NOISE-INDUCED HEARING LOSS

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The aim of the investigation was to compare different methods of subject classification regarding susceptibility to noise induced hearing loss in group of 949 workers of power plant. In the first two methods, simple and accurate the classification was performed according international reference standard ISO 1999:1990. In the tree other methods the entire group of workers was divided into subgroups to obtain similar distribution of age, time of employment and level of noise exposure in the susceptible and resistant group. In the first two classifications the susceptible group was significantly younger then resistant group, had shorter time of employment and lower level of noise exposure. This findings are in line with the definition of increased vulnerability to noise inducted hearing loss. Additionally, an excellent separation between hearing thresholds (HTs) of the susceptible and the resistant group was achieved. All three other methods resulted in worse separation of HTs between susceptible and resistant group of subjects. Subjects pre-selection deteriorates the reliability of workers' dichotomization into noise-susceptible and noise resistant groups.

Keywords: ISO 1999:1990 standard, noise-induced hearing loss modelling, hearing thresholds.

1. Introduction

Individual susceptibility (or vulnerability) to noise along with the degree of hearing loss varies greatly among subjects [1]. It means that, after the same exposure to noise, some subjects develop substantial hearing loss, whereas others develop little or no hearing loss at all. The other definition of an increased vulnerability towards noise says that vulnerable individuals experience acoustic trauma below noise exposure levels classified as being dangerous to hearing.

Individual susceptibility to noise depends on the interaction of intrinsic and environmental factors [2]. At the moment, several environmental factors are known to cause raised susceptibility to occupational noise-induced hearing loss. They include noise impulsiveness [3], noise exposures beyond workplace (leisure noise, military noise) [2, 4, 5], co-exposures to noise and chemicals (asphyxiants, organic solvents, heavy metals) [2, 6], and to noise and vibration [2], drug ototoxicity (aminoglycosides, cisplatin), other exposures (smoking) [7]. Several individual (biological) factors have been studied in their role to aggravate NIHL [8]. An association has been found between NIHL and elevated blood pressure (risk factor), cholesterol level (risk factor), gender (women are less susceptible) and age (increasing effect of presbyacusis with age).

The aim of this study was to assess the reliability of different methods of retrospective subject classification regarding their susceptibility to NIHL and compared them to the ISO 1999:1990 [9] model of NIHL prediction.

2. Material

The study group comprised 949 male workers of an electric power plant station, exposed to noise at workplace, aged from 20 to 67 years (mean 41.7 ± 7.9). Time of exposure (tenure) differed from 1 year to 30 years (mean 17.0 ± 4.7). The inclusion criteria were as follows: at least 1 year of exposure to noise, no history of middle ear diseases, no history of causes of hearing impairment other than noise exposure, no air-bone gap in pure-tone audiometry, no more than 40 dB difference between hearing thresholds in the right and the left ear at 4 and 6 kHz. The hygienic (sanitary inspection) records and medical files were explored. The following data were taken into account during classification into susceptible and resistant groups: age, gender, noise exposure levels averaged over whole period of employment and last pure-tone audiometry results. Hearing thresholds were measured in a sound-proof room by local occupational medicine staff using an ascending-descending technique in 5-dB steps (ISO 8253-1) [10]. The averaged individual levels of noise exposure ranged from 68.3 dB(A) to 90.3 dB(A); mean $L_{\mathrm{EX,8h}} = 84.5 \pm 3.0$ dB(A).

3. Method

The International Organization for Standardization (ISO) published in 1990 the mathematical model permitting to predict permanent hearing threshold shift (PTS) after a given occupational noise exposure (ISO 1999:1990) [9]. The ISO model uses three parameters: age, gender and exposure to noise ($L_{\mathrm{A\,eq}}$ and years of exposure) in the evaluation of permanent threshold shift PTS. Using these parameters, the distribution of NIHL can be calculated. The model assumes that hearing threshold level (HTL) of occupationally noise-exposed population is a combination of hearing threshold level associated with age (HTLA) according to (ISO 7029) [11] and noise-induced permanent threshold shift (NIPTS). Fractiles Q of HTL distribution are calculated using the following empirical formula (ISO 1999:1990):

$$\mathrm{HTL}_Q = \mathrm{HTLA}_Q + \mathrm{NIPTS}_Q - (\mathrm{HTLA}_Q \cdot \mathrm{NIPTS}_Q)/120 \;\; [\mathrm{dB}]. \tag{1}$$

