

## Hearing Ability in Orchestral Musicians

Małgorzata PAWLACZYK-ŁUSZCZYŃSKA, Adam DUDAREWICZ,  
Małgorzata ZAMOJSKA, Mariola ŚLIWIŃSKA-KOWALSKA

*Nofer Institute of Occupational Medicine  
Department of Physical Hazards  
Św. Teresy 8, 91-348 Łódź, Poland  
e-mail: {mpawlusz, aduddar9999}@imp.lodz.pl*

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Pure-tone audiometry (PTA) and transient-evoked otoacoustic emissions (TEOAEs) were determined in 57 classical orchestral musicians along with a questionnaire inquiry using a modified Amsterdam Inventory for Auditory Disability and Handicap ((m)AIADH). Data on musicians' working experience and sound pressure levels produced by various groups of instruments were also collected. Measured hearing threshold levels (HTLs) were compared with the theoretical predictions calculated according to ISO 1999:1990. High frequency notched audiograms typical for noise-induced hearing loss were found in 28% of the subjects. PTA and TEOAE consistently showed a tendency toward better hearing in females vs. males, younger vs. older subjects, and lower- vs. higher-exposed to orchestral noise subjects. Audiometric HTLs were better than theoretical predictions in the frequency range of 2000–4000 Hz. The (m)AIADH scores indicated some hearing difficulties in relation to intelligibility in noisy environment in 26% of the players. Our results indicated a need to implement a hearing conservation program for this professional group.

**Keywords:** musicians, exposure to orchestral noise, hearing impairment, pure-tone audiometry, transient-evoked otoacoustic emissions.

### 1. Introduction

Potential risk of noise-induced hearing loss (NIHL) in musicians has been extensively investigated since the 1960s. It has been shown that players, especially professional orchestral musicians, can develop NIHL and suffer from other hearing impairment symptoms such as tinnitus, hyperacusis, ringing in the ears, which can influence their work abilities more severely than hearing loss. However, due to insufficient audiometric evidence of hearing loss caused purely by music exposure, there are still disagreement and speculations about a risk of hearing loss from music exposure alone (AXELSSON, LINDGREN, 1981; KARLSSON *et al.*, 1983;

ROYSTER *et al.*, 1991; TEIE, 1998; OBELING, POULSEN, 1999; KÄHÄRI *et al.*, 2001; EMMERICH *et al.*, 2008; JANSEN *et al.*, 2009; ZHAO *et al.*, 2009).

The aim of this study was to assess hearing status of professional orchestral musicians and its relation with self-reported hearing ability. Another objective was to compare actual audiometric hearing threshold levels with theoretical predictions according to ISO 1999 (1990).

## 2. Materials and the research procedure

### 2.1. Subjects

57 professional musicians (26 females and 31 males), aged 24–67 years (mean  $\pm$  SD:  $43.6 \pm 11.9$  years, median: 44.0 years) from opera and symphony orchestras participated as subjects of the research. The study group comprised musicians playing violin (17), viola (8), cello (7), trombone (4), oboe (4), flute (3), trumpet (3), bassoon (2), double bass (2), clarinet (2), guitar (1), tube (1), harp (1), percussion (1) and horn (1).

### 2.2. Questionnaire inquiries

All musicians were interviewed to collect information concerning: (i) age and gender, (ii) education, (iii) professional experience, (iv) medical history (past middle-ear diseases and surgery, etc.), (v) physical features (body weight, height, skin pigmentation), (vi) lifestyle (smoking, noisy hobbies, etc.), and (vii) self-assessment of hearing status. 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. These data were crucial for evaluation musicians' exposure to orchestral noise and calculation of expected hearing threshold levels from ISO 1999 (1990).

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: (i) distinction of sounds (subscale I), (ii) auditory localization (subscale II), (iii) intelligibility in noise (subscale III), (iv) intelligibility in quiet (subscale IV), and (v) 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 (two questions were excluded as the authors of AIADH also excluded these questions after statistical analysis) (MEIJER *et al.*, 2003). Maximum total score of the questionnaire was 84. Addi-

tionally, the answers for each subscale were added up (the maximum score for subscale I was 24, while for the other subscales it was 15).

### 2.3. Hearing examinations

Conventional pure-tone audiometry (PTA) and transient-evoked otoacoustic emission (TEOAE) were determined in the subjects under study. Before the exact examinations, otoscopy was performed in order to screen for conditions that would exclude examined subjects from the study. Hearing tests were performed in quiet rooms located in concert halls and an opera building where the background noise did not exceed 35 dB(A).

PTA was performed using an Audio Traveller Audiometer type 222 (Interacoustics) with TDH 39 headphones. Hearing threshold levels (HTLs) for air conduction were set at frequencies from 250 to 8000 Hz 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.

The results of PTA and TEOAE were related to the results of hearing ability assessment expressed in terms of (m)AIADH. Additionally, the musicians' actual hearing threshold levels were compared with the theoretical predictions calculated according to ISO 1990 (1990).

### 2.4. Evaluation of exposure to orchestral noise

In order to evaluate musicians' exposure to orchestral noise, measurements of sound pressure level were performed in one opera and two concert halls during rehearsals, concerts and/or performances. These measurements comprised a diverse repertoire. However, due to organizational reasons, they did not include musicians' individual rehearsals.

The measurements of orchestral noise were carried out according to Polish standard PN-N-01307 (1994) and international standard ISO 9612 (1997), using both integrating-averaging sound level meters and personal sound exposure meters (i.e. the SVANTEK (Poland) sound analyzers type 912, 912E and 958 as well as the Bruel & Kjaer (Denmark) personal logging noise dosimeters type 4443) placed in various instrument groups. Both types of meters were positioned on tripods with the microphones close to the ear of the players. The distance to the ear (from 0.1 to 0.5 m) was kept as short as practically possible (without interfering with the musicians). Each single measurement period usually corre-

sponded to the duration of a rehearsal, concert or performance. In general, results of 211 measurement samples (lasting in total approx. 516 hours) were collected.

