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Noise-Induced Hearing Loss in Professional Orchestral Musicians

Małgorzata PAWLACZYK-ŁUSZCZYŃSKA, Małgorzata ZAMOJSKA, Adam DUDAREWICZ, Kamil ZABOROWSKI

Department of Physical Hazards, Nofer Institute of Occupational Medicine
Św. Teresy 8, 91-348, Łódź, Poland; e-mail: mpawlusz@imp.lodz.pl

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The overall purpose of this study was to assess hearing status in professional orchestral musicians. Standard pure-tone audiometry (PTA) and transient-evoked otoacoustic emissions (TEOAEs) were performed in 126 orchestral musicians. Occupational and non-occupational risk factors for noise-induced hearing loss (NIHL) were identified in questionnaire inquiry. Data on sound pressure levels produced by various groups of instruments were also collected and analyzed. Measured hearing threshold levels (HTLs) were compared with the theoretical predictions calculated according to ISO 1999 (1990).

Musicians were exposed to excessive sound at weekly noise exposure levels of for 81–100 dB (mean: 86.6±4.0 dB) for 5–48 years (mean: 24.0±10.7 years). Most of them (95%) had hearing corresponds to grade 0 of hearing impairment (mean hearing threshold level at 500, 1000, 2000 and 4000 Hz lower than 25 dB). However, high frequency notched audiograms typical for noise-induced hearing loss were found in 35% of cases. Simultaneously, about 35% of audiograms showed typical for NIHL high frequency notches (mainly occurring at 6000 Hz). When analyzing the impact of age, gender and noise exposure on hearing test results both PTA and TEOAE consistently showed better hearing in females vs. males, younger vs. older musicians. But higher exposure to orchestral noise was not associated with poorer hearing tests results.

The musician's audiometric hearing threshold levels were poorer than equivalent non-noise-exposed population and better (at 3000 and 4000 Hz) than expected for noise-exposed population according to ISO 1999 (1990). Thus, music impairs hearing of orchestral musicians, but less than expected from noise exposure.

Keywords: orchestral musicians, exposure to orchestral noise, hearing, risk of noise-induced hearing loss.

1. Introduction

The associations between exposure to noise and occupational hearing loss has been recognized for over 150 years. However, studies looking at the effects of music on hearing began more recently in the 1960.

It has been shown that musicians, in particular professional orchestral musicians, are often exposed to sounds at levels exceeding the upper exposure action values from Directive 2003/10/EC (Royster *et al.*, 1991; Obeling, Poulsen, 1999; Laitinen *et al.*, 2003; O'Brien *et al.*, 2008; Toppila *et al.*, 2011). Furthermore, they can also develop noise-induced hearing loss (NIHL) and suffer from other hearing symptoms such as tinnitus, hyperacusis, which can influence their work abilities more severely than hearing loss (Royster *et al.*, 1991; Jansson, Karlsson *et al.*, 1983; Teie, 1998; Kähäri *et al.*, 2001; Laitinen, 2005; Emmerich *et al.*, 2008; Jansen *et al.*, 2009).

However, because of insufficient audiometric evidence of hearing loss caused purely by music exposure, there is still disagreement and speculation about risk of hearing loss from music exposure alone (Royster *et al.*, 1991; Obeling, Poulsen, 1999; Karlsson *et al.*, 1983; Teie, 1998; Kähäri *et al.*, 2001; Emmerich *et al.*, 2008; Jansen *et al.*, 2009; Axelsson, Lindgren, 1981; Zhao *et al.*, 2010. There are studies that conclude that classical musicians have NIHL due to music exposure (Royster *et al.*, 1999; Axelsson, Lindgren, 1981; Ostri *et al.*, 1989) and studies that conclude just opposite (Karlsson *et al.*, 1983; Obeling, Poulsen, 1999; Kähäri *et al.*, 2001).

Nevertheless, when Directive 2003/10/EC was introduced to protect workers from harmful effects of noise, it recognized the needs of the music and entertainment sectors, including orchestral musicians (2003/10/EC). All member states were required to develop a code of conduct to provide practical guidelines which would help workers and employers in those sectors to attain the levels of protection established by that directive. Such regulations are still missing in Poland.

The purpose of this study was to assess hearing status in professional orchestral musicians and its relation with self-reported hearing ability as well as to compare the observed audiometric hearing threshold levels to the theoretical predictions according to ISO 1999 (1990) (PN-ISO 1999 (2000)).

2. Materials and methods

2.1. Study group

Participants were 126 professional musicians (58 females and 68 males), aged 24–67 years (mean ±SD: 43.0±10.7 years, median: 43.5 years) from two opera and four symphony orchestras. The study group comprised musicians playing violin (37), viola (13), cello (10), oboe (10), flute (8), horn (8), trombone (7), bassoon (7), clarinet (6), trumpet (5), double bass (4), percussion (3), tuba (2) and other instruments (4).

They were recruited by advertisement and did not receive any financial compensation for their participation in the experiment. The local Ethics Committee approved the study design.

2.2. Questionnaire inquiries

All musicians filled a questionnaire developed to enable identification of occupational and non-occupational risk factors for NIHL. The questionnaire consisted of items on: a) age and gender; b) education; c) professional experience; d) medical history (past middle-ear diseases, and surgery, etc.); e) physical features (body weight, height, skin pigmentation); f) lifestyle (smoking, noisy hobbies, etc.); g) self-assessment of hearing status and h) use of hearing protective devices. A special attention was paid to professional experience, i.e. the time of employment in orchestra/musical career or comparable experience, various work activities and instruments in use, time of daily and/or weekly practice, including individual rehearsals.

In addition, musicians' hearing ability was assessed using the (modified) Amsterdam Inventory for Auditory Disability and Handicap ((m)AIADH) (Meijer *et al.*, 2003). 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 the mentioned situation. The four answer categories were as follows: almost never, occasionally, frequently, and almost always. Responses to each question were coded on a scale from 0 to 3; the higher the score, the smaller the perceived hearing difficulties. The total score per subject was obtained by adding the scores for 28 questions. Maximum total score of the questionnaire was 84. Additionally, the answers for each subscale were summed up (maximum score for subscale I was 24, while for the other subscale it was 15).

2.3. Hearing examinations

Conventional pure-tone audiometry (PTA) was performed in all study subjects ($n = 126$). In addition, transient-evoked otoacoustic emission (TEOAE) determinations were made in 92,9% ($n = 117$) of musicians. Before the exact examinations, otoscopy was performed in order to screen for conditions that would exclude examined subject from the study.

PTA was performed using an Audio Traveller Audiometer type 222 (Interacoustics) with TDH 39 headphones. Hearing threshold levels (HTLs) for air conduction were determined using an ascending–descending technique in 5-dB steps.

