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Self-Assessment of Hearing Status and Risk of Noise-Induced Hearing Loss in Workers in a Rolling Stock Plant

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Noise measurements and questionnaire inquiries were carried out for 124 workers of a rolling stock plant to develop a hearing conservation program. On the basis of that data, the risk of noise-induced hearing loss (NIHL) was evaluated. Additionally, the workers' hearing ability was assessed with the (modified) Amsterdam inventory for auditory disability and handicap, (m)AIADH. The workers had been exposed to noise at A-weighted daily noise exposure levels of 74–110 dB for 1–40 years. Almost one third of the workers complained of hearing impairment and the (m)AIADH results showed some hearing difficulties in over half of them. The estimated risk of hearing loss over 25 dB in the frequency range of 3–6 kHz was 41–50% when the standard method of predicting NIHL specified in Standard No. ISO 1999:1990 was used. This risk increased to 50–67% when noise impulsiveness, coexposure to organic solvents, elevated blood pressure and smoking were included in calculations.

self-assessment of hearing ability   occupational exposure to noise
risk factors for noise-induced hearing loss (NIHL)   evaluation of NIHL risk

1. INTRODUCTION

The European Union officially recognizes the importance of protecting workers from risks to their health in noisy environments as expressed in Directive 2003/10/EC [1]. This directive requires assessment of individual risk of noise-induced hearing loss (NIHL). It also states that risk arising from exposure to noise should be eliminated or reduced to a minimum.

Noise exposure can result either in acute acoustic trauma or NIHL. Acoustic trauma is a sensorineural hearing loss that can appear after a single exposure to a high-level noise impulse, while NIHL is a sensorineural hearing impairment that develops over years of exposure to noise at moderately high levels. It is predominantly noted in the high-frequency region with typical notch at 4–6 kHz. Individual susceptibility (or vulnerability) to noise, along with the degree of hearing loss, varies greatly among people, which means that after the same exposure to noise, some persons develop substantial hearing loss, whereas others develop little or none [2]. NIHL depends on the interaction between intrinsic and environmental factors [3]. Besides well-known environmental factors contributing to occupational NIHL, such as exposure to noise, there are other ones, too, e.g., impulsiveness of noise (impulsive noise is more harmful than steady-state noise at the same equivalent level) [4]; exposure paradigm (breaks in noise exposure allow recovery);

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noise exposure beyond the workplace (leisure noise, noise exposure during compulsory military service) [3, 5, 6]; occupational exposure to certain chemicals (organic solvents and heavy metals) [3, 7, 8], coexposure to noise and vibration [3]; ototoxic drugs (aminoglycosides) [9, 10] and heat [11]. Associations have also been observed between several individual factors and NIHL, including smoking [12, 13, 14], elevated blood pressure [15, 16], elevated cholesterol level [17], skin pigmentation [18], gender [19] and age [20]. In contrast to environmental factors, very little is known about the genetic basis of NIHL. However, recent studies have suggested a possible role of potassium recycling pathway genes in determining individual susceptibility to NIHL [21]. Cadherin 23 is another candidate gene for NIHL susceptibility; it is a component of interstereocilila links on cochlear hair cells [22].

Hearing loss is still one of the most common occupational diseases in Poland (with a rate of 2.5 per 100 000 paid employees in 2009) [23]. NIHL is frequently diagnosed in the machine-building industry, e.g., in rolling stock plants. In an effort to develop a hearing conservation program for the rolling stock plant, noise measurements and questionnaire inquiries were gathered from its workers. The main objectives of this study were

- to assess the frequency of self-reported hearing problems and the usage rate of hearing protective devices (HPDs) in workers in the rolling stock plant; and
- to evaluate the risk of NIHL and the necessity to implement a hearing conservation program in that plant.

2. MATERIAL AND METHODS

2.1. Study Group

The study involved 124 workers in rolling stock plants, mainly males (n = 118), aged 21–59 years, M (SD) 46.6 (9.1), directly employed in the manufacturing of railway goods wagons. They

TABLE 1. Characteristics of the Study Group

	Cases		Age (years)	Total Exposure (years)
			M ± *SD* 10th / 50th / 90th percentiles	
Job	Males	Females		
Acetylene burner operator	6	0	49.2 ± 7.5 36.0 / 50.0 / 59.0	29.7 ± 7.7 16.0 / 31.0 / 39.0
Crane operator	0	8	48.1 ± 4.2 40.0 / 49.5 / 52.0	28.1 ± 4.9 19.0 / 29.0 / 34.0
Cutter	3	0	54.0 ± 1.3 53.0 / 54.5 / 54.9	32.0 ± 2.2 30.6 / 31.0 / 33.8
Shear operator	4	0	53.8 ± 3.2 49.0 / 55.0 / 56.0	31.5 ± 11.1 15.0 / 36.5 / 38.0
Driller	3	0	49.0 ± 2.8 47.0 / 49.0 / 51.0	29.0 ± 2.8 27.0 / 29.0 / 31.0
Automation engineer	4	0	49.0 ± 7.8 41.0 / 48.0 / 59.0	26.8 ± 8.4 20.0 / 24.0 / 39.0
Fitter	33	0	47.1 ± 9.3 32.0 / 50.0 / 57.0	26.4 ± 9.5 15.0 / 29.0 / 37.0
Foreman	3	0	53.0 ± 7.8 44.0 / 57.0 / 58.0	36.7 ± 6.8 29.0 / 39.0 / 42.0
Forgeman	3	0	50.7 ± 5.9 44.0 / 53.0 / 55.0	30.7 ± 5.0 26.0 / 30.0 / 36.0
Machinist miller	5	0	49.6 ± 3.4 44.0 / 50.0 / 53.0	30.4 ± 3.5 25.0 / 32.0 / 34.0
Quality controller	9	0	45.9 ± 8.9 31.0 / 50.0 / 55.0	27.6 ± 10.6 10.0 / 32.0 / 40.0
Trimmer-flattener	5	0	38.8 ± 11.8 28.0 / 34.0 / 52.0	17.2 ± 14.5 3.0 / 13.0 / 34.0
Turning machine operator	4	0	48.3 ± 11.1 32.0 / 52.0 / 57.0	27.5 ± 11.6 11.0 / 30.5 / 38.0
Welder	34	0	44.2 ± 10.1 29.0 / 48.0 / 55.0	25.2 ± 10.3 11.0 / 26.5 / 38.0

were recruited by advertisement. There were no exclusion criteria. Therefore, every worker who agreed to complete the questionnaires was included in the study. Table 1 shows the characteristics of the study group. In general, the plant employed ~760 people, of whom 66% were blue-collar workers.

2.2. Questionnaire Inquiries

All subjects were interviewed according to a questionnaire developed to enable identification of occupational and nonoccupational risk factors for NIHL. The questionnaire included inquiries on

- work history, i.e., jobs performed and time of employment/exposure to noise at current and previous workplaces as well as coexposure to organic solvents (*yes*/*no*);
- use of HPDs at current and previous workplaces, i.e., type of HPDs, usage rate (*every day*, *occasionally*, *when necessary*, etc.), wearing time per shift;
- medical history, i.e., signs and symptoms of auditory and vestibular disorders, past middle ear diseases and surgery, hereditary disorders, elevated cholesterol levels, arterial hypertension, head trauma, etc. (*yes*/*no*);
- physical features (body weight, height, skin pigmentation);
- lifestyle, i.e., smoking (currently and in the past [*yes*/*no*], number of years and cigarettes per day), noisy hobbies, etc. (*yes*/*no*);
- exposure to noise and organic solvents during compulsory military service (*yes*/*no*); and
- self-assessment of hearing status, i.e., self-reported hearing impairment, difficulties with speech intelligibility in a noisy environment, difficulties with hearing trebles, tinnitus, etc. (*yes*/*no*).

Additionally, hearing ability was assessed with the (modified) Amsterdam Inventory for Auditory Disability and Handicap, (m)AIADH [24, 25, 26]. This inventory consists of 30 items and includes five basic disability factors dealing with a variety of everyday listening situations: (a) distinction of sounds (subscale I), (b) auditory localization (subscale II), (c) intelligibility in noise (subscale III), (d) intelligibility in quiet (subscale IV) and (e) detection of sounds (subscale V).

The respondents were asked to report how often they were able to hear effectively in a specific situation. The four options were *almost never*, *occasionally*, *frequently* and *almost always*. Responses to each question were coded on a 0–3 scale; the higher the score, the smaller the perceived hearing difficulties. The total score per subject was obtained by adding the scores for 28 questions (two questions were excluded as the authors of AIADH also excluded them after statistical analysis) [26]. The maximum total score for the questionnaire was 84. Additionally, the answers for each subscale were summed up (the maximum score for subscale I was 24; 15 for the other subscales).