Results of the aforesaid noise measurements and data on musicians' professional experience were used for evaluation of their exposure to orchestral noise. For each subject, a distribution of weekly noise exposure level was determined from the equivalent continuous  $A$ -weighted sound pressure levels ( $L_{Aeq,T}$ ) produced by the respective instrument and declared time of weekly practice ( $T_w$  in hours). (Since some musicians played many instruments, these evaluations were based on data concerning the main instrument.) In particular, the weekly noise exposure levels ( $L_{EX,w,10}$ ,  $L_{EX,w,50}$  and  $L_{EX,w,90}$ ) corresponding to 10th, 50th and 90th percentiles of the  $L_{Aeq,T}$  level were calculated using following Eqs. (1)–(3):

$$L_{EX,w,10} = L_{Aeq,T,10} + 10 \lg(T_w/T_o) \quad [\text{dB}], \quad (1)$$

$$L_{EX,w,50} = L_{Aeq,T,50} + 10 \lg(T_w/T_o) \quad [\text{dB}], \quad (2)$$

$$L_{EX,w,90} = L_{Aeq,T,90} + 10 \lg(T_w/T_o) \quad [\text{dB}], \quad (3)$$

where  $L_{Aeq,T,10}$ ,  $L_{Aeq,T,50}$  and  $L_{Aeq,T,90}$  are the 10th, 50th and 90th percentiles of an equivalent continuous  $A$ -weighted sound pressure level produced by the respective instrument (in dB),  $T_w$  is declared time of weekly practice (in hours),  $T_o$  – is the reference duration,  $T_o = 40$  h.

Additionally, musicians' exposures were described by a noise immission level, i.e. a measure of the cumulative noise energy to which an individual was 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 ("noise immission level"). In particular, the noise immission level ( $L_{im50}$ ) corresponding to the  $L_{EX,w,50}$  level and total time of exposure ( $T$ ) in years was calculated from:

$$L_{im50} = L_{EX,w,50} + 10 \lg T \quad [\text{dB}]. \quad (4)$$

### 2.5. Prediction of noise-induced hearing loss

The international standard ISO 1999 (1990) specifies the method for determining a statistical distribution of hearing threshold levels in adult population after exposure to noise based on four parameters: age, gender, noise exposure level and duration of noise exposure (in years).

Since it was rather difficult to accurately evaluate musicians' noise exposure level averaged over total time of exposure (professional playing), for each subject the  $L_{EX,w}$  level was 10 times randomly chosen from their assigned distribution. (The aforesaid distributions of weekly noise exposure level were approximated by two different halves of two normal distributions with mean values equal to median value). Subsequently, for each randomly chosen value of the  $L_{EX,w}$  level and actual subject's values of age, time of exposure in years and gender, the

distributions of the expected hearing threshold levels (associated with noise and age) were calculated (separately at frequencies 1, 2, 3, 4 and 6 kHz) according to ISO 1999 (1990). Then, for each frequency from 1 to 6 kHz, the HTLs were selected randomly 10 times from each of the determined distributions. Results of the aforesaid random selection were rounded up to the closest multiple of five. In consequence, for each subject, a distribution of a predicted noise-induced permanent threshold shift (separately at frequencies 1, 2, 3, 4 and 6 kHz) consisting of 100 randomly selected HTLs, was determined. Finally, these individual distributions were summarized (with weight  $w = 0.01$ ) to obtain the distribution of theoretically predicted audiograms for population equivalent to study group according to age, gender, weekly noise exposure level and duration of exposure (in years).

### 2.6. Data analysis

The distributions of measured and predicted hearing threshold levels were compared with a t-test for dependent data. However, due to accuracy of PTA, hearing threshold levels below 0 dB were excluded from analysis.

The main effects ANOVA was used to analyze the first-order (non-interactive) effects of multiple factors such as: gender, age and exposure, on PTA and TEOAE results as well as the (m)AIAHD scores. 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 (high-exposed) or lower-exposed (low-exposed) on the basis of values of noise immission level ( $L_{im50}$ ) assigned to them. Subjects with the  $L_{im50}$  levels above the median value (calculated for the whole study group) were classified as higher-exposed, while the others as lower-exposed ones. Similarly, the median value of age was used as the basis for classification of subjects as younger and older ones.

The differences between the subgroups in the frequency of answers given in questionnaire as well as the incidence of certain hearing test results or scores in (m)AIAHD were assessed using the exact Fisher test. The possible relations between 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.

All statistical tests were done with an assumed level of significance  $p < 0.05$ . The STATISTICA (version 6.1) software package was employed for the statistical analysis of the data.

## 3. Results and discussion

### 3.1. Questionnaire inquiries

The musicians under study had from 6 to 49 years ( $25.3 \pm 11.7$  years) of musical career or comparable experience (including employment in opera or symphony orchestra). They were usually exposed to music from 7 to 70 hours per week

(29.1±9.7 hours per week) due to both on-the-job and off-the-job playing. The questionnaire also provided data about additional NIHL risk factors such as noisy hobbies, smoking, elevated blood pressure. However, these data will be described in detail elsewhere.

Generally, almost all the musicians (95.8%) assessed their hearing as good. However, about one quarter of them (26.1%) noticed hearing impairment associated with difficulty in speech intelligibility in noisy environment (45.8%) and hearing whisper (16.7%). Nearly every fifth (16.7%) musician complained of tinnitus, while 42.1% of them reported hyperacusis.