A Scout Otoacoustic Emission System ver. 3.45.00 (Bio-logic System Corp.) was applied for recording and analyzing of otoacoustic emissions. TEOAE recordings of 260 averages each were collected for every subject at stimuli levels of about 80 dB, using standard clicks. The artefact rejection level was set at 20 mPa. Each response was windowed from 3.5 to 16.6 ms post stimulus and band-pass filtered from 0 to 6000 Hz. The total TEOAE amplitude level and the TEOAE amplitude levels for frequency bands with central frequencies 1, 1.5, 2, 3 and 4 kHz were examined.

Hearing examinations were performed in quiet rooms located in concert halls and opera buildings where the A-weighted equivalent-continuous sound pressure level of background noise did not exceed 35 dB.

2.4. Evaluation of exposure to orchestral noise

Musicians' exposures to orchestral noise were evaluated based on data concerning sound pressure levels produced by various groups of instruments in orchestra. These data were collected during measurements performed with the measuring equipments placed in various instrument groups during collective and individual rehearsals, concerts and performances comprising diverse repertoire and various venues. Noise measurements were carried out according to Standards

No. PN-N-01307 (1994) and ISO 9612 (2009) (for details see (Pawlaczyk-Łuszczyńska *et al.*, 2011; Dudarewicz *et al.*, 2013).

For various groups of players the weekly noise exposure levels ($L_{EX,wi}$) were calculated from the values of the A-weighted equivalent-continuous sound pressure levels produced by the respective instrument (e.g. violins or trumpets) and time of weekly practice gathered from the questionnaire, using the following equation:

$$L_{EX,wi} = 10 \cdot \log\left[\frac{1}{T_0}(T_1 \cdot 10^{0.1 \cdot L_{Aeq,T_1}} + T_2 \cdot 10^{0.1 \cdot L_{Aeq,T2}})\right], \qquad (1)$$

where: L_{Aeq,T_1} – is the A-weighted equivalent-continuous sound pressure level during group playing (i.e. collective rehearsals, concerts and performances), in dB; L_{Aeq,T_2} – is the A-weighted equivalent-continuous sound pressure level during solo rehearsals, in dB, T_1, T_2 – is the declared time of group and individual practice per week, in hours, T_0 – is the reference duration, $T_0 = 40$ h.

The data on noise exposure levels in college music students were also collected (Zamojska *et al.*, 2013). Subsequently, for each study subject weekly noise exposure level averaged over total time of musical career (including academic music education) was determined using the following equation:

$$L_{EX,w} = 10 \cdot \log\left[(t_1 \cdot 10^{0.1 \cdot L_{EX,w1}} + t_2 \cdot 10^{0.1 \cdot L_{EX,w2}}/(t_1 + t_2)\right], \qquad (2)$$

where: $L_{EX,w1}/L_{EX,w2}$ – is the weekly noise exposure level assigned to orchestra musicians/ college music students playing respective instrument, in dB; t_1 – is the duration of music college education (over eighteen years of age), in years; t_2 – is the declared time of employment in orchestra (musical career), in years.

2.5. Prediction of noise-induced hearing loss

The musicians' actual hearing threshold levels were compared with the theoretical predictions calculated according to ISO 1999 (1990). The aforesaid standard specifies the method for determining a statistical distribution of hearing threshold levels in adult populations after given exposure to noise based on four parameters: age, gender, noise exposure level and duration of noise exposure (in years).

In order to compare predictions obtained for musicians of different gender, age, time and exposure, so-called standardized hearing threshold levels (STHLs) were determined using the following formulas (Śliwińska-Kowalska *et al.*, 2006):

$$\text{SHTL} = 1.282 \cdot \frac{\text{HTL} - \text{PHTL}_{\text{Q50}}}{\text{PHTL}_{\text{Q10}} - \text{PHTL}_{\text{Q50}}} \quad \text{for} \ \text{HTL} \geq \text{PHTL}_{\text{Q50}}, \qquad (3)$$

$$\text{SHTL} = 1.282 \cdot \frac{\text{HTL} - \text{PHTL}_{\text{Q50}}}{\text{PHTL}_{\text{Q90}} - \text{PHTL}_{\text{Q50}}} \quad \text{for} \ \text{HTL} < \text{PHTL}_{\text{Q50}}, \qquad (4)$$

where HTL – is the actual hearing threshold level, in dB, PHTL_{Q50} – is the median value of predicted hearing threshold level, in dB; $\text{PHTL}_{\text{Q10/Q90}}$ – is the fractile Q10/Q90 of predicted hearing threshold level, in dB.

These calculations were applied to the audiograms twice, i.e. the musicians' hearing was compared to the hearing of the non-noise-exposed population and noise-exposed population.

2.6. Statistical analysis

A three-way analysis of variance (ANOVA) for independent data was performed to analyze the impact of gender, age and exposure on PTA and TEOAE results as well as the (m)AIAHD scores. For this purpose, the study group was divided into subgroups according to gender (females and males), age (younger and older subjects) and exposure (lower- and higher-exposed to noise subjects). Musicians were categorized as higher-exposed or lower-exposed on the basis of their assigned values of the weekly noise exposure level ($L_{EX,w}$). Subjects with the $L_{EX,w}$ levels above median value were classified as higher-exposed, while the others as lower-exposed. Similarly, the median value of age was used as the basis for classification of subjects as younger and older ones.

Answers to the questionnaire were presented as the proportions with 95% confidence intervals The relations between variables, e.g. results of PTA or TEOAE and musicians' self-reported hearing ability expressed in terms of the (m)AIADH scores were evaluated using Pearson's correlation coefficient. The standardized hearing threshold levels were analyzed using t-test.

All statistical tests were done with an assumed level of significance $p < 0.05$. The STATISTICA (version 9.0) software package was employed for the statistical analysis of the data.

3. Results

3.1. Noise exposure evaluation and additional NIHL risk factors

Table 1 summarizes sound pressure levels measured in various groups of instruments during group and solo playing in orchestra (i.e. collective and individual rehearsals, concerts and performances) as well as during academic music education (i.e. solo and group practicing, lessons with teacher, concerts, etc.).

According to the responses to the questionnaire, musicians under study were employed in orchestras from 5 to 48 years (mean ±SD: 24.0±10.7 years, median: 24.5 years). They were playing instruments on average 30 hours a week, including 7.5 and 22.5 hours

Table 1. Results of sound pressure levels measurements performed in orchestral musicians and college music students during solo and group practicing, lessons with teacher, concerts, etc. (Pawlaczyk-Łuszczyńska *et al.*, 2011; Dudarewicz *et al.*, 2013; Zamojska *et al.*, 2013).