2.3. Noise Measurements

To evaluate current exposure to noise, measurements were done at various workplaces in the rolling stock. Those measurements were done in typical working conditions and followed the requirements of Standards No. PN-N-01307:1994 [27] and ISO 9612:1997 [28]. In accordance with those standards, the following noise parameters were determined: (a) *A*-weighted equivalent continuous sound pressure level ($L_{\mathrm{Aeq,Te}}$) [27, 28], (b) maximum *A*-weighted sound pressure level with S (slow) time constant ($L_{\mathrm{A\,max}}$) [27] and (c) peak *C*-weighted sound pressure level ($L_{\mathrm{C\,peak}}$) [27, 28].

First of all, the sampling technique with integrating-averaging sound level meters (sound analyzers type 912, 912E and 958 from SVANTEK, Poland) was used. Alternatively, measurements extended over complete working days and personal sound exposure meters (personal logging noise dose meters type 4443 from Brüel & Kjær, Denmark) were used. The first measurement method corresponded to the task-based measurement strategy in Standard No. ISO 9612:2009, while the second one to the full-day measurement strategy [29]. However, there was only one full-day measurement per worker instead of the recommended minimum of three. Sound pressure levels were measured continuously over complete working days for mobile workers with a large number of tasks or a complex work pattern (e.g., quality controller or automation engineer).

2.4. Assessment of Risk of Hearing Impairment

The risk of hearing impairment or handicap due to noise exposure and age, and due to noise exposure alone, was calculated as a function of the assumed limit value for hearing threshold levels (HTLs; 25, 30, 35, 40 and 45 dB) separately at 1, 2, 3, 4 and 6 kHz, along with the average value at 1, 2 and 3 kHz.

The risk of hearing impairment due to age and noise is defined as a percentage of the population with HTLs (associated with age and noise) exceeding the assumed limit value. On the other hand, the risk due to noise alone is defined as the difference between percentage of noise-exposed population and non-noise-exposed population (but otherwise equivalent to noise-exposed population) with HTLs greater or equal to the assumed limit value [30].

Two methods of predicting NIHL were used in evaluating individual risk of hearing impairment, namely, the method described in Standard No. ISO 1999:1990 [30] and the modified method [31] based on that standard.

Standard No. ISO 1999:1990 specifies a method for determining noise-induced permanent threshold shift of adult populations following exposure to noise [30]. It assumes that HTL, associated with age and noise (HTLAN), is a combination of hearing threshold shift associated with age (HTLA) and noise-induced permanent threshold shift (NIPTS):

$$\mathrm{HTLAN} = \mathrm{HTLA} + \mathrm{NIPTS} - \frac{\mathrm{HTLA} \cdot \mathrm{NIPTS}}{120} \quad \text{(dB)}. \tag{1}$$

Equation 1 is used to determine a statistical distribution of HTLs, and thus to evaluate the risk of hearing loss in a noise-exposed population on the basis of four parameters: age, gender, noise exposure level and duration of noise exposure (in years).

In addition to exposure to noise, the modified ISO 1999:1990 method considers other NIHL risk factors, such as coexposure to organic solvents, smoking and elevated blood pressure, along with the impulsive character of noise and the use of HPDs [31]. Equation 2 includes Equation 1 with penalties for the aforesaid risk factors:

$$\mathrm{HTLAN}_{\mathrm{rf}} = \mathrm{HTLA} + \mathrm{NIPTS}_{\mathrm{rf}} - \frac{\mathrm{HTLA} \cdot \mathrm{NIPTS}_{\mathrm{rf}}}{120} + \mathrm{CF}_{\mathrm{os}} + \mathrm{CF}_{\mathrm{s}} + \mathrm{CF}_{\mathrm{ebp}} \quad \text{(dB)}, \tag{2}$$

where $\mathrm{NIPTS}_{\mathrm{rf}}$—permanent threshold shift related to noise exposure level corrected for the use of HPDs and/or the impulsive character of noise (decibels); $\mathrm{CF}_{\mathrm{os}}$, $\mathrm{CF}_{\mathrm{ebp}}$, CF_{s}—penalties for co-exposure to organic solvents, elevated blood pressure and smoking, respectively (decibels).

Equation 3 expresses those penalties as a function of the noise immission level (L_{im}) and fractile (Q):

$$\begin{aligned} \mathrm{CF}_{\mathrm{rf}}(L_{\mathrm{im}};\mathrm{Q}) &= \mathrm{A} + \mathrm{B} \cdot L_{\mathrm{im}} + \mathrm{C} \cdot (100 - 100 \cdot Q) \\ &+ \mathrm{D} \cdot L_{\mathrm{im}}^2 + \mathrm{E} \cdot L_{\mathrm{im}} \cdot (100 - 100 \cdot Q) \\ &+ \mathrm{F} \cdot (100 - 100 \cdot Q)^2 \quad \text{(dB)}, \end{aligned} \tag{3}$$

where A, B, C, D, E, F—coefficients of correction function for additional risk factors (see Table 2); L_{im}—total immission level (see Equation 5) (decibels); Q—fractile.

The noise immission level "is a measure of the cumulative noise energy to which an individual is exposed over time; equal to the average noise level to which the person has been exposed, in decibels, plus 10 times the logarithm of the number of years for which the individual is exposed" [32].

The modified method for NIHL risk assessment was established on the basis of data on exposure to noise or to noise and organic solvents and the health status of workers in 24 enterprises (including power plants, coal mines, lacquer factories, ship and yacht yards, plastic factories and processing industry). The study group comprised 3741 male workers, aged 39 ± 8 years, exposed to noise at 86 ± 5 dB for 16 ± 7 years. For each subject, data on audiometric HTLs, blood pressure and exposure were collected from the records of local occupational healthcare and mandatory periodic measurements made by the employers. Additionally, the workers were interviewed with a questionnaire that included detailed inquiries on work history, present and previous

TABLE 2. Correction Function Coefficients A, B, C, D, E and F (see Equation 3) for Additional NIHL Risk Factors [31]

	Correction Coefficient					
Risk Factor	**A (dB)**	**B**	**C (dB)**	**D (1/dB)**	**E**	**F (dB)**
	at 2 kHz for $L_{im} \in$ (90 dB; 105 dB) and $Q \in$ (0.50; 0.10)					
Exposure to organic solvents	553.67	–10.360	–1.663	0.0480	0.0165	0.0015
Smoking	454.11	–8.901	–0.815	0.0453	0.0031	0.0043
Elevated blood pressure	–86.36	1.923	0.201	–0.0091	–0.0066	0.0038
	at 3 kHz for $L_{im} \in$ (90 dB; 105 dB) and $Q \in$ (0.60; 0.10)					
Exposure to organic solvents	1182.38	–24.170	–1.545	0.1241	0.0118	0.0040
Smoking	920.06	–18.838	–0.978	0.0974	0.0055	0.0047
Elevated blood pressure	173.27	–3.432	–0.106	0.0180	–0.0034	0.0046
	at 4 kHz for $L_{im} \in$ (90 dB; 105 dB), $Q \in$ (0.70; 0.10)					
Exposure to organic solvents	753.77	–15.134	–1.000	0.0762	0.0105	0.0004
Smoking	1081.97	–22.407	–0.700	0.1160	0.0075	0.0004
Elevated blood pressure	35.28	–0.300	–0.289	–0.0002	0.0024	0.0012
	at 6 kHz for $L_{im} \in$ (90 dB; 105 dB), $Q \in$ (0.60; 0.10)					
Exposure to organic solvents	384.00	–6.453	–2.136	0.0268	0.0202	0.0018
Smoking	701.43	–14.516	–0.417	0.0756	0.0030	0.0011
Elevated blood pressure	–74.79	1.540	0.383	–0.0073	–0.0055	0.0014

Notes. NIHL—noise-induced hearing loss, L_{im}—level of noise immission, Q—fractile.

employment exposure to physical and chemical agents, medical history, physical features, lifestyle, military service and exposure to ototoxic factors outside the working environment. To examine the influence of co-exposure to organic solvents, smoking and elevated blood pressure on hearing status of noise-exposed workers, the study group was divided into subgroups with respect to NIHL risk factors (i.e., noise exposure only, noise and organic solvents, noise and low or elevated blood pressure, noise and smoking). For each subgroup, the distribution of actual HTLs was compared with theoretical predictions according to Standard No. ISO 1999:1990 [30]. The differences between measured and predicted HTL distributions were used to establish, with the least square method, penalties for additional NIHL risk factors (CF_{os}, CF_{ebp}, CF_s) [31].

In this study, individual work-life exposure to noise, necessary in assessing NIHL risk assessment, was evaluated on the basis of the subjects' work histories and current noise exposure data in different working conditions (jobs). If necessary, to obtain information on previous noise exposure, records of obligatory periodic measurements made over the past 5 years were explored. Missing data were substituted with the best available information on the possible exposure parameters corresponding to the job. Alternatively, the noise level was assumed to be 70 dB if workers did not report exposure to loud noise at previous workplaces or 85 dB if they did.