Females more frequently than males complained on difficulty in speech intelligibility in noisy environment (64.3% vs. 28.6%,  $p < 0.05$ ) and hearing whisper (28.6% vs. 7.1%,  $p < 0.05$ ). A similar relationship was observed for older (age  $> 44$  years) and younger (age  $\leq 44$  years) subjects (62.5% vs. 37.5% and 37.5% vs. 6.3%, respectively).

The musicians examined using (m)AIADH obtained a mean total score of 89% of the maximum value, which suggests no substantial hearing difficulties in the subjects under study (Table 1). Relatively low scores were frequent only in the subscale evaluating intelligibility in noise (26.5% of the subjects scored below 70% of the maximum value).

**Table 1.** Musicians' self-assessment of hearing ability in the (m)AIAHD scores.

	Score: Mean ± SD					
	Total	Subscale I	Subscale II	Subscale III	Subscale IV	Subscale V
All subjects	74.8±7.8	22.7±1.7	13.1±2.0	12.1±2.3*	13.2±1.9*	13.9±1.6

\* Significant main effect of age ( $p < 0.05$ ).

Generally, neither gender nor exposure were found to significantly affect (m)AIAHD scores. The only significant differences noted were those between older and younger subjects in scores in the subscale intended to evaluate intelligibility in noise (subscale III) and intelligibility in quiet (subscale IV) (10.8±2.0 vs. 13.6±1.9 and 12.3±2.3 vs. 14.1±1.1,  $p < 0.05$ ). Older musicians more often than younger ones reported difficulties with intelligibility in noise and quiet, i.e. scored below 70% of the maximum value (47.1% vs. 5.7%,  $p < 0.05$  and 26.7% vs. 0.0%,  $p < 0.05$ ).

### 3.2. Evaluation of exposure to orchestral noise

Sound pressure levels produced by various groups of instruments are presented in Table 2. Equivalent continuous *A*-weighted sound pressure levels ( $L_{Aeq,T}$ ) varied at group rehearsals, concerts and performances from 72–97 dB. The weekly noise exposure levels and noise immission levels were calculated basing on these data ranged between 67–93 dB and 83–108 dB respectively (for the details see Table 3).

Several studies have investigated musicians' exposure to sound (JANSSON, KARLSSON, 1983; ROYSTER *et al.*, 1991; OBELING, POULSEN, 1999; LAITINEN *et al.*, 2003; O'BRIEN, BRADLEY, 2008). It has been shown that from an exposure prospective the individual rehearsals were as important as performances and group rehearsals (ROYSTER *et al.*, 1991; LAITINEN *et al.*, 2003). For example,

**Table 2.** Sound pressure levels (SPLs) for different instrument groups of orchestra. (Data collected during rehearsals, concerts or performances in one opera and two concert halls. No individual rehearsals were included).

Instrument group (number of samples)	Equivalent-continuous A-weighted SPL, $L_{Aeq,T}$ [dB]	Maximum A-weighted SPL, $L_{AS\max}$ [dB]	Peak C-weighted SPL, $L_{Cpeak}$ [dB]
	Mean $\pm$ SD – 10th/50th/90th percentile		
Viola (28)	83.3 $\pm$ 3.3 [84.3]* 78/84/88	97.1 $\pm$ 4.5 91/98/102	113.1 $\pm$ 5.8 105/115/120
Violin (30)	83.3 $\pm$ 2.9 [86.9] 80/83/87	98.1 $\pm$ 4.1 93/98/105	115.2 $\pm$ 5.2 108/116/120
Double bass (13)	80.1 $\pm$ 4.9 [88.4] 73/81/84	96 $\pm$ 5.8 89/97/103	114.7 $\pm$ 6.2 107/117/122
Cello (18)	80.2 $\pm$ 3.2 [81.1] 75/81/84	94.8 $\pm$ 4.3 89/95/101	113.5 $\pm$ 5 108/113/122
Harp (4)	81.5 $\pm$ 2.7 [82.1] 78/82/85	96.8 $\pm$ 3.1 92/98/99	119.3 $\pm$ 4.7 114/119/125
Bassoon (20)	85.8 $\pm$ 3.4 [88.2] 82/86/89	101.8 $\pm$ 5.1 96/101/108	120.2 $\pm$ 6.4 114/121/129
Flute (14)	85.7 $\pm$ 2.7 [86.3] 83/86/89	101.4 $\pm$ 3.3 98/102/107	118.3 $\pm$ 4 114/119/123
Oboe (7)	85.9 $\pm$ 2.4 [88.3] 83/86/89	100.9 $\pm$ 2.1 97/102/103	120.7 $\pm$ 2.7 115/121/124
Clarinet (10)	85.9 $\pm$ 3.3 [82.2] 81/87/90	101.5 $\pm$ 3.6 97/102/106	120.2 $\pm$ 5.3 113/121/127
Horn (25)	87.9 $\pm$ 3.4 [89.4] 84/88/92	104.7 $\pm$ 4.7 99/105/112	122.5 $\pm$ 6.4 115/123/128
Trombone (12)	87.7 $\pm$ 2.3 [84.2] 84/88/90	105.4 $\pm$ 2.7 102/105/110	124.1 $\pm$ 3.4 119/125/128
Trumpet (12)	88.6 $\pm$ 2.4 [89.2] 86/89/91	106.8 $\pm$ 3.3 104/106/110	125.7 $\pm$ 6.8 121/124/129
Tube (5)	88.2 $\pm$ 2.3 [88.5] 87/88/90	107.6 $\pm$ 2.7 106/108/110	125 $\pm$ 4.7 122/125/128
Percussion section (11)	86.1 $\pm$ 5.7 [86.5] 77/87/91	104.2 $\pm$ 7.2 98/106/111	128.4 $\pm$ 8.6 122/131/134
Total (211)	84.7 $\pm$ 4.2 [86.5] 79/85/90	99.9 $\pm$ 8.2 92/100/107	119.7 $\pm$ 7.2 109/119/128

\* Data recalculated according to the job-based measurement strategy as specified in the recently published international standard ISO 9612 (2009).