	Individual rehearsals in orchestra			Group playing in orchestra			Academic music education		
	A-weighted equivalent-continuous SPL [dB] Mean ±SD (10th/50th/90th percentile)								
Violin	14*	85.1±2.0 [85.5]**	(82/86/87)	77	84.0±2.4 [84.6]	(82/84/87)	32	85.5±3.9 [87.0]	(80/86/91)
Viola	9	87.0±1.0 [87.1]	(86/87/89)	34	83.7±3.3 [84.7]	(79/84/88)	6	85.9±2.3 [86.5]	(84/85/89)
Cello	14	81.9±4.7 [84.0]	(76/82/88)	33	81.5±3.2 [82.6]	(77/82/85)	12	81.0±3.7 [82.5]	(78/80/86)
Double bass	10	80.4±4.1 [82.7]	(76/80/87)	27	82.4±4.7 [84.6]	(75/84/87)	5	80.5±3.4 [81.5]	(77/80/84)
Clarinet	11	89.1±3.7 [90.6]	(85/88/94)	28	86.2±3.4 [87.6]	(81/86/90)	8	89.7±1.2 [89.8]	(88/90/91)
Oboe	7	87.4±4.5 [89.2]	(82/86/92)	23	87.0±3.0 [88.1]	(83/87/92)	6	86.9±1.8 [87.3]	(85/87/89)
Bassoon	11	87.4±3.9 [88.4]	(84/88/91)	39	85.4±3.3 [86.4]	(81/86/90)	2	94.9±0.8 [94.9]	(94/95/95)
Flute	17	91.0±4.6 [92.9]	(83/91/97)	32	86.7±3.1 [87.8]	(84/87/91)	14	91.2±5.7 [94.2]	(83/91/98)
Horn	8	92.4±2.6 [92.9]	(87/93/95)	48	88.0±3.1 [89.3]	(85/88/92)	6	93.8±3.0 [94.4]	(91/95/96)
Trumpet	11	89.1±8.7 [100.9]	(84/86/97)	38	88.1±2.8 [88.9]	(84/89/92)	14	97.2±3.2 [98.3]	(94/98/101)
Trombone	14	94.8±2.9 [95.7]	(90/95/99)	31	88.0±4.0 [90.1]	(84/87/94)	14	95.1±4.8 [97.3]	(89/95/101)
Tuba	12	91.2±3.7 [92.5]	(86/91/95)	17	85.9±5.1 [87.9]	(79/87/91)	8	94.3±1.8 [94.7]	(93/94/96)
Percussion	3	89.6±3.2 [90.3]	(86/90/93)	25	85.2±4.5 [87.1]	(80/86/91)	21	95.9±7.6 [105.7]	(89/94/104)
Harp	2	81.4±6.5 [83.5]	(77/81/86)	12	82.0±3.4 [83.3]	(78/82/85)	4	85.5±0.6 [85.5]	(85/85/86)
Total	148	88.1±5.7 [93.2]	(80/88/95)	465	85.4±4.0 [87.2]	(81/86/90)	199	89.9±7.2 [97.9]	(81/90/99)

* Number of noise samples; ** An energy average of the number of measured *A*-weighted equivalent-continuous SPLs.

of solo practicing and group playing. The weekly noise exposure levels calculated from this data ranged between 81–95 dB (mean ±SD: 85.7.0±3.2 dB, median: 84.2 dB) (Fig. 1).

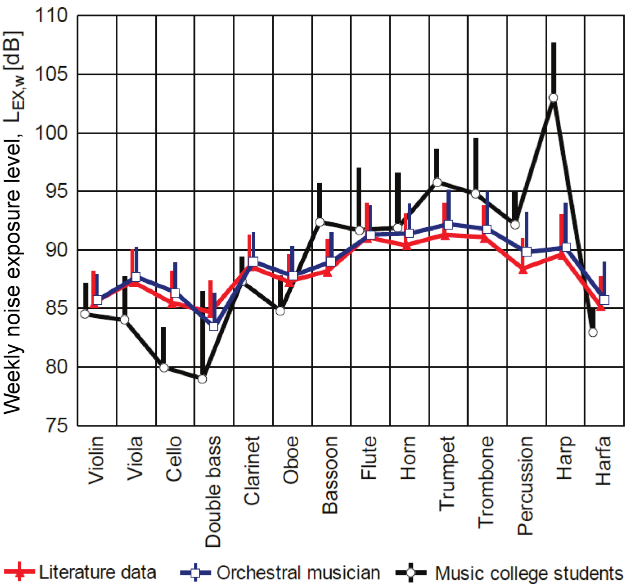

Fig. 1. Results of noise exposure evaluation for various groups of players among orchestral musicians and college music students together with evaluations based on literature data (Dudarewicz *et al.*, 2013; Zamojska *et al.*, 2013). (Weekly noise exposure levels $L_{EX,w}$ are specified with one-side 95% CI).

Figure 1 illustrates the aforesaid data together with our noise exposure determination for college music students and evaluations based on literature data (Pawlaczyk-Łuszczyńska *et al.*, 2011; Dudarewicz *et al.*, 2013; Zamojska *et al.*, 2013). As can be seen there are differences in exposure condition between professional and college music students; the highest difference was noted for percussion instruments players. However, there is a good agreement between literature data and our assessment of noise exposure in orchestral musicians. Thus, these results seem to be a reliable basis for assessing risk of NIHL in orchestral musician.

Subsequently, weekly noise exposure level averaged over total time of musical career (including academic music education) varied from 81–100 dB (mean ± SD: 86.6±4.0 dB, median: 84.3 dB). Please note that nearly half (47.0%) of study subjects were exposed to the $L_{EX,w}$ levels exceeding the Polish maximum admissible intensity values ($L_{EX,w} = 85$ dB), while 47.0% – the exposure limit value according to the noise directive ($L_{EX,w} = 87$ dB) (Fig. 2).

As to other NIHL risk factors, 7.1% (95%CI: 2.5–11.2%) of musician reported elevated blood pressure. Moreover, 5.6% (95%CI: 3.6–13.2%) of them were current smokers, while 17.5% (95%CI: 11.8–25.1%) smoked in the past. 12.7% (95%CI: 7.9–19.7%) of musicians had used regularly painkillers. The presence of white-finger syndrome was reported by only 7.1% (95%CI: 3.6–13.2%) of them, while overweight (BMI > 25) by 17.5% (95%CI: 11.8–25.1%).

Furthermore, 15.1% (95%CI: 9.8–22.4%) of musicians often used noisy tools and 25.4% (95%CI: 18.6–33.7%), listened often to music through headphones.

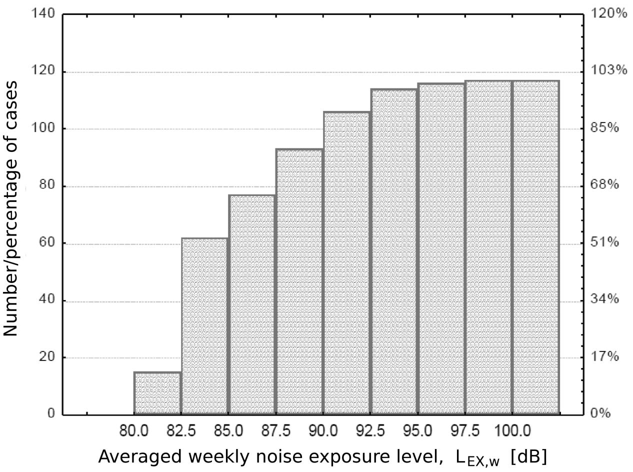

Fig. 2. Cumulative distribution of the weekly noise exposure level averaged over total time of musical career (including academic music education) in study group.