The work-life exposure to noise was based on noise exposure level normalized to a nominal 8-h working day averaged over the total time of employment:

$$\overline{L_{EX,8h}} = 10\ \lg\left(\sum_{i=1}^{N} T_i \cdot 10^{0.1 L_{EX,8h_i}} / \sum_{i=1}^{N} T_i\right) \quad (\text{dB}), \quad (4)$$

where $L_{EX,\,8h_i}$—equivalent continuous *A*-weighted sound pressure level normalized to a nominal 8-h working day in the time interval/workstation/job *i* (decibels), T_i—duration of time interval *i* (years), *N*—total number of various time intervals/workstation/jobs.

Equation 5 determined the noise immission level:

$$L_{im} = \overline{L_{EX,8h}} + 10\ \lg\left(\sum_{i=1}^{N} T_i\right) \quad (\text{dB}). \quad (5)$$

If necessary, the calculated noise exposure levels were corrected for the use of HPDs and the impulsive character of noise. To give extra weight to impulsive noise, a penalty of 5 dB was added to noise levels in accordance with Standards No. ISO 1999:1990 [30] and ISO 9612:1997 [28]. Equation 6 considered the protection efficiency of HPDs:

$$(\overline{L_{\text{EX,8h}}})_{\text{HP}} = 10\log\left(\frac{R\cdot T_{\text{h}}}{T}\cdot 10^{0.1\cdot(\overline{L_{\text{EX,8h}}}-\text{PNR})} + \frac{T-R\cdot T_{\text{h}}}{T}\cdot 10^{0.1\cdot\overline{L_{\text{EX,8h}}}}\right) \text{ (dB)}, \qquad (6)$$

where $(\overline{L_{\text{EX,8h}}})_{\text{HP}}$—noise exposure level corrected for to the use of HPDs (decibels), $(\overline{L_{\text{EX,8h}}})$—noise exposure level normalized to a nominal 8-hr working day averaged over the total time of employment (decibels), PNR—predicted noise reduction (decibels), R—rate of using HPDs, T_{h}—time subject used HPDs (years), T—total time of employment (years).

Since data on actual protection efficiency of ear plugs or earmuffs used by the subjects were not accessible, a mean value of predicted noise reduction of HPDs, based on literature data, was assumed to be 15 dB [17]. The usage rate of HPDs of 0.5 (4 h per an 8-h shift) or higher was used in the calculations.

3. RESULTS

3.1. Questionnaire Inquires

The subjects were employed in the current workplace (in the rolling stock plant) for 1–40 years, *M* (*SD*) 24.4 ± 1.1, *Mdn* 28. Over three quarters
1 of them had never worked elsewhere.

Most subjects (81.5%) were conscious of noise at the current workplace; 78.6% of them said it was too loud. About 40.0% of workers reported exposure to excessive noise in the previous workplace. Most respondents (89.5%) declared they used HPDs at present, mainly formable earplugs made of expandable foam or premolded earplugs made from flexible plastics (83.9%). Only 3.6% of the subjects wore earmuffs. The same percentage of the subjects used custom-made HPDs. Nearly half of the subjects reported using HPDs every day for over three quarters of the work shift, 71.8% reported using them for at least half of the work shift. whereas 55.8% of workers exposed to noise reported using HPDs in the past. It is worth noting that the questionnaire did not inquire if workers had been instructed how to use earplugs or earmuffs or if they had been wearing them correctly. There were no questions on attenuation efficiency, either.

TABLE 3. Workers' Self-Assessment of Hearing Ability in (m)AIAHD Scores

	Total		Subscale I		Subscale II	
Subjects	***M (SD)***	***Mdn***	***M (SD)***	***Mdn***	***M (SD)***	***Mdn***
All	67.5 (12.3)	67.0	19.7 (3.5)	19.5	12.2 (2.3)	11.0
aged < 50 years	70.4 (11.9)*	73.5	20.4 (3.4)	21.0	12.7 (2.2)*	13.5
aged ≥ 50 years	64.8 (12.2)*	59.5	19.0 (3.5)	17.5	11.7 (2.3)*	10.5
exposed to L_{im} < 104 dB	68.4 (12.8)	71.0	19.8 (3.5)	20.5	12.3 (2.5)	13.0
exposed to L_{im} ≥ 104 dB	66.9 (12.0)	64.0	19.6 (3.5)	19.0	12.0 (2.2)	11.0

	Subscale III		Subscale IV		Subscale V	
Subjects	***M (SD)***	***Mdn***	***M (SD)***	***Mdn***	***M (SD)***	***Mdn***
All	11.2 (2.7)	10.0	12.0 (2.4)	11.0	12.4 (2.3)	13.0
aged < 50 years	12.0 (2.3)*	12.0	12.5 (2.4)*	13.0	12.8 (2.2)	13.5
aged ≥ 50 years	10.5 (2.8)*	10.0	11.5 (2.3)*	10.0	12.1 (2.4)	12.0
exposed to L_{im} < 104 dB	11.3 (2.9)	10.0	12.3 (2.5)	12.0	12.6 (2.4)	13.0
exposed to L_{im} ≥ 104 dB	11.2 (2.4)	10.0	11.7 (2.3)	11.0	12.4 (2.3)	13.0

Notes. *—significant differences between subgroups (Mann–Whitney *U* test, $p < .05$); (m)AIADH—(modified) Amsterdam Inventory for Auditory Disability and Handicap, subscale I—distinction of sounds, subscale II—auditory localization, subscale III—intelligibility in noise, subscale IV—intelligibility in quiet, subscale V—detection of sounds; L_{im}—level of noise immission.

In addition to noise exposure, a small percentage of the study group was also exposed to organic solvents at current (12.1%) or previous (10.5%) workplaces. A similar percentage of the subjects (12.1%) suffered from elevated blood pressure. Nearly half of the subjects (48.4%) declared smoking at present, while 29.8% declared smoking in the past.

Almost one third of the workers (28.2%) noticed hearing impairment, 23.4% reported diffi-

TABLE 4. Results of Noise Measurements Done at Various Workplaces in the Rolling Stock Plant; Polish Maximum Admissible Intensity (MAI) Values, and European Union Exposure Limit Values and Exposure Action Values [1, 33]

		$L_{EX,8h}$ (dB)	$L_{A\,max}$ (dB)	$L_{C\,peak}$ (dB)
Job	**Cases**	***M* ± *SD*** 10th / 50th / 90th Percentile		
Driller	2	78.5 ± 0.7 78.0 / 78.5 / 79.0	88.5 ± 2.0 87.1 / 88.5 / 89.9	108.6 ± 1.8 107.3 / 108.6 / 109.8
Technical gasses handler	1	79.1	89.7	106.9
Grinder operator	1	80.1	88.8	107.7
Automation engineer	1	82.3	107.7	132.3
Cutter	5	80.0 ± 1.4 79.1 / 79.2 / 82.4	94.4 ± 3.9 88.2 / 94.7 / 97.8	115.7 ± 4.3 109.1 / 118.1 / 118.9
Crane operator	3	81.7 ± 1.4 80.0 / 82.4 / 82.6	104.6 ± 4.1 101.7 / 102.7 / 109.3	117.4 ± 10.3 105.9 / 120.7 / 125.6
Painter	1	83.0	95.7	117.0
Turning machine operator	4	80.2 ± 4.9 74.0 / 81.0 / 84.6	93.7 ± 7.1 85.5 / 93.2 / 102.7	111.2 ± 6.5 101.9 / 113.7 / 115.6
Lathe operator	8	82.0 ± 2.5 78.8 / 81.4 / 85.6	92.3 ± 5.4 84.6 / 93.3 / 99.0	112.5 ± 7.2 103.5 / 114.1 / 125.5
Distributor	1	87.5	108.7	144.0
Shear operator	4	86.6 ± 0.9 85.9 / 86.4 / 87.7	101.4 ± 2.5 97.8 / 102.4 / 103.1	124.4 ± 0.4 124.0 / 124.3 / 125.0
Fork-lift driver	1	87.9	110.6	133.8
Acetylene burner operator	2	87.0 ± 2.8 85.0 / 87.0 / 88.9	100.0 ± 7.5 94.7 / 100.0 / 105.3	120.1 ± 10.7 112.5 / 120.1 / 127.7
Maintenance locksmith	2	84.6 ± 8.3 78.7 / 84.6 / 90.4	106.0 ± 10.9 98.3 / 106.0 / 113.7	125.1 ± 12.0 116.6 / 125.1 / 133.5
Foreman	5	85.7 ± 4.3 81.1 / 85.0 / 91.0	110.4 ± 8.2 100.2 / 109.9 / 119.3	127.5 ± 4.0 124.0 / 125.5 / 132.5
Welder-fitter	5	91.0 ± 4.1 83.6 / 92.8 / 92.8	101.3 ± 4.0 94.1 / 103.1 / 103.1	131.6 ± 9.8 114.1 / 136.0 / 136.0
Machinist miller	8	85.1 ± 5.2 77.3 / 84.3 / 93.5	98.5 ± 8.8 87.2 / 99.5 / 115.2	119.0 ± 9.5 106.5 / 116.8 / 132.3
Forgeman	2	92.2 ± 2.3 90.5 / 92.2 / 93.8	102.8 ± 0.5 102.4 / 102.8 / 103.1	131.9 ± 2.4 130.2 / 131.9 / 133.6
Quality controller	1	94.0	113.8	131.2
Trimmer-flattener	6	97.1 ± 4.7 90.1 / 97.4 / 102.3	108.9 ± 6.3 98.9 / 109.0 / 117.8	125.2 ± 8.2 116.2 / 124.6 / 138.0
Fitter	14	96.1 ± 4.1 92.4 / 96.7 / 100.5	106.5 ± 5.3 101.7 / 106.4 / 114.0	125.3 ± 5.4 117.4 / 125.2 / 132.7
Welder	41	91.5 ± 5.2 86.6 / 91.6 / 96.5	103.7 ± 7.3 96.8 / 101.3 / 113.8	127.3 ± 6.0 119.4 / 126.2 / 134.6
total	118	88.9 ± 6.8 79.7 / 88.8 / 97.3	102.2 ± 8.1 92.4 / 101.8 / 113.8	123.6 ± 8.9 110.3 / 124.7 / 134.6
Polish MAI values		85	115	135
European Union exposure limits				
lower exposure action values		80	N/A	135
upper exposure action values		85	N/A	137
exposure limit values		87	N/A	140