Table 3. Summary results of noise exposure evaluation in musicians under study.

Noise exposure parameters	Subgroup of subjects					All subjects	
	Females	Males	Younger subjects	Older subjects	Lower-exposed subjects		Higher-exposed subjects
	Mean $\pm$ SD						
10th percentile of equivalent-continuous A-weighted sound pressure level ( $L_{Aeq,T,10}$ ) [dB]	79.0 $\pm$ 2.5 75/80/83	80.8 $\pm$ 3.8 75/81/86	80.0 $\pm$ 3.7 75/80/84	80.0 $\pm$ 3.1 75/80/84	78.7 $\pm$ 3.4 75/80/83	81.4 $\pm$ 2.8 78/80/86	80.0 $\pm$ 3.4 75/80/84
50th percentile of equivalent-continuous A-weighted sound pressure level ( $L_{Aeq,T,50}$ ) [dB]	83.2 $\pm$ 1.6 81/83/86	85.3 $\pm$ 2.6 81/86/88	84.4 $\pm$ 2.4 81/84/88	84.3 $\pm$ 2.5 81/83/88	83.3 $\pm$ 2.2 81/83/86	85.4 $\pm$ 2.2 83/85.5/89	84.4 $\pm$ 2.4 81/84/88
90th percentile of equivalent-continuous A-weighted sound pressure level ( $L_{Aeq,T,90}$ ) [dB]	86.8 $\pm$ 1.7 84/87/89	88.5 $\pm$ 2.2 84/89/91	87.8 $\pm$ 2.1 84/88/90	87.7 $\pm$ 2.2 84/87/91	86.7 $\pm$ 2.1 84/87/89	88.8 $\pm$ 1.6 87/89/91	87.7 $\pm$ 2.2 84/88/90
Weekly practice ( $T_w$ ) [hours]	29.8 $\pm$ 7.3 20/30/40	28.4 $\pm$ 11.4 18/30/40	28.8 $\pm$ 8.5 18/30/40	29.3 $\pm$ 10.9 18/30/40	27.9 $\pm$ 9.3 7/30/40	30.3 $\pm$ 10.1 18/30/40	29.1 $\pm$ 9.7 18/30/40
Weekly noise exposure level ( $L_{EX,w,10}$ ) corresponding to $L_{Aeq,T,10}$ [dB]	77.6 $\pm$ 3.2 73.8/78.55/80.8	79.0 $\pm$ 3.5 75/78.8/82.5	78.3 $\pm$ 3.1 73.8/78/82.5	78.4 $\pm$ 3.7 73.8/78.8/82.5	76.8 $\pm$ 3.1 73.5/76.8/80.8	80 $\pm$ 2.9 76.8/79.15/83	78.4 $\pm$ 3.4 73.8/78.8/82.5
Weekly noise exposure level ( $L_{EX,w,50}$ ) corresponding to $L_{Aeq,T,50}$ [dB]	81.8 $\pm$ 2.3 79.8/81.8/83.8	83.5 $\pm$ 2.6 80.4/83.7/85.8	82.8 $\pm$ 2.0 80.4/82.8/85.8	82.7 $\pm$ 3.1 79.8/82.3/85.5	81.4 $\pm$ 2.2 79.8/81.3/84.4	84 $\pm$ 2.2 81.8/83.8/86.8	82.7 $\pm$ 2.6 80/82.8/85.5
Weekly noise exposure level ( $L_{EX,w,90}$ ) corresponding to $L_{Aeq,T,90}$ [dB]	85.4 $\pm$ 2.4 82.8/85.8/87.4	86.6 $\pm$ 2.4 83.5/86.8/88.8	86.1 $\pm$ 2.0 82.8/86.4/88.8	86.0 $\pm$ 2.9 82.8/85.8/88.5	84.8 $\pm$ 2.4 82.4/85/87.4	87.4 $\pm$ 1.8 85.8/87/89.8	86.1 $\pm$ 2.5 82.8/86.4/88.8
Total time of exposure ( $T$ ) [years]	25.6 $\pm$ 11.7 10/24/40	25.1 $\pm$ 11.9 9/24/40.3	15.3 $\pm$ 5.2 7.5/15/22.1	35.7 $\pm$ 6 27.7/36/43	19.0 $\pm$ 10.6 7.5/16.5/37.8	31.8 $\pm$ 9.1 15/32.9/41.7	25.3 $\pm$ 11.7 10/24/40.3
Noise inmission level ( $L_{im,10}$ ) corresponding to $L_{EX,w,10}$ [dB]	91.3 $\pm$ 3.7 85.4/92.5/94.8	92.4 $\pm$ 4.4 86.9/92.8/96.9	89.9 $\pm$ 3.6 84.6/89.4/94.4	94 $\pm$ 3.5 90/94.5/97.1	89.1 $\pm$ 3.1 84.6/89.4/92.8	94.8 $\pm$ 2.7 91.2/94.75/97.3	91.9 $\pm$ 4.1 85.4/92.7/96.9
Noise inmission level ( $L_{im,50}$ ) corresponding to $L_{EX,w,50}$ [dB]	95.5 $\pm$ 2.9 91.3/96.2/99.2	96.9 $\pm$ 3.6 92.6/97.3/100.1	94.3 $\pm$ 2.6 90.6/94.3/97.4	98.3 $\pm$ 2.9 95.7/98.15/101.1	93.7 $\pm$ 2.3 90.4/94.1/96.4	98.9 $\pm$ 1.9 97.2/98.7/101.1	96.3 $\pm$ 3.4 91.3/96.7/100
Noise inmission level ( $L_{im,90}$ ) corresponding to $L_{EX,w,90}$ [dB]	99.1 $\pm$ 3.1 94.4/99.2/103.2	100.1 $\pm$ 3.5 95.4/101.1/103.7	97.7 $\pm$ 2.6 94.4/98.1/101.2	101.6 $\pm$ 2.8 99/101.8/104.3	97.0 $\pm$ 2.4 93.4/97.9/99.7	102.3 $\pm$ 1.6 100.6/101.85/104.3	99.6 $\pm$ 3.4 95.3/100.3/103.2
Age [years]	44.2 $\pm$ 12.2 28/47/58	43.1 $\pm$ 11.9 27/42/58.3	33.2 $\pm$ 5.2 25.5/33/40.1	54.4 $\pm$ 5.3 47/54/61	37.6 $\pm$ 11.3 25.5/34.5/57.9	49.8 $\pm$ 9.1 33/50.9/59.7	43.6 $\pm$ 11.9 28/44/58.3
Number of subjects	26	31	29	28	29	28	57