On the other hand, only 11.1% (95%CI: 6.6–17.9%) of them declared using hearing protective devices (HPDs) at present or in the past, while 31.0% (95%CI: 23.5–39.5%) players intended to use HPDs in the future.

3.2. Results of hearing tests

In the majority (95.6%) of cases a mean value of the hearing threshold level for 500, 1000, 2000 and 4000 Hz was lower than 25 dB, which corresponds to grade 0 of hearing impairment according to the World Health Classification (WHO). Only 3.8% and 0,8% of the measured audiograms corresponded to grade 1 and 2 of hearing impairment, respectively. Moreover, almost all of them (88.9%) were found in the older musicians. Table 2.

Typical NIHL notches at 4000 or 6000 Hz of at least 15 dB depth relative to the best preceding threshold (from 1000 Hz) were observed in 35.1% of audiograms, including 61.4% for left ear. Most of them (73,9%) occurring at 6000 Hz. The portion of total population with bilateral notching at any frequency was 19.2%.

Audiometric hearing threshold levels determined in 126 professional orchestral musicians (251 ears) are shown in Fig. 3. A significant main effect of age on the HTLs was observed in the frequency range from 1000 to 8000 Hz (Fig. 3a, Table 2).

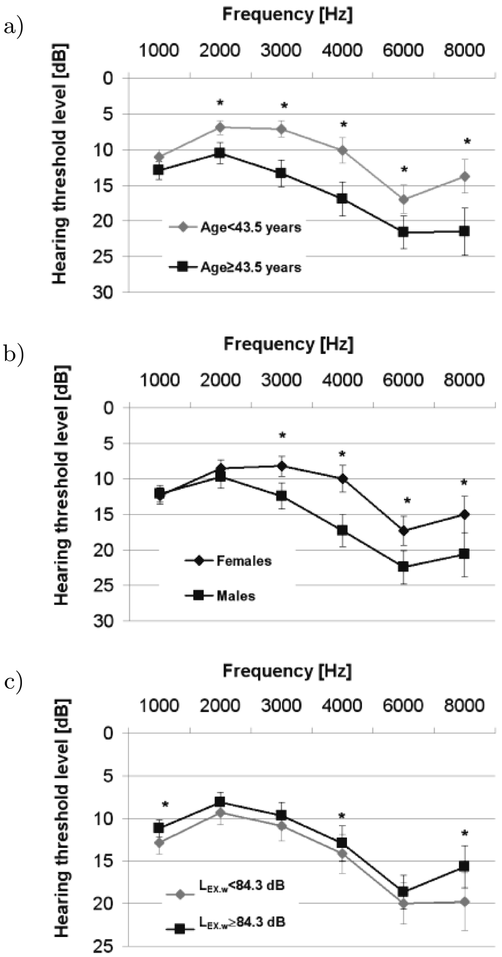

Fig. 3. Audiometric hearing threshold levels (mean ±95% CI) in various subgroups of musicians, i.e. females and males (a), younger and older subjects (b), and lower- and higher-exposed subjects (c). Significant differences ($p < 0.05$) between subgroups are marked (*).

Generally, older subjects showed higher reduction of hearing threshold level than younger ones. Similar relation was observed between males and females

Table 2. Summary results of the three-way ANOVA – influence of gender, age and noise exposure on audiometric hearing threshold levels in orchestral musicians. Significant main effects or interactions are given in bold ($p < 0.05$).

Frequency [Hz]	Main effect			Interaction			
	Age (A)	Exposure (E)	Gender (G)	E × A	A × G	E × G	A × E × G
	Statistical significance, *p*						
1000	0.110	**0.042**	0.664	**0.001**	0.221	0.488	0.587
2000	**0.007**	0.096	0.454	**0.006**	0.435	0.188	0.969
3000	**0.000**	0.067	**0.000**	0.177	**0.048**	**0.039**	0.773
4000	**0.000**	**0.028**	**0.000**	0.481	0.098	0.368	0.489
6000	**0.002**	0.083	**0.000**	**0.031**	0.074	**0.031**	0.122
8000	**0.000**	**0.012**	**0.001**	**0.023**	0.108	0.072	**0.049**

in the high frequency region from 3000 to 8000 Hz (Fig. 3b). There was also a significant main effect of noise exposure on the HTLs at frequencies of 1000, 4000 and 8000 Hz. However, contrary to our expectations, higher-exposed subjects ($L_{EX,w} > 84.3$ dB) had lower (better) audiometric hearing levels compared to lower-exposed individuals ($L_{EX,w} \leq 84.3$ dB) (Fig. 3c). Moreover, significant two-way interactions between noise exposure and age (for the HTLs at 1000, 2000, 6000 and 8000 Hz) as well as between noise exposure and gender (for the HTLs at 3000 Hz) were noted (Table 2).

As can be seen in Fig. 4a, among older subjects, those lower-exposed had higher (poorer) hearing level (at 6000 Hz) compared to higher-exposed individuals, while in younger musicians there were no differences due to noise exposure. (Similar, relations were observed for other frequencies, i.e. 1000, 2000 and 8000 Hz). On the other hand, when analysing lower-exposed musicians, females had better hearing than males, while there were no differences in case of higher-exposed subjects.

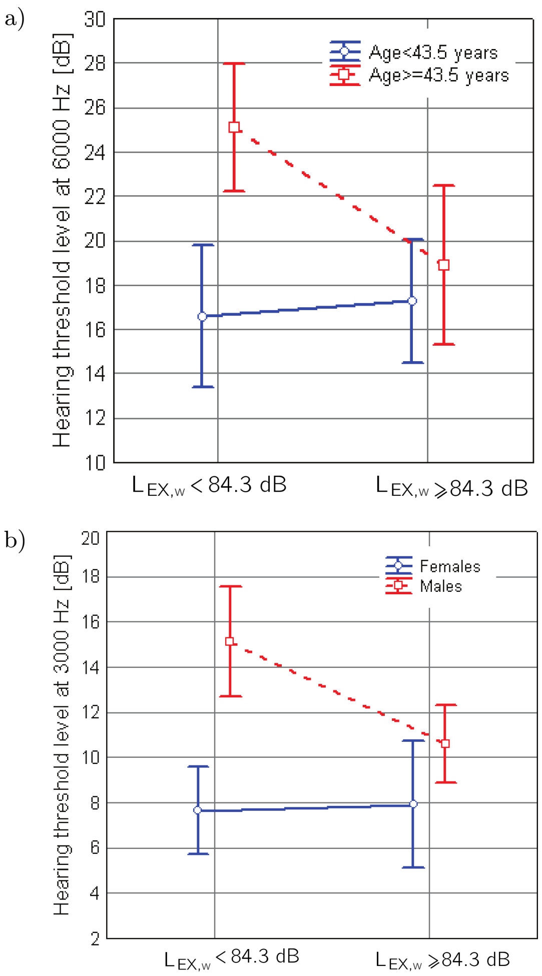

Fig. 4. A two-way interaction between: a) noise exposure and age for the HTLs at 6000 Hz ($F(1, 225) = 4.732$, $p = 0.031$), b) noise exposure and gender for the HTLs at 3000 Hz ($F(1, 225) = 4.305$, $p = 0.039$).