Notes. $L_{EX,8h}$—daily noise exposure level, $L_{A\,max}$—maximum *A*-weighted sound pressure level, $L_{C\,peak}$—peak *C*-weighted sound pressure level, N/A—not applicable.

culties with speech intelligibility in a noisy environment. Few complained of tinnitus (9.7%) and difficulties with hearing trebles such as a door bell (3.2%). Most respondents (74.5%) said their hearing deteriorated from year to year. In most cases (63.6%), hearing was impaired in both ears.

Table 3 presents workers' self-assessment of hearing ability, in terms of (m)AIADH scores. The total score was 45–84, *M* (*SD*) 67.5 (12.3). The median score of 67 was rather far under the maximum score of 84, which means that the subjects had some hearing difficulties. About two fifths of the subjects scored under 70% of the maximum value. Relatively low scores were particularly frequent in subscale III (evaluating intelligibility in noise) with 54.1 and 23.9% of the subjects scoring under 75 and 65% of the maximum value of the subscale, respectively.

It is worth noting that there were significant differences between younger and older subjects in self-assessment of hearing ability, both in the total score and in the scores in subscales II (auditory localization), III (intelligibility in noise) and IV (intelligibility in quiet). However, there were no such differences if the work-life exposure was under and over the median value (Table 3).

3.2. Noise Exposure

Table 4 and Figure 1 summarize the results of measurements at various types of jobs in the rolling stock. The highest noise exposure levels normalized over an 8-h working day ($L_{EX,8h}$) were observed in welders (up to 110.4 dB), fitters (up to 104.6 dB) and trimmer-flatteners (up to 102.3 dB).

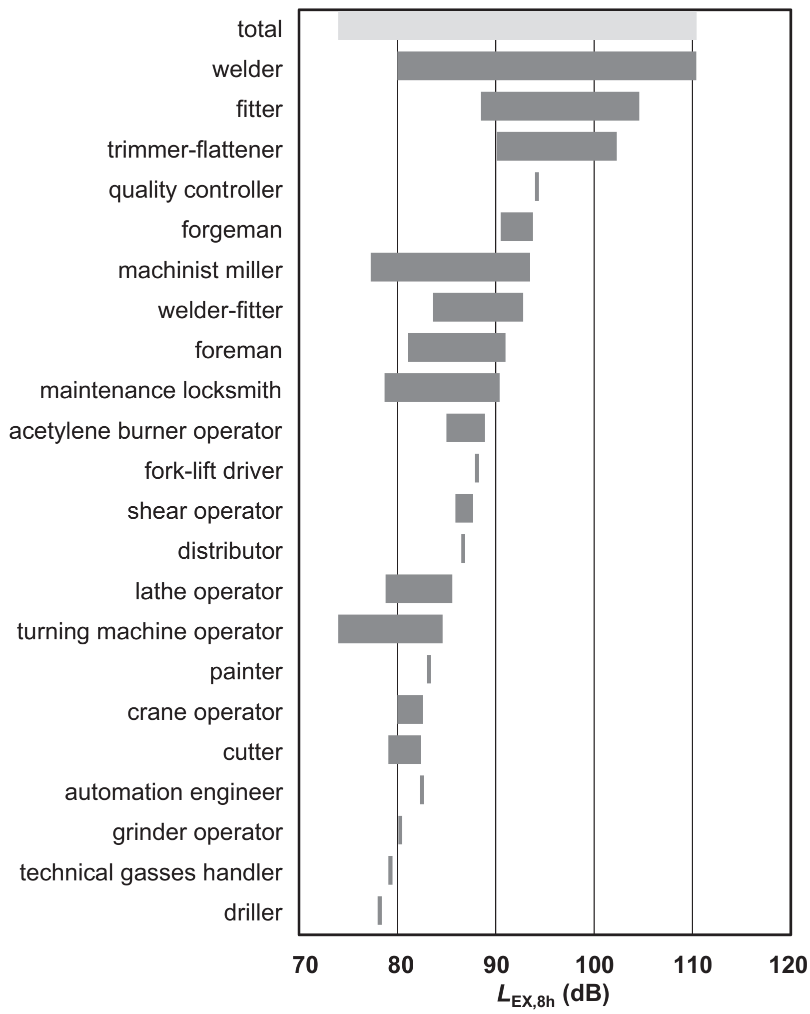

Figure 1. Daily noise exposure levels ($L_{EX,8h}$) determined for various workstations (each bar represents a range from minimum to maximum values).

Those noise exposure levels exceeded the Polish maximum admissible intensity (MAI) values ($L_{EX,8h}$ = 85 dB) [33] in 74.2% of the subjects, while the lower exposure action value from Directive 2003/10/EC ($L_{EX,8h}$ =80 dB) [1] was found in almost all cases (95.8%). Most workers (80.0%) were exposed to impulsive noise.

Individual work-life exposure evaluated on the basis of the subjects' work histories and noise exposure data in terms of noise exposure level ($\overline{L_{EX,8h}}$) was 74.0–110.4 dB, *M* (*SD*) 89.6 (6.0), *Mdn* 91.6 The respective noise immission levels (L_{im}) were 88.6–125.0 dB, *M* (*SD*) 103.5 (6.1), *Mdn* 103.8. The L_{im} levels over 101 dB (a value equivalent to noise exposure at the $L_{EX,8h}$ level of 85 dB for 40 years) were found in 67.5% of the subjects (Figures 2).

Table 5 and Figure 3 show detailed data on work-life exposure ($\overline{L_{EX,8h}}$) and respective noise immission levels (L_{im}) in various job groups.

3.3. Assessment of Risk of Hearing Impairment

Table 6 summarizes the results of risk assessment of hearing impairment due to noise exposure and age, and due to noise exposure alone. Those evaluations considered noise exposure, the protective effects of using HPDs, penalty for impulsive character of noise and other risk factors, e.g., co-exposure to organic solvents, smoking and elevated blood pressure (Table 5). However, all additional factors modifying risk of hearing loss were considered only if questionnaire data required that.