LAITINEN *et al.* (2003) investigated sound exposure among the Finnish National Opera Personnel. During performances and group rehearsals, the equivalent continuous *A*-weighted sound pressure levels varied among the groups from 82 dB for the double bass players to 98 dB for flute/piccolo players. For individual rehearsals, the lowest sound level was observed among double bass players (79 dB), while the highest levels were found among percussionists and flute/piccolo players (up to 99 dB).

Unfortunately, this study did not evaluate personal rehearsals in detail. It was simply assumed that sound pressure levels produced by various instruments during solo practicing were similar to those occurring during group rehearsals or concerts and performances. Therefore, the evaluated weekly noise exposure levels were likely to be overestimated in case of double bass, bassoon and some other instruments players, while an opposite relation probably occurred among percussionists, flute players and some other brass players. Thus, the further research is necessary to evaluate musicians' sound exposure in more detail.

### 3.3. Results of PTA and TEOAE

Audiometric hearing threshold levels determined in 57 professional orchestral musicians (114 ears) are shown in Fig. 1.

Significant main effects of age and/or gender on HTLs in the frequency range from 750 to 8000 Hz were observed (Figs. 1a and 1b). Similar to earlier findings (KÄHÄRI *et al.*, 2001), male, compared to the female musicians, showed a considerably higher reduction of hearing threshold level in the high frequency region from 3000 to 6000 Hz. Significantly higher HTLs in the frequencies from 750 Hz to 8000 Hz were noted in younger (age  $\leq 44$  years) rather than older (age  $> 44$  years) musicians (Fig. 1b). A tendency to higher reduction of hearing threshold level in the whole frequency range was observed in the higher-exposed subjects ( $L_{im50} > 96.7$  dB) compared to the lower-exposed individuals ( $L_{im50} \leq 96.7$  dB) (Fig. 1c). However, a significant difference was noted only for HTLs at 8000 Hz.

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 28.1% of the subjects. An overall prevalence of notches (both ears) was 31.6%, with 80.6% of the notches occurring at 6000 Hz. The portion of the total population with a bilateral notching at any frequency was 15.6%.

In the majority (93.9%) 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 (WHO). Such situation more frequently occurred in the case of younger rather than the older musicians (100.0% vs. 87.5%,  $p < 0.05$ ). Only 6.1% of the measured audiograms corresponded to grade 1 of hearing impairment. Moreover, all of them were found in the older musicians. According to the classification of the World Health Organization (WHO) 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