In almost all cases (94.4% of ears) the reproducibility of the TEOAE above 70% for the total response was noted. On the other hand, higher than 6 dB signal to noise ratio (SNR) was observed in the 72.1% of cases. Both higher values of reproducibility and SNR were more frequently noted in the females than males.

Results of TEOAE testing are summarized in Fig. 5. Significant main effects of gender and age on TEOAE amplitude, SNR as well reproducibility was noted (Table 3, Figs. 5b, 5e and 5h).

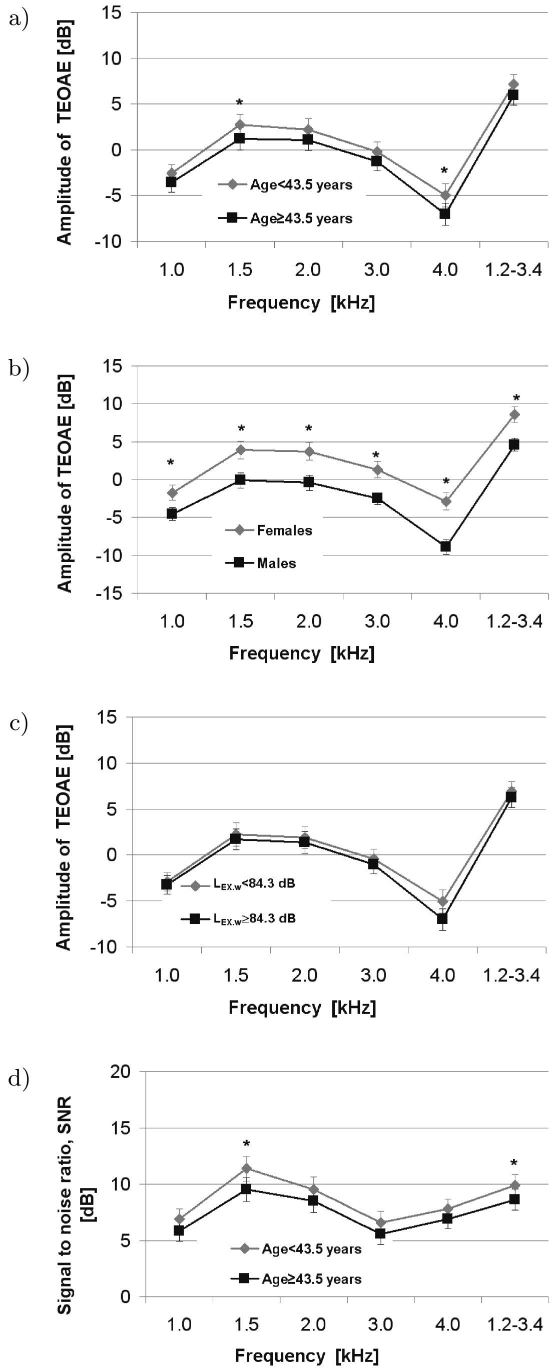

Fig. 5 a–d

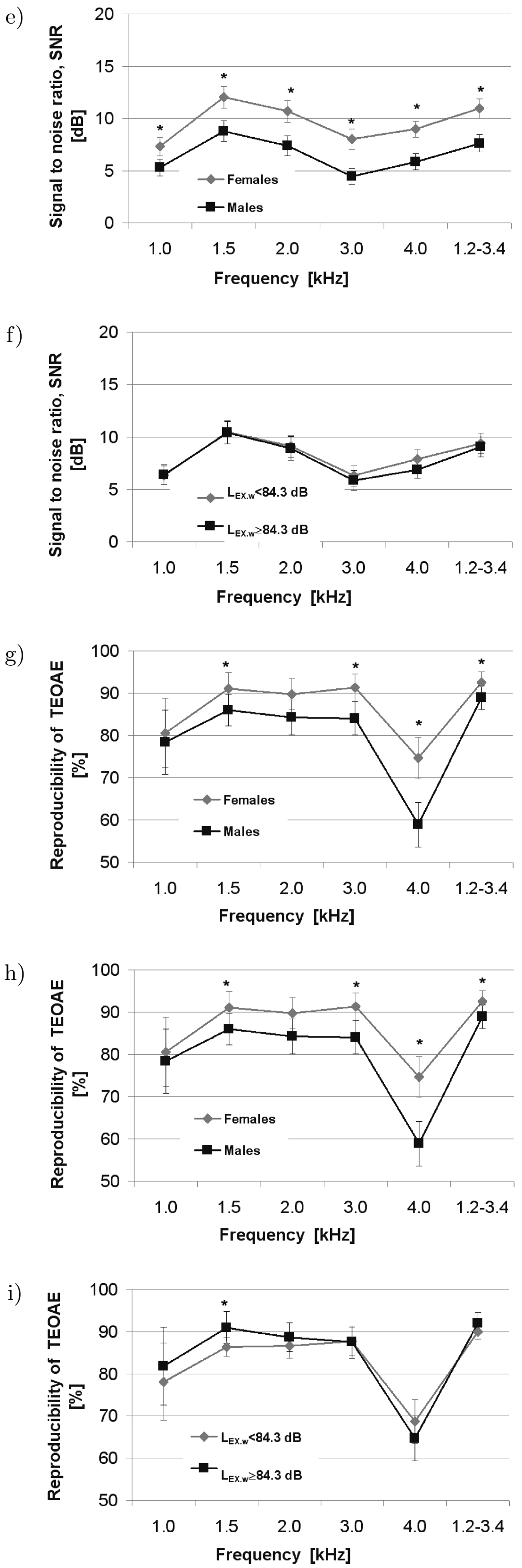

Fig. 5. TEOAEs (mean ±95% CI) in various subgroups of musicians, i.e. females and males (a, d, g), younger and older subjects (b, e, h), and lower- and higher-exposed subjects (c, f, i). Significant differences between subgroups were marked (*) (ANOVA, $p < 0.05$).

Generally, females showed better results of TEOAE testing compared to males. Similar relation was observed when analysing younger and older musicians. On the other hand, noise exposure was only found to significantly affect the reproducibility of TEOAE in the frequency bands of 1.5 kHz (Fig. 5i). Similar to PTA, higher-exposed musicians had better results (i.e. greater reproducibility) than lower-exposed ones.

