Hearing loss amongst classical music students

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INTRODUCTION

Performing artists must be able to practice, rehearse, and perform safely. With respect to hearing and the "noise" of performance however, the nature of their work and the dedication of performers themselves may mean that they are placed in a difficult position when complying with new international noise at work regulations.

Since 2008, with the introduction of the new Control of Noise at Work Regulations 2005 (HSE 2005) in the UK, hearing health surveillance is necessary for any employee at risk of high noise exposure. Being at the forefront of classical music education, the Royal Academy of Music decided two years before the enforcement of the new regulations in 2008 to start the implementation of a health surveillance programme and the continuous collection of data on the hearing acuity of their music students. This paper presents the approach of the Royal Academy of Music on the issue of health surveillance for classical music students and discusses the findings of audiometric hearing tests conducted during 2006-2010.

THE APPROACH

The Royal Academy of Music took an inclusive view whereby every new student had to compulsorily take an automated audiometric screening test during the first week of his or her studies at the Academy (Fresher's week). The testing closely followed the methodology outlined in the Control of Noise at Work Regulations. Students, prior to testing, attended a 1-hour hearing seminar, which amongst others, informed students on the purpose and procedure of the audiometric testing. To minimise the influence of any Temporary Threshold Shift (TTS), students were asked to avoid exposure to any loud noise a day before their testing and the use of ipod while travelling to the test. One-to-one interviews with each student and an otoscopic examination were used to identify any factors, which may influence the health surveillance results.

The test was based on a pure-tone air conduction Bekesy test (frequencies 500 Hz to 8 kHz) and was conducted in the audiometric soundproof booths at the Acoustic Laboratory of London South Bank University (LSBU); see Figure 1. Both booths used met the criteria given in ISO 8253-1:1989 (ISO 1989). Once the test and questionnaire was completed, each audiogram was categorised according to the Health and Safety Executive (HSE) categorisation scheme (HSE 2005); see Table 1. Students received a copy of their audiogram with the original being sent to the Academy for their records. Results were discussed individually with each student and advice has been given on protection from noise exposure, including advice on most suitable hearing protection option based on the instrument played.

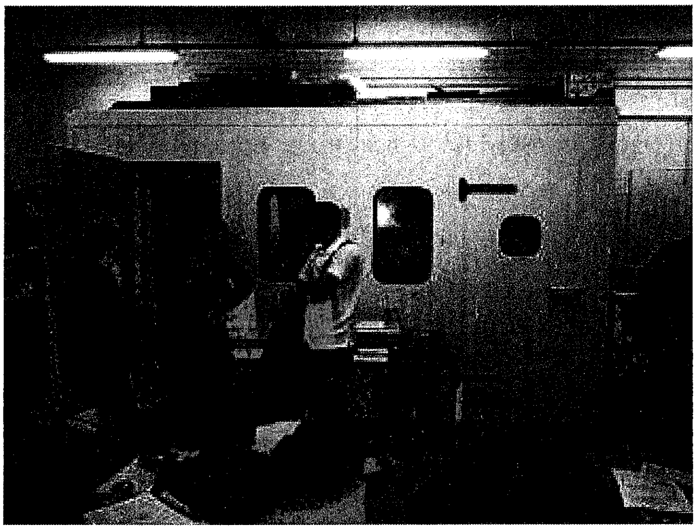

Figure 1: Audiometric booths and audiometers

Table 1: HSE categorisation scheme

Category	*Calculation*	*Action*
1 **ACCEPTABLE HEARING ABILITY** Hearing within normal limits	Sum of hearing levels at 1, 2, 3, 4 and 6 kHz.	None
2 **MILD HEARING IMPAIRMENT** Hearing within 20th percentile. May indicate developing NIHL.	Sum of hearing levels at 1, 2, 3, 4 and 6 kHz. Compare value with figures given for appropriate age band and gender.	Warning
3 **POOR HEARING** Hearing within 5th percentile. Suggests significant NIHL.	Sum of hearing levels at 1, 2, 3, 4 and 6 kHz. Compare value with figures given for appropriate age band and gender.	Referral
4 **RAPID HEARING LOSS** Reduction in hearing level of 30 dB or more, within 3 years or less. Such a change could be due to noise exposure or disease.	Sum of hearing levels at 1, 2, 3, 4 and 6 kHz.	Referral

RESULTS

As a result of the testing over the last four years, a large audiometric database has been developed, holding almost 1,300 student audiograms. By categorising the audiometric data based on the new regulations categorization scheme, it was established that 94 % of the Academy students have what is considered to be good hearing, 4.5 % of students showed a mild hearing impairment (warning) and only 1.5 % of students had poor hearing (referral); see Figure 2. Among the latter, most recorded referral cases were due to genetic hearing problems or accidents that occurred in the past and can't therefore be associated with noise induced hearing loss. For the general population, percentages for warning and referral levels are set at 20 % and 5 % respectively (see Table 1 above) indicating that young musicians have excellent hearing. Please note that another reason behind the excellent hearing results recorded among music students may be the fact that with their well-trained ears and developed sensitivity to sound/changes in pitch, music students could simply be better at detecting pure tones than general population of same age. On the other hand, noise induced hearing loss has a dose-response relationship, and hence may take up to 20 years to become apparent amongst classical musicians.