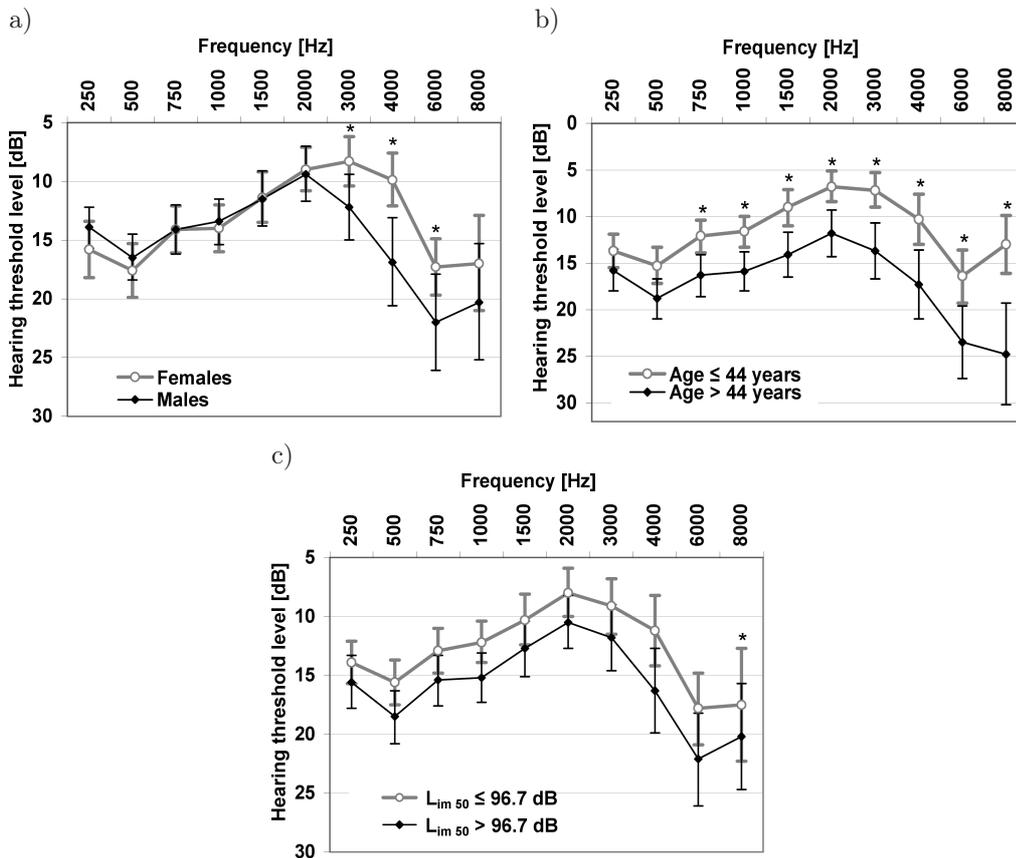


Fig. 1. Audiometric hearing threshold levels (Mean  $\pm$  95% CI) in various subgroups of musicians, i.e. a) females vs. males, b) younger (age  $\leq$  44 years) vs. older (age  $>$  44 years) subjects, and c) lower-exposed ( $L_{im50} \leq 96.7$  dB) vs. higher-exposed ( $L_{im50} > 96.7$  dB) subjects. Subjects were classified as younger and older or lower- and higher-exposed based on median values of age and noise immersion level ( $L_{im50}$ ), respectively. Significant differences between subgroups were marked by (\*).

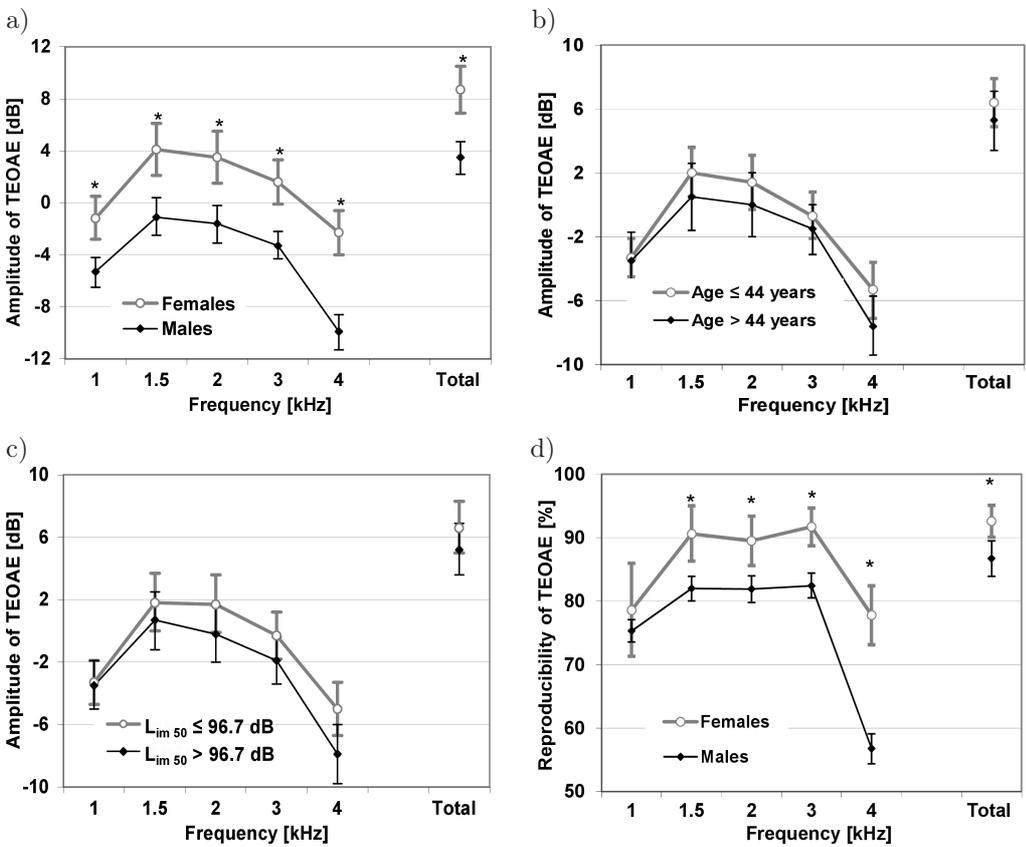
repeat words spoken in normal voice at a distance of 1 meter, but hearing aids may be needed (WHO).

Summary results of TEOAE testing are shown in Fig. 2. A significant main effect of gender on TEOAE amplitude, signal to noise ratio (SNR) as well as reproducibility (excluding the frequency band of 1000 Hz) was noted (Figs. 2a, 2d and 2g,  $p < 0.05$ ). Both younger vs. older subjects and lower- vs. higher-exposed ones showed a tendency towards higher TEOAE amplitudes, but no significant differences were found (Figs. 2b and 2c). A significant main effect of age was observed in the case of SNR (at the frequency band of 1500 kHz) and reproducibility (for the total response and frequency bands of 1 and 1.5 kHz) (Figs. 2e and 2h). Generally, there were no significant differences in the results of TEOAE testing between the subjects with lower and higher noise immis-

sion levels ( $L_{im50} \leq 96.7$  dB and  $L_{im50} > 96.7$  dB, respectively) (Figs. 2c, 2f and 2i).

A reproducibility of TEOAE above 70% for the total response and frequency band of 4000 Hz was noted in the case of 91.6% and 58.9% of ears, respectively. On the other hand, the signal-to-noise ratio higher than 6 dB was observed in 63.6% and 57.0% of the cases for the total response and frequency band of 4000 Hz, respectively. Both higher values of reproducibility and SNR were more frequently noted in the females than males.