Furthermore, a significant two-way interaction between exposure and gender was observed for the signal to noise ratio and reproducibility of TEOAE in the frequency band of 4 kHz (Figs. 6a and 6b, $p < 0.05$). Among lower-exposed musicians, females showed better reproducibility compared to males, while among higher-exposed subjects there were no differences caused by gender. On the other hand, the opposite relations was observed when analyzing SNR at 4 kHz. Higher-exposed females had better results than higher-exposed males, while there was no gender-related difference in the lower-exposed musicians.

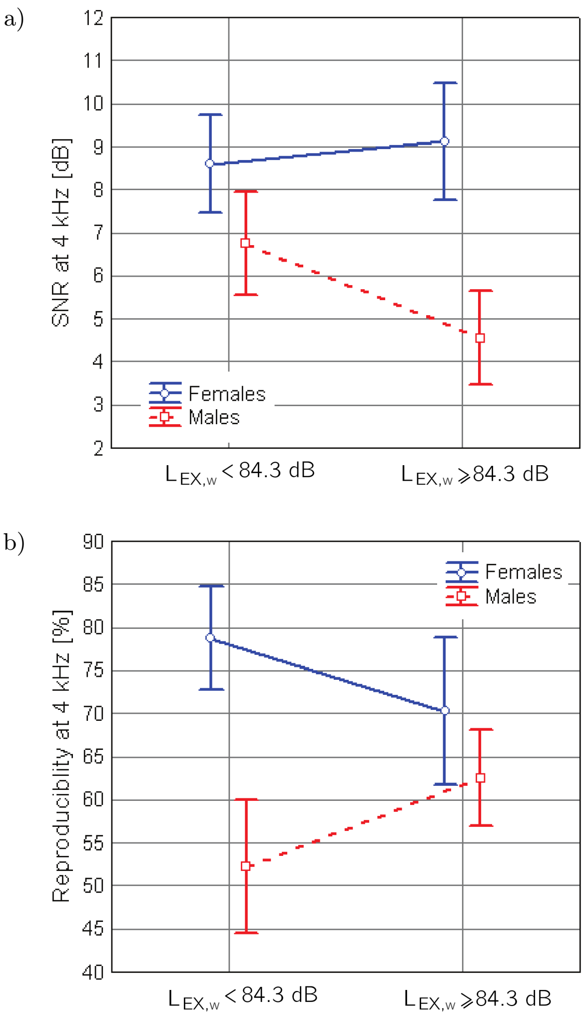

Fig. 6. A two-way interaction between noise exposure and gender for a) the signal to noise ratio ($F(1, 207) = 5.501$, $p = 0.020$), and b) reproducibility of TEOAE in the frequency band of 4 kHz ($F(1, 207) = 6.867$, $p = 0.009$).

Table 3. Summary results of the three-way ANOVA – influence of gender, age and noise exposure on TEOAE in orchestral musicians. Significant main effects or interactions are given in bold.

Frequency [Hz]	Main effect			Interaction			
	Age (A)	Exposure (E)	Gender (G)	E × A	A × G	E × G	A × E × G
	Statistical significance, p						
TEOAE amplitude							
1	0.078	0.737	**0.000**	0.606	0.474	0.705	0.101
1.5	**0.034**	0.781	**0.000**	0.802	0.856	0.692	0.072
2	0.109	0.668	**0.000**	0.944	0.820	0.867	0.069
3	0.126	0.706	**0.000**	0.101	0.334	0.663	0.426
4	**0.009**	0.538	**0.000**	0.324	0.566	0.228	0.342
Total response (1.2–3.4)	0.057	0.810	**0.000**	0.676	0.869	0.581	0.087
Signal to noise ratio							
1	0.073	0.490	**0.002**	0.885	0.545	0.880	0.184
1.5	**0.012**	0.493	**0.000**	0.639	0.779	0.862	0.100
2	0.125	0.500	**0.000**	0.568	0.948	0.901	0.092
3	0.141	0.593	**0.000**	0.096	0.312	0.696	0.479
4	0.173	0.872	**0.000**	0.870	**0.028**	**0.020**	0.916
Total response (1.2–3.4)	**0.044**	0.594	**0.000**	0.877	0.979	0.735	0.116
TEOAE reproducibility							
1	**0.029**	0.203	0.422	0.254	0.079	0.249	0.604
1.5	**0.001**	**0.021**	**0.034**	0.092	**0.014**	0.339	**0.012**
2	0.310	0.200	0.059	0.068	**0.023**	0.333	0.058
3	0.500	0.407	**0.002**	0.354	0.184	0.247	0.709
4	0.276	0.796	**0.000**	0.735	**0.027**	**0.009**	0.691
Total response (1.2–3.4)	**0.006**	0.104	**0.040**	0.116	**0.013**	0.266	**0.034**

3.3. Comparison of actual and predicted hearing threshold levels

Figure 7 shows standardized hearing threshold levels in musicians under study. It is worth noting that the closer to zero value of SHTL, the better the prediction of hearing loss according to ISO 1999 (1990). On the other hand, the positive values of SHTLs indicate that actual hearing threshold levels are higher than predicted.

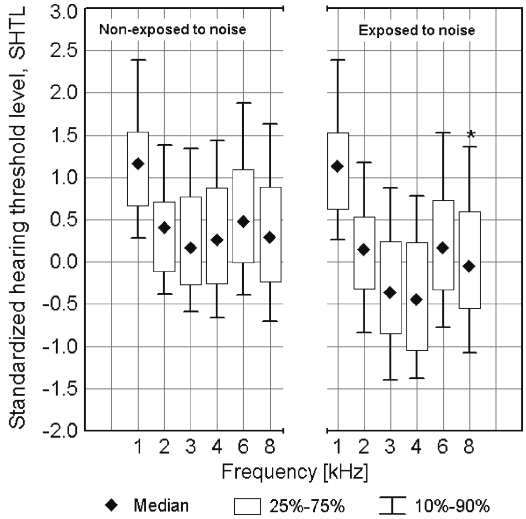

Fig. 7. Comparison of the musicians' hearing loss to that of non-noise-exposed and noise-exposed populations. All SHTL values, excluding those marked (*) significantly differ from 0 (t-test, $p < 0.05$).

Comparing the musicians to non-noise-exposed population (database A from ISO 1999 (1990)) revealed that their hearing losses (in the frequency range 1000–8000 Hz) were higher than predicted ($p > 0.05$). On the other hand, the actual hearing threshold levels were lower (better) than expected for 3000 and 4000 ($p < 0.05$) with an expected value at 8000 Hz ($p > 0.05$), when compared to equivalent population exposed to industrial noise. Furthermore, the observed audiometric hearing losses were higher than predicted for 1000, 2000 and 6000 Hz.