If the NIHL and HTLA are not correlated the HTL has distribution being a compounding of distribution HTLA and NIPTS.

$$\mathrm{HTL}_Q = \iint\limits_q \mathrm{HTL}(\mathrm{HTLA}, \mathrm{NIPTS}) \cdot \mathrm{d}\,\mathrm{HTLA} \cdot \mathrm{d}\,\mathrm{NIPTS} \quad [\mathrm{dB}]. \tag{2}$$

The ISO model, although not perfect one, is at present the most reliable method allowing for segregation of noise-susceptible and noise-resistant subjects, thereby making it possible to proceed with further genetic, or other research analysis.

For the purpose of this study, a so-called "standardized hearing threshold scale" was introduced that was based on the following assumption: the difference (Δ) between actual individual HTL (HTLm) and median HTL (HTL0.50) predicted for the individual by ISO1999 model.

$$\Delta = \mathrm{HTL}_m - \mathrm{HTL}_{0.50}\,.$$

This variable allows to compare the individuals' HTL within population of the same gender, age, and noise exposure. Because the widths of the predicted distribution change with changing exposure to noise and age, the widths of the distribution were applied to standardisation according to following formulas:

$$\begin{aligned}
\Delta_{\mathrm{stand}} &= 1.282(\mathrm{HTL}_m - \mathrm{HTL}_{0.50})/(\mathrm{HTL}_{0.10} - \mathrm{HTL}_{0.50}) \quad \text{for } \mathrm{HTL}_m \geq \mathrm{HTL}_{0.50}\,,\\
\Delta_{\mathrm{stand}} &= 1.282(\mathrm{HTL}_m - \mathrm{HTL}_{0.50})/(\mathrm{HTL}_{0.50} - \mathrm{HTL}_{0.90}) \quad \text{for } \mathrm{HTL}_m < \mathrm{HTL}_{0.50}\,.
\end{aligned}$$

This procedure is similar to the standardization in case of the normal distribution but the predicted HTL distribution consists of two halves of Gaussian distributions of different widths; thus different functions were applied to standardize HTLm of values above and below the expected $\mathrm{HTL}_{0.50}$. The constant 1.282 corresponds with 0.10 and 0.90 fractiles of the standardized Gaussian distribution, and it could be changed if one applies the fractiles other than 0.10 and 0.90 in the above equations.

The value of Δ is expressed in units equal to standard deviation of normal distribution (standard units). The highest positive values of HTL in standard units indicate the subjects who are the most susceptible to noise, while the lowest negative values of HTL in standard units indicate the subjects who are most resistant to noise.

In this way one can obtain a scale of hearing state combining information on hearing threshold level, noise exposure and age, whereby it is possible to make direct comparison between individuals of different age and exposure to noise.

Since the frequencies 4 and 6 kHz are the most sensitive for noise trauma and the left ear was shown to be more vulnerable than the right ear, the categorization was based on hearing thresholds (HT) in the left ear at 4 and 6 kHz. HT at 4 and 6 kHz were taken into account simultaneously and 10% of subjects with the poorest hearing thresholds were categorized as susceptible to NIHL, and 10% of subjects with the best hearing thresholds were categorized as resistant to noise. If one plots each case in Cartesian coordinate system (where axis X is Ht at 6 kHz and axis Y is Ht at 6 kHz) the scheme of the classifications my be illustrated by Fig. 1.

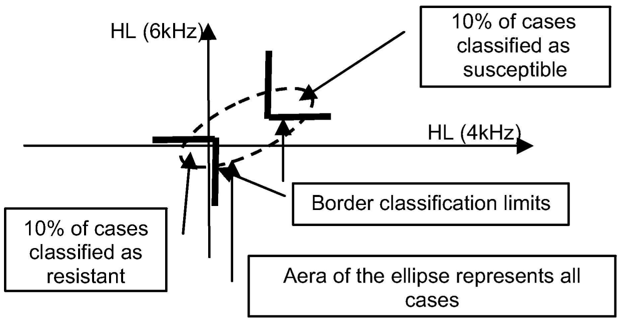


Fig. 1. Schematic diagram showing the method of selection of 10% susceptible to noise subjects and 10% resistant to noise subjects.