The effects of music on hearing have been extensively investigated since the 1960s. However, there are still disagreement and speculations about a risk of hearing loss from music exposure alone. There are studies concluding that classical musicians have NIHL due to music exposure (AXELSSON, LINGDREN, 1981; ROYSTER *et al.*, 1991; OSTRI *et al.*, 1989) and studies suggesting just the opposite (KARLSSON *et al.*, 1983; OBELING, POULSEN, 1999; KÄHÄRI *et al.*, 2001). Recently, JANSEN *et al.* (2009) have performed an audiological test battery (PTA and otoacoustic emissions (OAE)) in 241 professional musicians aged between 23 and 64. Most of them had normal hearing, but their audiograms showed notches



[Fig. 2a-d]

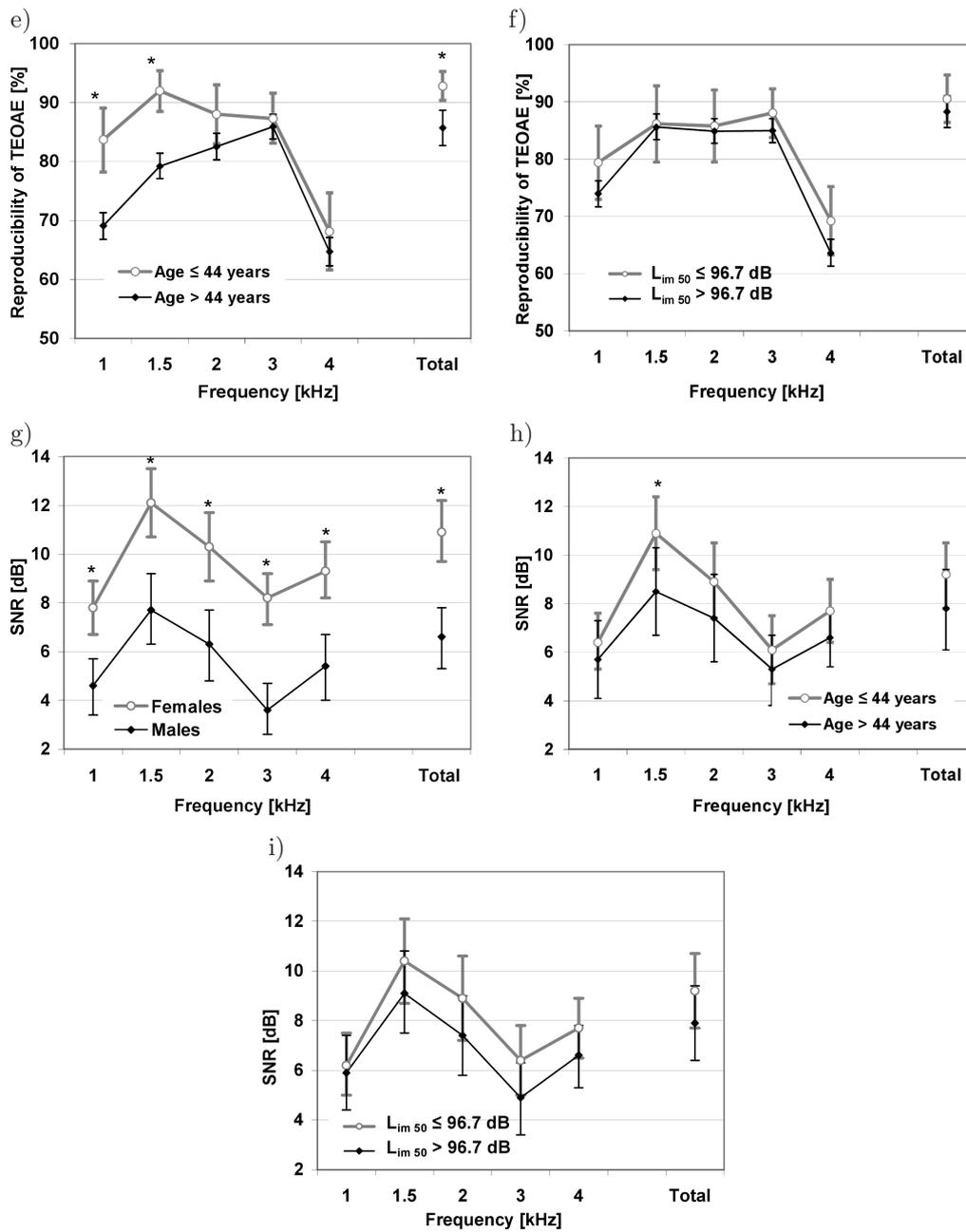


Fig. 2. TEOAEs (Mean  $\pm$  95% CI) in various subgroups of musicians, i.e. (a, d, g) females vs. males, (b, e, h) younger (age  $\leq$  44 years) vs. older (age  $>$  44 years) subjects, and (c, f, i) lower-exposed ( $L_{im50} \leq 96.7$  dB) vs. higher-exposed ( $L_{im50} > 96.7$  dB) subjects. Subjects were classified as younger and older or lower- and higher-exposed based on median values of age and noise immission level ( $L_{im50}$ ), respectively. Significant differences between the subgroups were marked by (\*).

at 6 kHz. They often complained about tinnitus and hyperacusis, 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 agreement with the aforesaid findings. Almost all musicians under study had normal hearing (mean hearing threshold level for 500, 1000, 2000 and 4000 Hz up to 25 dB). However, high frequency notched audiograms typical for NIHL were found in 28% of subjects. Moreover, both PTA and TEOAE consistently showed a tendency towards better hearing in females vs. males, younger vs. older subjects, and lower- vs. higher-exposed to orchestral noise subjects. Although, in the latter case, no significant differences were noted.