3.4. Self-assessment of hearing status

Over half of musicians (54.4%, 95%CI: 45.3–63.4%) assessed their hearing as very good, while 17.5% (95%CI: 11.8–25.1%) of them noticed hearing impairment. In majority cases (90.9%) hearing deficit developed gradually. Moreover, it was associated with difficulty in speech intelligibility in noisy environment 27.0% (95%CI: 20.0–35.4%) and hearing whisper 12.7% (95%CI: 7.9–19.7%). 20.6% (95%CI: 14.4–28.6%) of musician complained of hyperacusis, while 11.9% (95%CI: 7.2–18.8%) of them reported tinnitus.

Musicians examined using the (m)AIADH obtained mean total score of 89.9±11.0% of maximum value, which suggests no substantial hearing difficulties in subjects under study (Table 4). Relatively low scores were frequent only in the subscale (III) evaluating intelligibility in noise (23.0% of subjects scored below 70% of maximum value). No significant main effects of age, gender and noise exposure on the (m)AIAHD scores were noted. There were no significant interactions between of age, gender and exposure, either (ANOVA, $p < 0.05$).

However, weak but statistically significant linear relationships were noted between PTA results and the total score of (m)AIAHD and scores of the individual subscales (Table 5). In particular, relatively high values of correlation coefficients were observed for subscale evaluating intelligibility in noise (subscale III) (up to −0.36, $p < 0.05$). The linear relationships were also noted between musicians' self-assessment of hear-

Table 4. Musicians' self-assessment of hearing ability in the (m)AIAHD scores.

(m)AIAHD scores Mean ±SD (10th/50th/90th percentiles)					
Total	Subscale I	Subscale II	Subscale III	Subscale IV	Subscale V
75.5±9.2 (64/78/84)	22.8±2.4 (21/24/24)	13.4±2.0 (10/14/15)	12.0±2.6 (8/12/15)	13.3±2.1 (9/14/15)	13.8±1.8 (11/15/15)

Table 5. Relationships between results of hearing tests (PTA and TEOAE) and the (m)AIAHD scores and Pearson's correlation coefficient r. Statistically significant Pearson's correlation coefficient r values are given in bold ($p < 0.05$).

	Pearson's correlation coefficient r					
	Total score	Subscale I	Subscale II	Subscale III	Subscale IV	Subscale V
Audiometric hearing threshold level/Frequency [kHz]						
1	**−0.19**	−0.02	−0.14	**−0.31**	**−0.22**	−0.13
1.5	**−0.21**	−0.04	**−0.16**	**−0.31**	**−0.28**	**−0.20**
2	**−0.23**	−0.05	**−0.15**	**−0.32**	**−0.31**	**−0.21**
3	**−0.29**	**−0.15**	**−0.21**	**−0.36**	**−0.33**	**−0.24**
4	**−0.22**	−0.13	**−0.15**	**−0.27**	**−0.16**	−0.14
6	**−0.22**	−0.09	**−0.16**	**−0.33**	**−0.23**	−0.10
Total response	**−0.24**	−0.12	−0.13	**−0.33**	**−0.20**	−0.12
Amplitude of TEOAE/Frequency [kHz]						
1	−0.08	−0.08	−0.11	−0.04	−0.06	−0.05
1.5	−0.02	−0.07	−0.11	0.06	−0.05	−0.03
2	0.09	0.02	−0.02	**0.18**	0.10	0.03
3	0.12	0.10	0.00	**0.17**	0.08	0.07
4	**0.22**	**0.16**	0.12	**0.28**	0.12	0.13
Total response	0.03	−0.02	−0.06	0.12	0.02	0.00
Signal to noise ratio/Frequency [kHz]						
1	−0.11	−0.08	−0.12	−0.07	−0.08	−0.06
1.5	−0.05	−0.08	−0.13	0.04	−0.07	−0.05
2	0.08	0.01	−0.01	**0.17**	0.09	0.03
3	0.12	0.10	0.00	**0.17**	0.08	0.07
4	**0.25**	**0.21**	**0.18**	**0.29**	**0.15**	**0.16**
Total response	0.02	−0.02	−0.06	0.11	0.00	−0.01
Reproducibility of TEOAE/Frequency [kHz]						
1	0.04	0.04	−0.03	0.02	0.03	0.08
1.5	0.06	−0.02	−0.07	**0.17**	0.05	0.00
2	0.12	0.05	0.02	**0.21**	0.13	0.01
3	**0.19**	0.14	0.10	**0.22**	**0.16**	0.09
4	**0.26**	**0.23**	**0.20**	**0.29**	**0.15**	**0.16**
Total response	0.10	0.02	0.00	**0.19**	0.08	0.02

ing ability in the (m)AIAHD scores and the TEOAE results ($0.15 \leq r \leq 0.29$, $p < 0.05$). In the latter case, the highest values of correlation coefficient were noted between score of subscale III and amplitude, SNR and reproducibility of TEOAE in the frequency band of 4 kHz (up to 0.29, $p < 0.05$).

4. Discussion

Although hazardous aspects of music have been extensively studied for several decades, there is still lack of unanimous opinion on music exposure causing hearing loss. Nevertheless, studies on orchestral musicians have been relatively consistent that hearing threshold levels in this staff group are higher (worse) when compared to age-related reference data from otologically normal persons, that is ISO 7029 (Royster *et al.*, 1991; Jansson, Karlsson, 1983; Axelsson, Lindgren, 1981; Ostri, 1989).

For example, Royster *et al.*, (1991) analyzed audiometric hearing threshold levels in 59 musicians from the Chicago Symphony Orchestra exposed to orchestral noise at A-weighted daily noise exposure levels of 75–95 dB. Although musicians' HTLs were better than those of unscreened non-industrial population, typical NIHL notches were observed in over half (52.5%) of them.

Recently, Emmerich *et al.* (2008) measured the noise exposure and assessed the audiologic status of 109 professional musicians aged 30–69 years from three major German orchestras. They observed hearing loss ($\geq$ 15 dB) in over half of musicians. The highest losses were found among the string and the brass players. Moreover, among string players a dominant hearing deficit was observed in the left ear.

On the other hand, Jansen *et al.* (2009) have performed an audiological test battery (PTA and otoacoustic emissions (OAEs)) in 241 professional musicians aged between 23 and 64. Most of them had normal hearing, but their audiograms showed notches at 6 kHz. They often complained about tinnitus and hyperacousis, while diplacusis was generally not reported as a problem. The OAEs were more intense with better PTA thresholds. Moreover, the musicians showed worse HTLs than it could be expected on the basis of age and gender.

Our results are in line with the aforesaid findings. Almost all musicians under study had normal hearing (mean hearing threshold level for 0.5, 1, 2 and 4 Hz up to 25 dB) corresponding to grade 0 of hearing impairment according to the classification of the WHO, while only a few of them had hearing loss corresponding to grade 1 or 2. It is worth noting that according to the aforesaid classification in the case of grade 0 ("no impairment") no or very slight hearing problems can occur, and one is able to hear whispers, while in grade 1 ("slight impairment") one is able to hear and repeat words spoken in normal voice at a distance of 1 meter, but hearing aids may be needed (WHO).