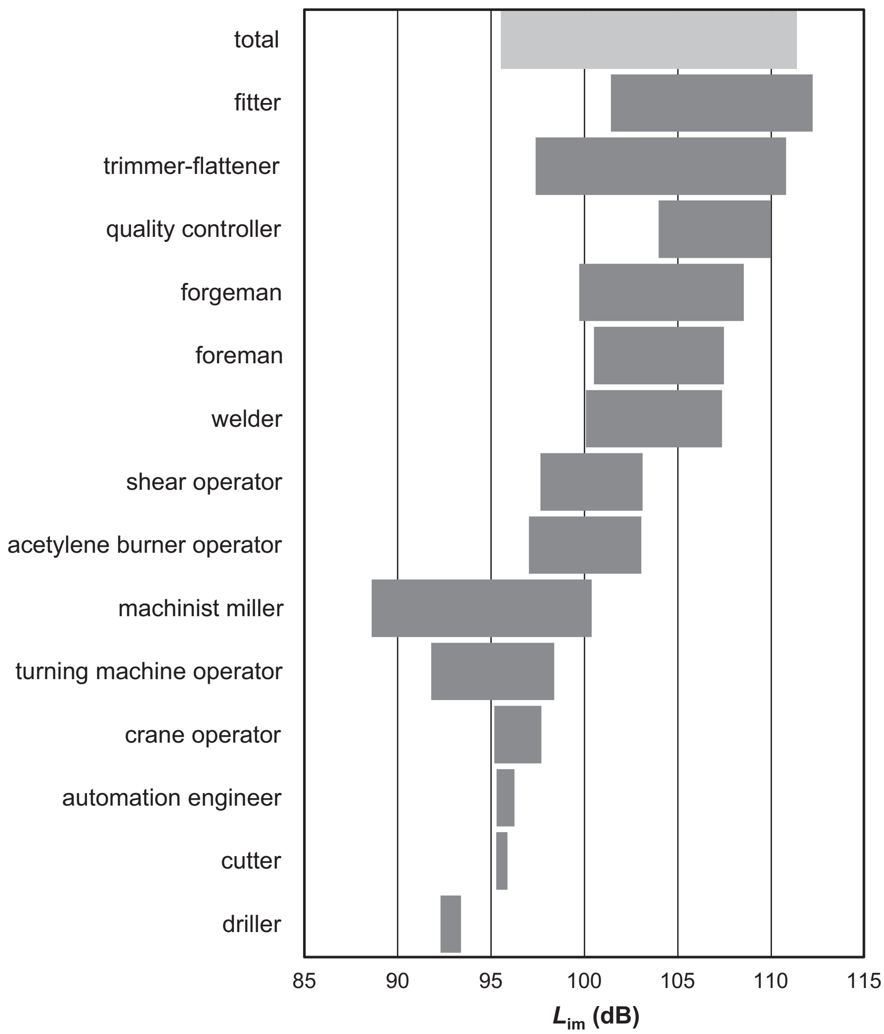

Figure 2. Noise immission levels (L_{im}) at various workstations (each bar represents a range from 10th to 90th percentiles).

TABLE 5. Averaged Daily Noise Exposure Level ($\overline{L_{EX,8h}}$) and Incidence of Impulsive Noise, Use of Hearing Protectors (HPD), Coexposure to Organic Solvents, Smoking and Elevated Blood Pressure During Total Time of Exposure to Noise in Various Job Groups

	($\overline{L_{EX,8h}}$) (dB)	Cases (%)				
Job	$M \pm SD$ 10th / 50th / 90th Percentiles	Impulsive Noise	HPD	Coexposure to Organic Solvents	Smoking	Elevated Blood Pressure
Acetylene burner operator	86.5 ± 1.3 85.0 / 86.7 / 87.9	33.3	100	33.3	66.7	0
Crane operator	82.5 ± 0.4 82.4 / 82.4 / 83.4	0	25.0	0	25.0	12.5
Cutter	80.5 ± 0.5 80.2 / 80.4 / 81.0	100	66.7	0	0	33.3
Shear operator	86.5 ± 0.8 85.9 / 86.2 / 87.7	100	100	0	50.0	25.0
Driller	78.3 ± 0.4 78.0 / 78.3 / 78.5	100	66.7	0	33.3	0
Automation engineer	81.7 ± 1.2 80.0 / 82.3 / 82.3	0	100	50.0	25.0	50.0
Fitter	94.0 ± 4.0 86.8 / 96.7 / 96.7	100	100	27.3	90.9	12.1
Foreman	88.7 ± 3.9 84.3 / 90.2 / 91.6	100	100	0	100	0
Forgeman	90.4 ± 4.3 85.6 / 91.8 / 93.8	100	100	33.3	66.7	0
Machinist miller	80.5 ± 4.9 74.0 / 81.2 / 85.1	0	80.0	0	80.0	0
Quality controller	93.8 ± 0.6 92.3 / 94.0 / 94.0	100	77.8	22.2	77.8	11.1
Trimmer-flattener	93.3 ± 7.1 82.5 / 93.2 / 99.7	100	100	40.0	40.0	20.0
Turning machine operator	80.9 ± 2.0 78.7 / 80.8 / 83.5	0	100	0	50.0	0
Welder	91.2 ± 4.3 87.7 / 91.6 / 91.8	100	94.1	17.6	67.6	11.8

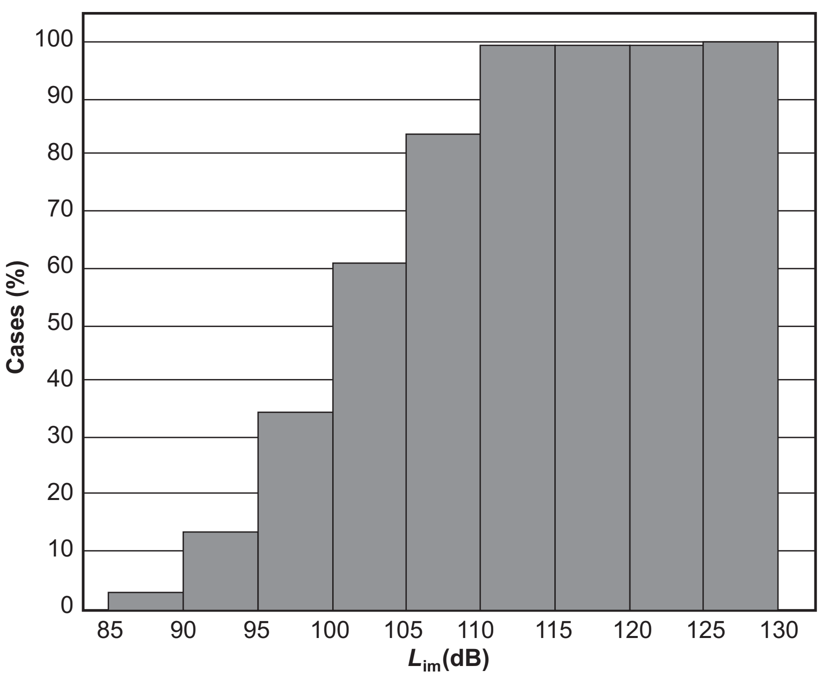

Figure 3. Cumulative distribution of noise immission level (L_{im}) at various workstations.

The risk of hearing impairment due to noise and age, i.e., the percentage (mean value) of subjects whose HTLs (mean value for 1, 2 and 3 kHz) reached or exceeded the limit value of 45 dB increased by 1.7–14.0% if, in addition to noise, other risk factors or the impulsive character of noise were considered (Figure 4a, Table 6). On the other hand, when the use and efficiency of HPDs were considered, the effect was opposite. The relations were similar in assessing risk due to noise exposure alone (Figure 4b, Table 6).

In general, the lower the limit value of HTL, the higher the risk of hearing impairment (Figures 4a–4b). The risk of NIHL with the limit value set at 25 dB (i.e., HTL ≥ 25 dB) increased from 34.9–50.3 to 55.7–73.6% at 3–6 kHz after adjusting for additional risk factors and the impulsive character of noise. If the limit value was set at 45 dB, the risk of NIHL (HTL ≥ 45 dB) decreased to 11.4–19.5 and 38.0–50.7% for an assessment based on noise exposure alone, and after adjusting for additional risk factors and the impulsive character of noise, respectively (Table 6).

Table 7 and Figure 5 present, respectively, the results of risk assessment of hearing impairment due to noise, and age and due to noise alone in various job groups. Fitters, quality controllers, forgemen, trimmer-flatteners and welders were at the highest risk of NIHL (expressed as a mean value for 1, 2 and 3 kHz, with the limit value set at 25 dB; Figure 5). Moreover, nonzero risk of hearing loss (due to noise and age) equal to or over 45 dB (mean value for 1, 2 and 3 kHz) was observed in fitters and welders, even though the calculations considered noise exposure data only. However, after adjusting for additional risk factors and the impulsive character of noise, a similar effect was observed in quality controllers, forgemen, trimmer-flatteners, acetylene burner operators, foremen and shear operators (Table 7).