4. Classifications and results

In the classifications I and Ia based on ISO 1999:1990 model, absolute hearing threshold values were converted to so-called "relative standardized scale", i.e. they were shown as the differences between real hearing thresholds (measured on the last worker's audiometric exam). In the classification I HTLs were calculated according to Eq. (1) whereas in classification Ia HTLs were calculated using the Eq. (2). To classify cases into susceptible and resistant categories the procedure shown in the Fig. 1 (HLs express in "relative standardized scale") was applied.

Results of both classifications are shown in Table 1 and Figs. 2.1 and 2.2. There is a difference in ages of susceptible and resistant groups. More significantly younger subjects (below 40 years old) are in the susceptible group in the case of classification I while in the Ia classification there is no significant age difference between categories. There is a significant difference in tenure of both groups and there are more subjects with shorter length of employment in the susceptible group. Subjects of the resistant group were exposed to significantly higher noise exposure levels. In the case of both classifications, the Figs. 2.1d and 2.2d of hearing thresholds at 4 and 6 kHz ("relative standardized scale") show an excellent separation of values of both groups.

To minimize the effect of age, classification II was performed in ten age subgroups with the similar number of subjects (ranging from 53 to 139). In each subgroup, 10% of subjects with the poorest absolute hearing thresholds and 10% with the best absolute hearing thresholds were selected. Afterwards, to compare with the results of classification I, hearing threshold absolute values were converted to the relative standardized scale.

2.1. Selection I

2.2. Selection Ia

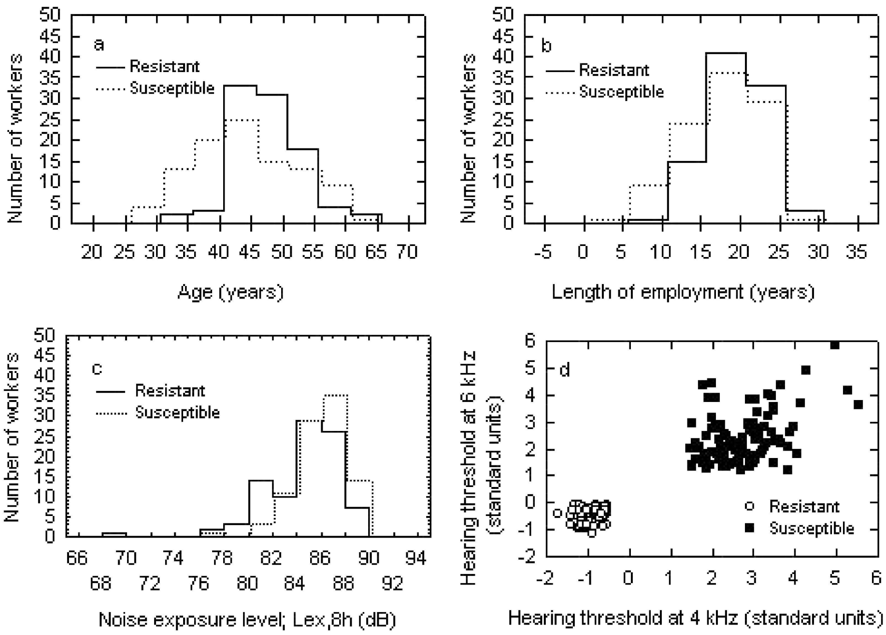


Fig. 2. Classification I and Ia – categorization performed over entire group of workers using "relative standardized scale" of the hearing threshold.

Table 1. Mean and median values of age, tenure, exposure noise level and hearing levels at 4 and 6 kHz in the NIHL-susceptible and NIHL-resistant subjects for I and Ia methods of subject classification.