Nevertheless, 35.1% of audiograms showed high frequency notches (mainly at 6 kHz). Furthermore, over half of them (61.4) were noted in case of left ear. Nearly every fifth musician had bilateral notching at any frequency (4 or 6 kHz).

Moreover, both PTA and TEOAE consistently showed better hearing in females vs. males and younger vs. older subjects. These findings confirmed some earlier observations. For example, Emmerich *et al.* (2008) in the quoted above study also observed lower hearing loss (at 4 and 6 kHz) in younger musicians (aged 30–39 years) when compared to older ones (aged over 60 years). On the other hand, Kähäri *et al.* (2001) analyzing audiometric HTLs in 140 classical orchestral musicians employed at the Gothenburg Symphony Orchestra and the Gothenburg Opera, found that female musicians had significantly better hearing thresholds in the high-frequency area (above 2 kHz) than did male musicians.

However, contrary to our expectations higher noise exposure levels ($L_{EX,w}$) were not associated with higher (worse) audiometric HTLs and worse results of TEOAE. In our study, higher-exposed musicians ($L_{EX,w} >$ 84.3 dB) had better hearing thresholds (at 1, 4 and 8 kHz) than the lower-exposed individuals ($L_{EX,w} \leq$ 84.3 dB). Furthermore, among older subjects, those lower-exposed had higher hearing level (at 1, 2, 6 and 8 kHz) compared to higher-exposed individuals, while in younger musicians (as expected) there were no differences due to noise exposure.

The impact of noise exposure on TEOAE was less pronounced than was in case of PTA. Higher-exposed musicians had only greater reproducibility (in the frequency band of 1.5 kHz) than lower-exposed ones. Furthermore, among lower-exposed musicians, females showed better results (higher reproducibility of TEOAE at 4 kHz) compared to males, while among higher-exposed subjects there were no differences caused by gender. Among lower-exposed musicians, females showed better reproducibility (at 4 kHz) compared to males, while among higher-exposed subjects there were no differences caused by gender. On the other hand, higher-exposed females had higher SNR (at 4 kHz) than higher-exposed males, while there was no gender-related difference in the lower-exposed musicians.

Generally, the latter results might be explained by high-resistance to NIHL in musicians, in particular those higher-exposed to orchestral noise. It has been shown that individual susceptibility to hearing loss is very diversified (Śliwińska *et al.*, 2006). It is worth to underline that the study group comprised only volunteers. It is obvious that professional musicians which had any hearing problems did not responded positively to the invitation to participate in the study. Nevertheless, the results of hearing tests are consistent with musicians' self-reported hearing ability assessed by the (m)AIAHD showing some hearing difficulties in relation to intelligibility in noisy environment in 29.0% players.

Please note that the (m)AIAHD has been used for various purposes. For example, attempts were made to apply this questionnaire for measuring the effect of middle ear surgery with the aim of improving hearing, as well as for evaluation of the relation between the audiometric and psychometric measures of hearing after tympanoplasty (WHO). The results of the latter investigation indicated that the (m)AIADH scores were almost independent of hearing loss for postoperative hearing levels in the range of 25–40 dB. For the permanent threshold shifts (PTS) higher than 40 dB, the (m)AIAHD scores clearly decreased with an increasing PTS. However, even small residual hearing losses (less than 25 dB) led, on average, to (m)AIADH scores which were substantially lower than scores for normal hearing. Thus, the (modified) Amsterdam Inventory for Auditory Disability and Handicap seems to be a useful tool for a hearing conservation programme.

In this study, the observed audiometric hearing threshold levels were compared with the theoretical predictions according to ISO 1999 (1990). It is worth to underline that aforesaid standard specifies the method for prediction of NIHL after given exposure to noise based on four parameters: age, gender, noise exposure level and duration of noise exposure (in years). However, it does not take into consideration risk factors other than occupational noise, such as exposure to noise beyond workplace (e.g., leisure noise, noise exposure during compulsory military service), co-exposure to certain chemicals (organic solvents and heavy metals), vibrations, and several individual factors and NIHL, including smoking, elevated blood pressure, cholesterol and skin pigmentation (Toppila *et al.*, 2001, Pyykko *et al.*, 2007; Dudarewicz *et al.*, 2010). It does not discuss the protective effects of hearing protective devices, either.

Since in musicians' working conditions there are no ototoxic chemicals or vibrations, to assess the incidence of additional NIHL risk factors, the study subjects filled in a questionnaire. According to the responses, risk factors (such as exposure to noise beyond workplace, smoking, elevated blood pressure, cholesterol and white-finger syndrome) were rather seldom. Moreover, only 11.1% of musicians declared using hearing protective devices at present or in the past. Hence, their protective effect was negligible.

It has been shown that musicians' hearing threshold levels were higher (worse) than equivalent (in terms of age and gender) non-noise-exposed population. When compared to the equivalent population exposed to industrial noise, the actual hearing threshold levels were lower (better) than expected for 3000 and 4000 Hz, while there was no significant difference for 8000 Hz. Furthermore, the observed audiometric hearing losses were higher than predicted for 6000 Hz as well as for 1000 and 2000 Hz.

The latter results (i.e. a relatively high permanent threshold shift at lower frequencies) might be dependent on the testing procedure. Relatively low hearing threshold levels were determined with 5 dB accuracy. Moreover, PTA was performed in quiet rooms (with background noise up to 35 dB) located in concert halls and opera building instead of sound-proof cabins, which is especially important when determining HTLs in the low frequency range. Nevertheless, our findings confirm earlier observations that orchestral noise deteriorate hearing less than expected from noise exposure (Obeling, Polusen, 1999; Toppila *et al.*, 2011).

Recently, Toppila *et al.* (2011) compared audiograms of 63 musicians from four Helsinki orchestras with the theoretical predictions calculated according to ISO 1999 (1990) and analyzed the role of individual susceptibility factors in the onset of hearing loss among this staff group. Number of individual NIHL risk factors was small in their study group. No age dependency was found. The musicians' hearing loss distribution corresponded to that of the general population. However, the highly-exposed players had greater (poorer) permanent threshold shift at the frequencies over 3000 Hz than the lower-exposed individuals. Moreover, the musicians' hearing loss was smaller than expected for the frequencies of 2000, 3000 and 4000 Hz, with an expected value for 6000 Hz, when compared to an industrial population with the same lifetime exposure (Toppila *et al.*, 2011).

Earlier, Obeling and Poulsen (1999) compared audiograms of 57 symphony orchestras to expected (basing on noise exposure) hearing threshold levels from ISO 1999 (1990). They also found out that musicians' actual hearing threshold levels were better than expected from noise exposure and concluded that exposure of musicians cannot be expected to result in pronounced audiometric hearing losses from playing in a symphony orchestra.

To sum up, music impairs hearing of orchestral musicians, but less than expected from noise exposure. Nevertheless, a special hearing conservation program should be developed for the professional group of orchestral musicians.

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