TABLE 6. Risk Assessment of Hearing Impairment Due to Noise Exposure and Age, and Due to Noise Exposure Alone

		Subjects With HTLAN ≥ Limit Value (%)					Risk of NIHL (%)				
		Limit Value of HTLAN (dB)					Limit Value of HTLAN (dB)				
Frequency (kHz)		25	30	35	40	45	25	30	35	40	45
Noise	1	1.6	0.7	0.6	0.5	0.4	1.6	0.7	0.6	0.5	0.4
	2	18.2	11.1	6.5	3.4	1.7	18.2	11.1	6.5	3.4	1.7
	3	41.8	31.7	23.3	16.4	11.4	41.2	31.7	23.3	16.4	11.4
	4	54.3	44.0	34.5	26.4	19.5	50.3	43.4	34.5	26.4	19.5
	6	49.6	40.2	31.7	24.4	18.5	34.9	31.9	28.1	23.2	18.3
	M	18.9	11.4	6.5	3.5	1.7	12.9	9.7	6.4	3.5	1.7
Noise + RF	1	8.2	4.6	2.6	1.3	0.7	8.2	4.6	2.6	1.3	0.7
	2	41.6	32.4	24.7	18.8	13.7	41.6	32.4	24.7	18.8	13.7
	3	68.5	60.6	52.9	45.3	38.0	67.9	60.6	52.9	45.3	38.0
	4	77.6	71.2	64.7	57.7	50.7	73.6	70.6	64.7	57.7	50.7
	6	70.4	62.6	54.5	46.5	38.8	55.7	54.3	50.9	45.3	38.6
	M	42.9	33.2	25.6	19.1	14	36.8	31.3	25.4	19.1	14.0
Noise + HPD	1	0.8	0.7	0.6	0.5	0.4	0.8	0.7	0.6	0.5	0.4
	2	12.4	6.5	3.1	1.4	0.6	12.4	6.5	3.1	1.4	0.6
	3	32.9	23.5	16.2	10.6	6.6	32.3	23.5	16.2	10.6	6.6
	4	46.1	35.7	26.8	19.8	13.7	42.2	35.1	26.8	19.8	13.7
	6	43.6	34.5	26.5	19.8	14.5	28.9	26.2	22.9	18.5	14.4
	M	13.5	6.8	3.0	1.5	0.7	7.6	5.2	3.0	1.5	0.7
Noise + RF + HPD	1	3.5	1.7	0.8	0.7	0.7	3.5	1.7	0.8	0.7	0.7
	2	33.0	24.2	17.5	12.6	8.9	33	24.2	17.5	12.6	8.9
	3	59.1	50.6	42.5	34.7	28.2	58.6	50.6	42.5	34.7	28.2
	4	71.0	63.6	55.9	48.4	41.0	67.1	63.0	55.9	48.4	41.0
	6	64.3	55.8	46.9	38.7	31.2	49.6	47.5	43.3	37.5	31.1
	M	33.5	24.4	17.4	12.4	8.7	27.4	22.6	17.3	12.4	8.7

Notes. HTLAN—hearing threshold level associated with age and noise, NIHL—noise induced hearing loss; *M*—mean value at 1, 2 and 3 kHz; noise—noise exposure, RF—additional risk factors, HPD—use of hearing protector devices; data given as mean values.

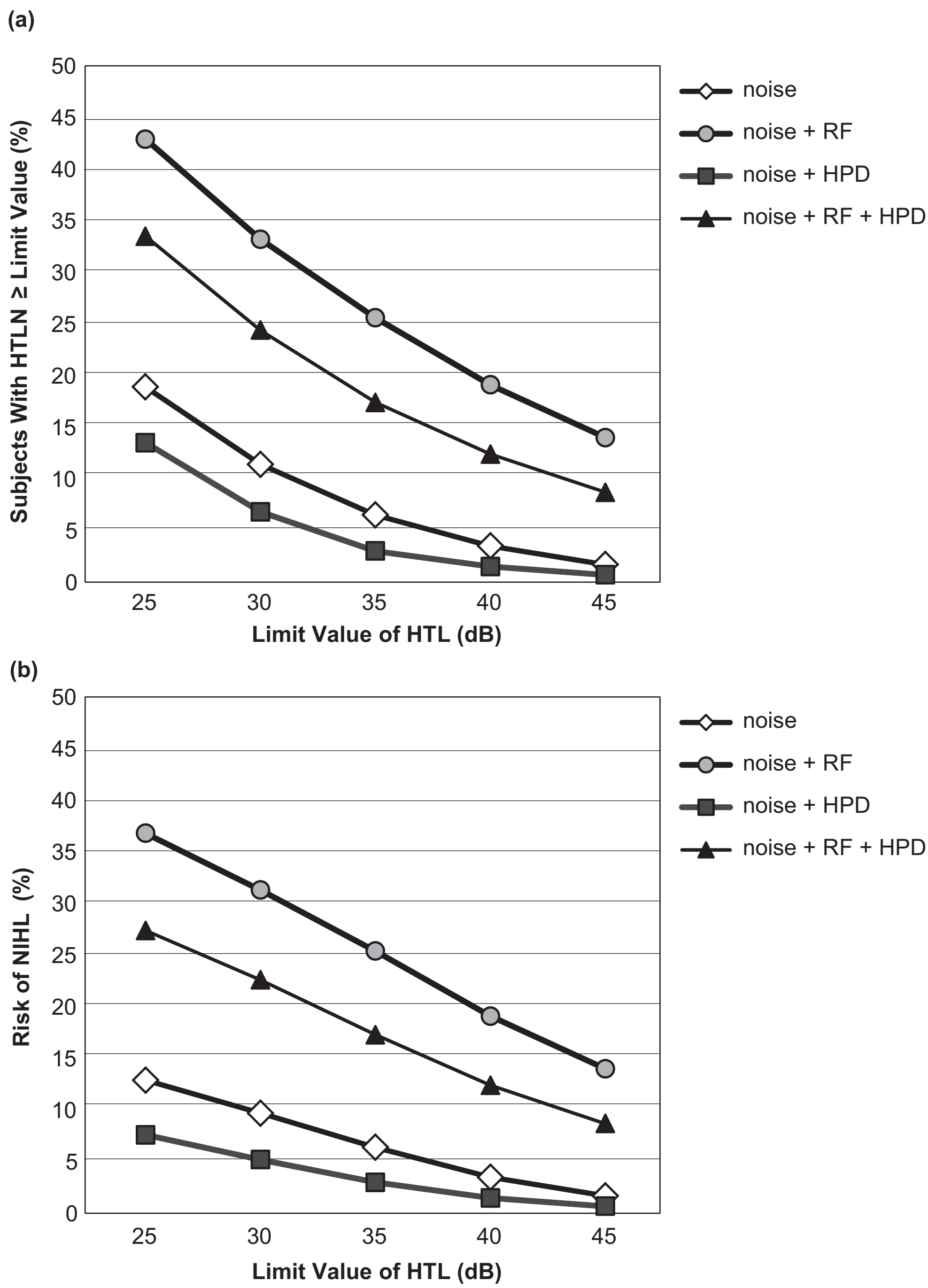

Figure 4. Risk of NIHL in function of assumed limit value of HTL (for mean values at 1, 2 and 3 kHz) due to (a) noise exposure and age and (b) noise exposure alone. *Notes.* NIHL—noise-induced hearing impairment, HTL—hearing threshold level, noise—noise exposure, RF—additional risk factors, HPD—use of hearing protector devices; data given as mean values.

4. DISCUSSION

Hearing conservation programs are launched in different companies to co-ordinate and to improve the efficiency of all obligatory and voluntary activities and efforts undertaken to protect workers' hearing. According to Directive 2003/10/EC, hearing conservation programs should include estimating individual risk of NIHL [1]. The directive also sets many new requirements that must be considered in risk assessment, including "the level, type and duration of exposure, including any exposure to impulsive noise", "any effects concerning the health and safety of workers belonging to