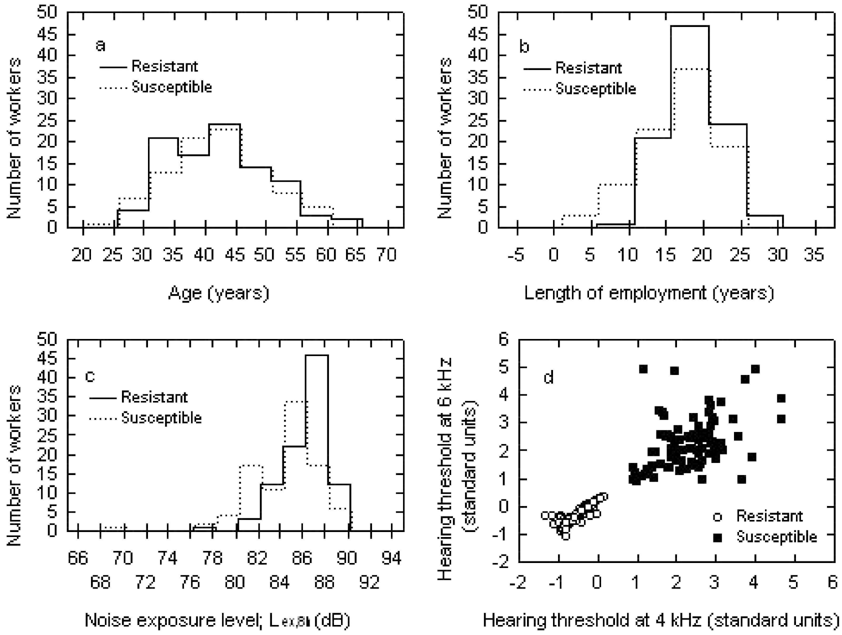
Classification I		Age [years]	Tenure [years]	Exposure L_{ex}[1)] [dBA]
Susceptible No of cases 94	mean	43.5	17.4	84.3
	median	43.0	18.0	84.7
	std. dev.	8.0	5.0	3.1
Resistant No of cases 93	mean	47.4	19.2	85.1
	median	47.0	20.0	85.8
	std. dev.	5.4	3.8	2.7
Difference[2)]	p-level	**$<$ 0.0001**	**0.0346**	**0.0261**
Classification Ia				
Susceptible No of cases 93	mean	43.0	17.2	84.5
	median	42	18.0	83.1
	std. dev.	7.9	4.9	3.16
Resistant No of cases 92	mean	47.7	19.3	86.1
	median	47.0	20.0	84.9
	std. dev.	5.7	3.7	2.16
Difference[2)]	p-level	0.1416	**0.0052**	**0.0183**

[1)] Noise exposure level normalized to 8-h working day averaged over total exposure time;
[2)] Mann-Whitney U Test.

To minimize the effect of all three variables: age, level of noise exposure and tenure in the classification III, the entire group of workers was divided into three age – subgroups (35 years or below, 36–50 years, and above 50 years), two level of exposure subgroups (85 dB-A or below, and 85–90 dB-A), and three tenure subgroups (10 years or below, 11–20 years, and above 20 years). The number of subgroups was 18 (3 age subgroups $\times 2$ noise subgroups $\times 3$ tenure group). The number of subjects in each subgroup ranged from 60 to 280. The following procedures were the same as in the classification II.

The classification II (in ten age subgroups), apparently no age and no tenure differences between susceptible group and resistant group were seen (Table 2), with the histograms of age distribution very similar in both groups (Figs. 3.1a and 3.1b). The exposure noise level was on average almost 2 dB higher in the resistant than in the susceptible group (Table 2, Fig. 3.1c). The scatterplot of hearing thresholds at 4 and 6 kHz shows that the segregation of HTLs was poorer as compared to the classification I and Ia. In several cases, less than 1 standard unit gap is seen between HTLs of both groups (Fig. 3.1d).