A weak but statistically significant linear relationship was noted between the audiometric hearing threshold level at 1500 Hz and the total score of (m)AIAHD ( $r = -0.38$ ,  $p < 0.05$ ), as well as scores of subscales intended to evaluate intelligibility in noise (subscale III), intelligibility in quiet (subscale IV), and detection of sounds (subscale V) ( $r$  varied from  $-0.36$  to  $-0.46$ ,  $p < 0.05$ ). The same relationships were found for other individual audiometric frequencies (excluding 250 and 4000 Hz) and the subscale III score ( $r$  varied from  $-0.35$  to  $-0.52$ ,  $p < 0.05$ ). The latter score was also significantly correlated with SNR (at the frequency band of 4000 Hz) in the TEOAE testing ( $r = 0.40$ ,  $p < 0.05$ ).

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 (MEIJER *et al.*, 2004, 2006). 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) lead, 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.

### 3.4. Comparison of actual and predicted hearing threshold levels

Figure 3 presents a distribution of weekly noise exposure levels which were included in the calculations of expected hearing losses in musicians, while Fig. 4 shows averaged audiogram of the 57 subjects (114 ears) and predicted hearing threshold levels according to ISO 1999 (1990).

As it can be seen, there were no significant differences between the measured and predicted HTLs at 6000 Hz ( $p > 0.05$ ). On the other hand, the actual hearing threshold levels were lower (better) than predicted at 2000, 3000 and 4000 Hz, while an opposite relationship was observed for 1000 Hz ( $p < 0.05$ ).

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(A)) located in concert halls and opera building instead of sound-proof cabins, which is especially important when determining HTLs in the low frequency range.

In general, the findings presented here confirm earlier observations that orchestral noise deteriorates hearing less than expected from ISO 1999 (1990). They are particularly in line with those obtained by KOSKINEN (2010). Recently she has compared audiograms of 63 orchestral musicians with the theoretical predic-

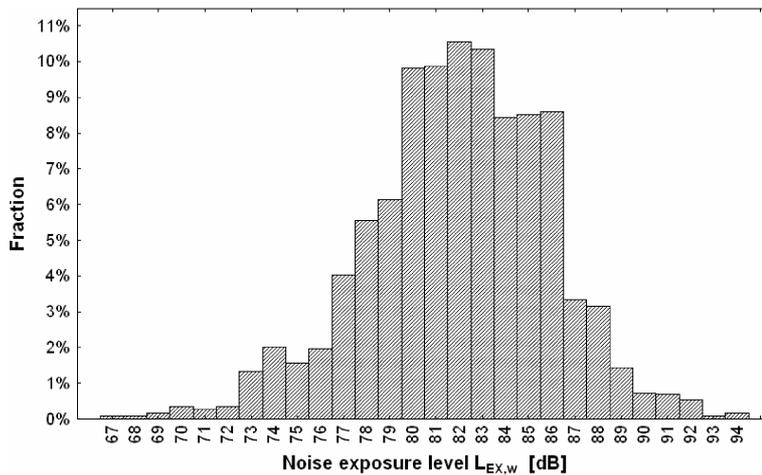


Fig. 3. Distribution of weekly noise exposure levels ( $L_{EX,w}$ ) underlying the calculations of predicted hearing threshold levels in musicians. (For each musician the  $L_{EX,w}$  level was randomly chosen 10 times from their assigned distribution).

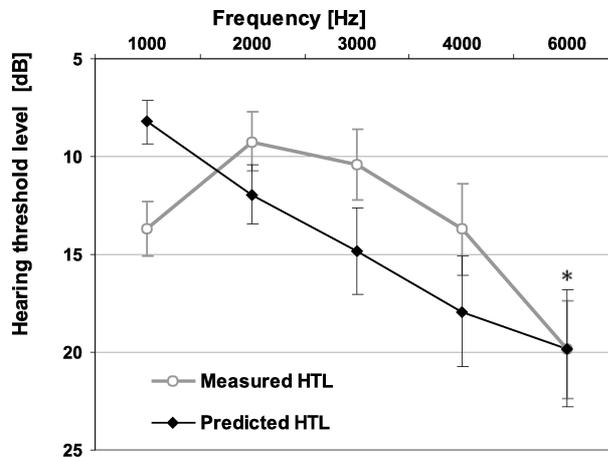


Fig. 4. Measured hearing threshold levels (HTLs) in musicians and predicted HTLs according to ISO 1999 (Mean  $\pm$  95% CI). Cases without significant differences were denoted by (\*).

tions calculated according to ISO 1990 (1990) as well as with hearing threshold levels of non-exposed population and found that musicians' hearing loss distribution corresponded to that of the general population. However, the highly-exposed individuals had greater (worse) permanent threshold shift at the frequencies over 3000 Hz than the less-exposed ones. Moreover, the musicians' hearing loss was smaller than expected for the frequencies of 2000, 3000 and 4000 Hz, with an expected value of 6000 Hz, when compared to an industrial population with the same lifetime exposure (KOSKINEN, 2010).

#### 4. Conclusions

Results of pure-tone audiometry performed in professional orchestral musicians indicated high frequency notched audiograms in 28% of the individuals. Nevertheless, most musicians (94%) had hearing threshold levels corresponding to grade 0 ("no impairment") according to the WHO Grades of hearing impairment.

Both pure tone audiometry and transient-evoked otoacoustic emissions consistently showed a tendency towards better hearing in females vs. males and younger vs. older musicians. A similar relationship was observed between lower- and higher-exposed to orchestral noise subjects. However, in the latter case differences in hearing were generally non-significant.

Musicians' actual hearing threshold levels were better than theoretical predictions from ISO 1999 in the frequency range of 2000–4000 Hz. However, there was a good agreement between the measured and predicted hearing threshold levels at 6000 Hz.

Hearing test results were consistent with musicians' self-reported hearing ability assessed by a (modified) Amsterdam Inventory for Auditory Disability and Handicap showing some hearing difficulties in relation to intelligibility in noisy environment in 26% of players.

Hearing conservation programs should be applied for professional orchestral musicians.

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