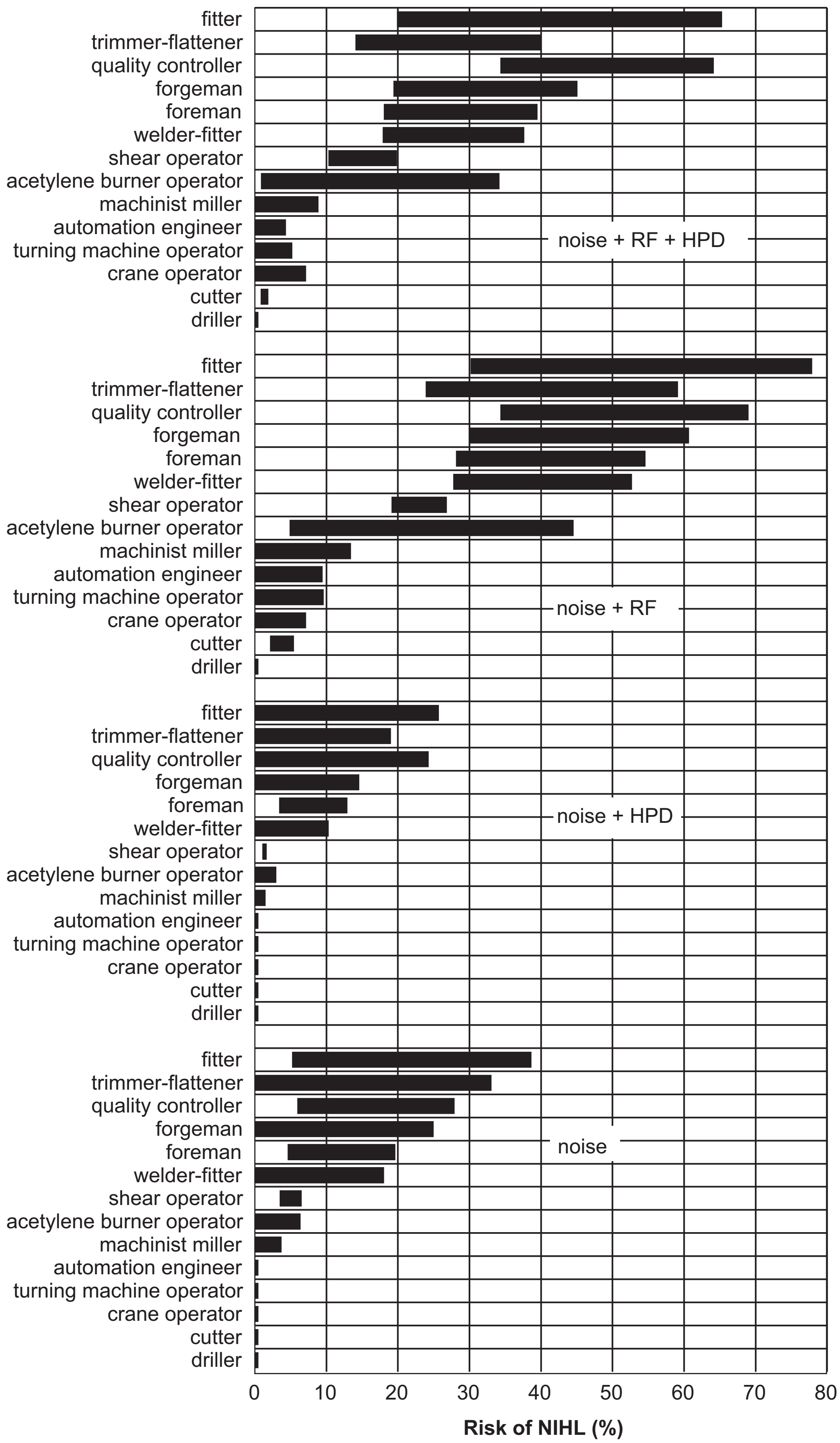

Figure 5. Risk of NIHL (for limit value of HTL set at 25 dB) at various workplaces (each bar represents a range from 10th to 90th percentile). *Notes.* NIHL—noise-induced hearing impairment, HTL—hearing threshold level, noise—noise exposure data, RF—additional risk factors, HPD—use of hearing protector devices.

TABLE 7. Risk Assessment of Hearing Impairment Due to Noise Exposure and Age in Various Jobs

	Subjects With HTLAN ≥ 45 dB (%)			
Job	**Noise**	**Noise + HPD**	**Noise + RF**	**Noise + RF + HPD**
Fitter	3.4	0.4	26.9	17.8
Quality controller	0.0	0.0	22.5	15.1
Forgeman	0.0	0.0	16.1	10.8
Welder	2.8	2.4	12.8	7.2
Trimmer-flattener	0.0	0.0	11.1	5.7
Foreman	0.0	0.0	14.3	4.9
Acetylene burner operator	0.0	0.0	4.5	2.2
Shear operator	0.0	0.0	2.5	1.3
Turning machine operator	0.0	0.0	0.0	0.0
Milling machine operator	0.0	0.0	0.0	0.0
Automation engineer	0.0	0.0	0.0	0.0
Driller	0.0	0.0	0.0	0.0
Cutter	0.0	0.0	0.0	0.0
Crane operator	0.0	0.0	0.0	0.0

Notes. HTLAN—hearing threshold level associated with age and noise, noise—noise exposure, HPD—use of hearing protector devices, RF—additional risk factors; 45 dB—limit value of HTLN; data given as mean values.

particularly sensitive risk groups", effects on worker's health and safety resulting from interaction between noise and ototoxic substances found in occupational environment, and between noise and vibration, and "the availability of hearing protectors with adequate attenuation characteristics" (p. 40–41).

The ISO 1999:1990 method [30], which is currently used for predicting NIHL, does not fulfill all aforesaid requirements. In this study, we proposed a modified method, which considers coexposure to organic solvents, smoking, elevated blood pressure, impulsiveness of noise and protective effects of HPDs, in addition to the variables in the standard method, i.e., age, gender, noise level and time of employment [31].

The study group mostly comprised workers exposed to noise at levels that exceeded Polish MAI values ($L_{EX,8h}$ = 85 dB) [33]. In most cases, noise had an impulsive character. Most subjects (82%) were aware of exposure to excessive noise and declared using HPDs (90%). Nearly half of the workers smoked. Other NIHL risk factors were less frequent. About 12% of the workers were exposed to organic solvents. The same percentage reported elevated blood pressure. Nevertheless, the questionnaire data suggested a higher risk of NIHL than the risk resulting from noise exposure alone.

The estimated risk of NIHL (mean value for all subjects), associated with HTLs at frequencies most dangerous to hearing (3–6 kHz) [34] equal to or over 25 dB was 35–50% when the ISO 1999:1990 method [30] was used. This risk dropped to 29–42% if the efficiency of HPDs was considered in the calculations. Adjusting for additional NIHL risk factors (smoking, elevated blood pressure) and the impulsive character of noise increased risk to 56–74%. However, even if attenuation of HPDs was also considered, NIHL risk continued to be relatively high (50–67%).

It is worth noting that, according to Standard No. ISO 1999:1990 [30], the risk of hearing impairment can be evaluated not only separately at 1, 2, 3, 4 and 6 kHz, but also for a combination of various frequencies. Therefore, the risk of hearing loss expressed as the average value at 1, 2 and 3 kHz was additionally calculated in this study. This frequency range is not the most vulnerable to noise, but it corresponds to the most important speech frequency range of the Polish language. Thus, this frequency range is considered crucial for social efficiency of hearing. Moreover, HTL (expressed as a mean value for 1, 2 and 3 kHz) equal to or over 45 dB is the precondition for diagnosing occupational hearing loss in Poland [35].

In this study, the estimated risk of hearing impairment due to age and noise, expressed as a percentage of subjects (mean value) with the average HTL at 1, 2 and 3 kHz equal to or over the limit value of 25–45 dB was 18.9–1.7% if the standard method for predicting NIHL was used. After adjusting for additional risk factors (co-exposure to organic solvents, smoking and elevated blood pressure), the impulsive character of noise and the use of HPDs, this risk was 33.5–8.7% (for the limit values of 25 and 45 dB, respectively). Moreover, even though noise-only exposure data corrected for the use of HPDs were considered in the calculations, there was nonzero risk of permanent hearing threshold shift, especially in fitters and welders. In Poland, that nonzero risk is sufficient to diagnose occupational hearing loss (mean value of HTLs for 1, 2 and 3 kHz ≥ 45 dB).

Thus, it is not surprising that even though most workers reported using HPDs, nearly one third of them complained of hearing impairment. Moreover, ~25% of the subjects complained of difficulties with speech intelligibility. Those findings were consistent with workers' self-reported hearing ability assessed with the (m)AIAHD. The questionnaire inquiry with (m)AIAHD showed some hearing difficulties in over half of the subjects, especially in relation to intelligibility in noisy environments.

It had been shown earlier that the handicapping effects of different hearing disabilities in a population of hearing-impaired people did not have equal weight. Handicap resulting from the inability to understand speech in noise is most strongly felt. Moreover, difficulties in intelligibility in noise and auditory localization are the most frequent disabilities, followed by intelligibility in quiet and detection of sounds [25].

It is worth stressing that earlier psychometric studies indicated that the (m)AIADH was a promising tool for assessing hearing impairment, regardless of its origin [26]. Criterion validity showed a moderate but significant correlation (Spearman's rank correlation coefficient $\rho = .59$, $p < .001$) between scores on the (m)AIADH and hearing thresholds in decibels (averaged across 0.5, 1, 2, 3 and 4 kHz for both ears), when results of pure-tone audiometry done on 94 subjects (with near-normal hearing and perceptive, mixed and conductive hearing losses) were related to their total scores on the (m)AIAD [26].

The (m)AIAHD has been used for various purposes, e.g., to measure the effect of middle-ear surgery to improve hearing and to evaluate the relation between audiometric and psychometric measurements of hearing after tympanoplasty [36, 37]. The results of the latter investigation indicated that (m)AIADH scores were almost independent of hearing loss for postoperative hearing levels in the range of 25–40 dB. For permanent threshold shifts over 40 dB, (m)AIAHD scores clearly decreased with increasing permanent threshold shifts. However, even small residual hearing losses (under 25 dB) lead, on average, to (m)AIADH scores substantially lower than scores for normally hearing.

The findings presented here showed that the risk of NIHL among the workers of the rolling stock plant was substantial. Their self-reported hearing status and hearing ability indicated that some had a hearing deficit. This means that their hearing protection was ineffective. Because of the profile of production, HPDs were the only way to reduce noise exposure in that plant (in addition to reducing exposure time). Thus, the attenuation performance of those HPDs was too low or they were not properly used or the wearing time in a noisy environment was too short, etc. Our results confirmed the need to implement a more effective hearing conservation program for those workers.