3.1. Classification II



3.2. Classification II

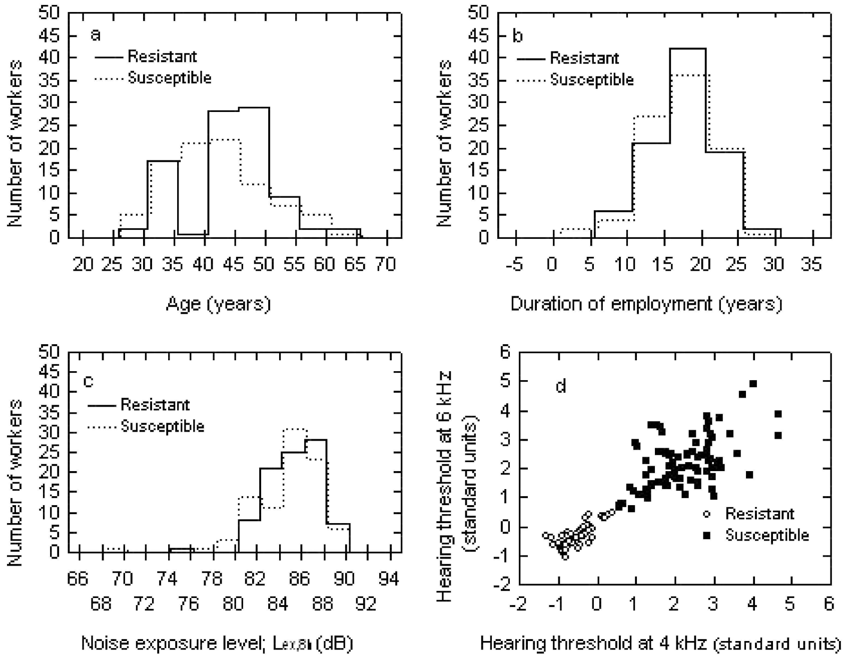


Fig. 3. Classification I and Ia – categorization performed subgroups of workers using absolute hearing thresholds. Selection II – ten age subgroups; Selection III – eighteen subgroups accounting for age, exposure noise level and tenure.

Table 2. Mean and median values of age, tenure, exposure noise level and hearing levels at 4 and 6 kHz in the NIHL-susceptible and NIHL-resistant subjects for all methods of subject classification.

Classification I		Age [years]	Tenure [years]	Exposure $L_{\mathrm{ex}}^{1)}$ [dBA]
Classification II				
Susceptible No of cases 92	mean	41.6	16.3	84.0
	median	41.5	18.0	84.4
	std. dev.	7.6	5.3	3.1
Resistant No of cases 96	mean	42.0	18.1	86.1
	median	41.0	17.0	86.8
	std. dev.	8.0	4.0	2.1
Difference[2)]	p-level	0.8396	0.0795	< 0.0001
Classification III				
Susceptible No of cases 90	mean	41.4	17.1	84.4
	median	41.0	18.0	85.0
	std. dev.	7.8	4.7	3.0
Resistant No of cases 90	mean	44.3	17.6	85.2
	median	45.0	18.0	85.1
	std. dev.	7.4	4.1	2.4
Difference[2)]	p-level	**0.0028**	0.6389	0.1210

[1)] Noise exposure level normalized to 8-h working day averaged over total exposure time;
[2)] Mann-Whitney U Test.

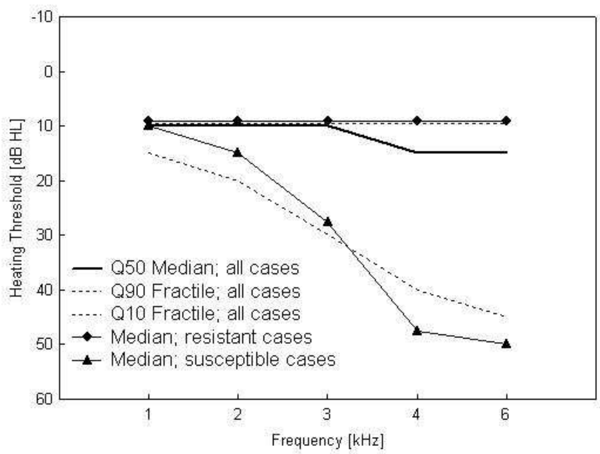


Fig. 4. Hearing thresholds of the entire examined group, resistant and susceptible groups categorized with method I.

In the case of the the classification III (with 18 subgroups with respect to age, tenure and level of exposure), there were no differences in tenure and exposure levels between groups; however, the difference in mean age was still present (Table 2 and Figs. 3.2a, b, c). The resistant group was on average over 3 years older than was the susceptible group (Table 2, Fig. 3.2a). The segregation of HTL values was poor in the classification III, with no gap between the susceptible and resistant subjects (Fig. 3.2d).

5. Conclusions

The hearing threshold expressed in the "relative standardized scale" based on the ISO 1999:1990 standard allows to compare hearing status of subjects of different age and noise exposure what may be convenient in the case of small number of cases in the examined groups (Fig. 4).

The selection of subjects from the entire examined group based on the ISO 1999:1990 standard seems to be the most reliable and convenient method of classification of noise-susceptible and noise-resistant cases.

Acknowledgments

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