To sum up, questionnaire inquiries aimed at self-assessing hearing status and hearing ability in workers, e.g., using the (m)AIADH, seem to be a useful tool for analyzing the effectiveness of past personal protective equipment and other provisions aimed at eliminating or reducing exposure to noise at the workplace. On the other hand, questionnaire inquiries intended to identify occupational and nonoccupational NIHL risk factor together with the modified ISO 1999:1990 method for predicting NIHL presented here make better risk assessment possible and, thereby, the development of more effective hearing conservation programs.

REFERENCES

1. Directive 2003/10/EC of European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (17th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). OJ. 2003;L42:38–44. Retrieved March 27, 2012, from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:042:0038:0044:EN:PDF
2. Plontke S, Zenner Tübingen HP. Current aspects of hearing loss from occupational and leisure noise. In: Schultz-Coulon HJ, editor. Environmental and occupational health disorders. Niebüll, Germany: Videel; 2004. vol. 3, p. 233–325
3. Pyykkö I, Starck J, Toppila E, Ulfendahl M. Noise-induced hearing loss. In: Luxon L, Furman JM, Martini A, Stephens D, editors. Textbook of audiological medicine, clinical aspects of hearing and balance. London, UK: Martin Dunitz; 2003. p. 495–512.
4. Starck J, Toppila E, Pyykkö I. Impulse noise and risk criteria. Noise Health. 2003; 5(20):63–73. Retrieved March 27, 2012, from: http://www.noiseandhealth.org/article.asp?issn=1463-1741;year=2003;volume=5;issue=20;spage=63;epage=73;aulast=Starck
5. Abbate C, Concetto G, Fortunato M, Brecciaroli R, Tringali MA, Beninato G, et al. Influence of environmental factors on the evolution of industrial noise-induced hearing loss. Environ Monit Assess. 2005;107(1–3):351–61.
6. Henderson D, Subramaniam M, Boettcher FA. Individual susceptibility to noise-induced hearing loss: an old topic revisited. Ear Hear. 1993;14(3):152–68.
7. Sliwinska-Kowalska M, Zamyslowska-Szmytke E, Szymczak W, Kotylo P, Fiszer M, Wesolowski M, Pawlaczyk-Luszczynska M. Exacerbation of noise-induced hearing loss by co-exposure to workplace chemicals. Environ Toxicol Pharmacol. 2005;19(3):547-53.
8. Śliwinska-Kowalska M. Exposure to organic solvent mixture and hearing loss: literature overview. Int J Occup Med Environ Health. 2007;20(4);309–14.
9. Dayal VS, Kokshanian A, Mitchell DP. Combined effects of noise and kanamycin. Ann Otol Laryngol. 1971;80(6):897-902.
10. Brown JJ, Brummett R E, Fox KE, Bendrik TW. Combined effects of noise and kanamycin: cochlear pathology and pharmacology. Arch Otolaryngol. 1980;106(12):744–50.
11. Pekkarinen J. Noise, impulse noise, and other physical factors: combined effects on hearing. Occup Med. 1995;10(3):545–59.
12. Starck J, Toppila E, Pyykkö I. Smoking as a risk factor in sensory neural hearing loss among workers exposed to occupational noise. Acta Otolaryngol. 1999;119(3):302–5.
13. Mizoue T, Miyamoto T, Shimizu T. Combined effect of smoking and occupational exposure to noise on hearing loss in steel factory workers. Occup Environ Med. 2003;60(1):56–9. Retrieved March 27, 2012, from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1740373/?tool=pubmed
14. Namura K, Nakao M, Miriomoto T. Effect of smoking on hearing loss: quality assessment and meta-analysis. Prevent Med. 2005;40(2);138–44.
15. van Kempen EE, Kruize H, Boshuizen HC, Ameling CB, Staatsen BA, de Hollander AE. The association between noise exposure and blood pressure and ischemic heart disease: a meta-analysis. Environ Health Perspect. 2002;110(3): 307–17. Retrieved March 27, 2012, from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1240772/?tool=pubmed
16. Esparza CM, Jáuregui-Renaud K, Morelos CMC, Muhl GE, Mendez MN, Carillo NS, Bello NS, Cardenas M. Systematic high blood pressure and inner ear dysfunction: a preliminary study. Clin Otolaryngology. 2007;32(3):173–8.
17. Toppila E, Pyykkö I, Starck J. Age and noise-induced hearing loss. Scand Audiol. 2001;30(4):236–44.

18. Barrenas M. Pigmentation and noise-induced hearing loss: is the relationship between pigmentation and noise-induced hearing loss due to an otoxic pheolaminin interaction or to otoprotective eumelan effects. In: Prasher D, Luxon L, editors. Biological effects of noise (Advances in noise research, vol. 1). London, UK: Whurr; 1998. p. 59–70.
19. Berger EH, Royster LH, Tomas WG. Presumed noise-induced hearing permanent threshold shift resulting from exposure to an A-weighted Leq of 89 dB. J Acoust Soc Am. 1978;64(1):192–7.
20. Borg E, Canlon, Engström B. Noise-induced hearing loss. Literature review and experiments in rabbits. Morphological and electrophysiological features, exposure parameters and temporal factors, variability and interactions. Scand Audiol Suppl. 1995;40:1–147.
21. Pawelczyk M, Van Laer L, Fransen E, Rajkowska E, Konings A, Carlsson PI, et al. Analysis of gene polymorphisms associated with K+ ion circulation in the inner ear of patients susceptible and resistant to noise-induced hearing loss. Ann Hum Genet. 2009;73(Pt 4):411-21.
22. Sliwinska-Kowalska M, Noben-Trauth K, Pawelczyk M, Kowalski TJ. Single nucleotide polymorphisms in the cadherin 23 (CDH23) gene in Polish workers exposed to industrial noise. Am J Hum Biol. 2008;20(4):481–3.
23. Szeszenia-Dąbrowska N, Wilczyńska U, Sobala W. Choroby zawodowe w Polsce w 2009 r. [Occupational diseases in Poland in 2009]. Łódź, Poland: Nofer Institute of Occupational Medicine; 2010.
24. Kramer SE, Kapteyn TS, Festen JM, Tobi H. Factors in subjective hearing disability. Audiology. 1995;34(6):311–20.
25. Kramer SE, Kapteyn TS, Festen JM. The self-reported handicapping effect of hearing disabilities. Audiology. 1998;37(5):302–12.
26. Meijer AGW, Wit HP, TenVergert EM, Albers FW, Muller Kobold JE. Reliability and validity of the (modified) Amsterdam Inventory for Auditory Disability and Handicap. Int J Audiol. 2003;42:220–6.
27. Polski Komitet Normalizacyjny (PKN). Hałas—dopuszczalne wartości hałasu w środowisku pracy—wymagania dotyczące wykonywania pomiarów [Noise—permissible values of noise in the workplace—requirements relating to measurements] (Standard No. PN-N-01307:1994). Warszawa, Poland: Wydawnictwa Normalizacyjne Alfa-Wero; 1994. In Polish.
28. International Organization for Standardization (ISO). Acoustics—guidelines for the measurement and assessment of exposure to noise in a working environment (Standard No. ISO 9612:1997). Geneva, Switzerland: ISO; 1997.
29. International Organization for Standardization (ISO). Acoustics—determination of occupational noise exposure—engineering method (Standard No. ISO 9612:2009). Geneva, Switzerland: ISO; 2009.
30. International Organization for Standardization (ISO). Acoustics—determination of occupational noise exposure and estimation of noise-induced hearing impairment (Standard No. ISO 1999:1990). Geneva, Switzerland: ISO; 1990.
31. Dudarewicz A, Toppila E, Pawlaczyk-Łuszczyńska M, Śliwińska-Kowalska M. The influence of selected risk factors on the hearing threshold level of noise exposed employees. Arch Acoust. 2010;35(3): 371–82. Retrieved March 27, 2012, from: http://versita.metapress.com/content/j7q0rk82n17t4455/fulltext.pdf
32. noise immission level. McGraw-Hill dictionary of scientific and technical terms. McGraw-Hill. 2003. Retrieved March 27, 2012, from: http://www.answers.com/topic/noise-immission-level
33. Regulation of the Minster of Labor and Social Policy of November 29, 2002, on maximum admissible concentrations and intensities for agents harmful to health in the working environment. Dz U. 2002;(217):item 1833. In Polish.
34. Gates GA, Schmid P, Kujawa SG, Nam B, D'Agostino R. Longitudinal threshold changes in older men with audiometric notches. Hear Res. 2000;141(1-2):220–28.
35. Regulation of the Council of Ministers of June 30, 2009, on occupational diseases. Dz U. 2009;(105):item 869. In Polish.

36. Meijer AGW, Wit HP, Albers FWJ. Relation between change of hearing and (modified) Amsterdam Inventory for Auditory Disability and Handicap Score. Clin Otolaryngol Allied Sci. 2004;29(6):565–70.

37. Korsten-Meijer AGW, Wit HP, Albers FWJ. Evaluation of the relation between audiometric and psychometric measures of hearing after tympanoplasty. Eur Arch Otorhinolaryngol. 2006;263(3):256–62.