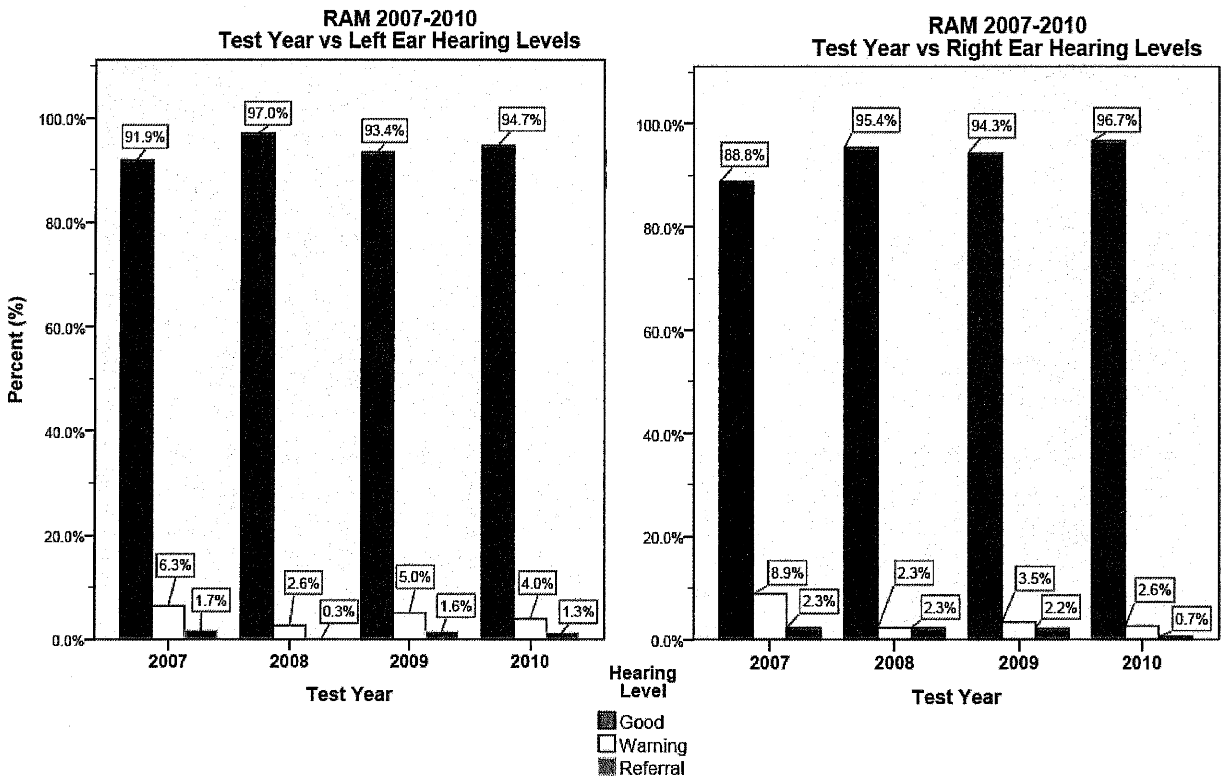

Figure 2: Health and safety hearing levels per test year

Results also indicated that female students tested have better hearing than male. The incidence of males with mild hearing impairment is 3 and 2 times higher than of the females for the left and right ear respectively. This may be due to the fact that male musicians tend to be involved with louder instruments, as for example brass, percussion, etc.

Due to the large number of musicians studying string instrument (27 % of students tested), highest incidence of warning and referral levels was calculated for the string instruments (25 % and 33 % respectively, both ears averaged). Second largest incidence of warning and referral levels was calculated for the brass instruments (18 % and 30 %) being followed by pianists and singers.

However, when comparing incidence of warning/referral levels within each instrument group, results show higher percentages of hearing loss among brass students. Specifically, 11 % of brass students tested have a mild hearing impairment compared to the 4 % of string and wind instrument students (averaged results from both ears; see Table 2). Highest incidence of poor hearing (referral levels) within each instrument group was once more calculated for the brass (3 %) and string (2 %) students. It must be noted that although higher percentages of both warning and referral levels were calculated for conductors and percussion/timpani students (5 % and 4 % respectively with warning, 5 % and 6 % with referral), however the total amount of students tested at those instrument groups was not statistically significant (22 and 26 students respectively). Lower incidences of hearing loss were found amongst piano, voice and musical theatre students. For detailed results on the incidence of hearing loss within each instrument group, see Table 2.

Table 2: Incidence of health and safety hearing levels within instrument groups (RAM 2007-2010)

INSTRUMENT (number of tests)	**Number of Students**	**LEFT EAR**			**RIGHT EAR**		
		Good (%)	**Warning** (%)	**Referral** (%)	**Good** (%)	**Warning** (%)	**Referral** (%)
Strings	349	93.4	4.3	2.0	94.8	3.7	1.4
Brass	96	86.5	11.5	2.1	85.4	10.4	4.2
Woodwind	118	95.8	4.2	0.0	94.1	4.2	1.7
Percussion/Timpani	26	84.6	7.7	7.7	96.2	0.0	3.8
Piano	215	96.3	3.3	0.5	95.8	3.3	0.9
Voice	174	96.0	2.9	0.6	94.3	3.4	1.7
Musical Theatre	123	96.7	2.4	0.8	95.1	3.4	1.7
Conductors	22	90.9	4.5	4.5	90.9	4.5	4.5

When comparing right and left ear hearing results within the strings, it is easily identified that the string players' left ears showed higher levels of hearing loss than that of their right ears. Specifically, an increase of 15 % and 20 % in the incidence of warning and referral levels respectively was calculated for the string players' left ear. This expected result is due to the fact that the most popular string instruments are asymmetric (violin/viola) with the noise being emitted at a very short distance to the left ear.

Finally, when comparing averaged hearing loss per frequency for each instrument group, a 6 kHz notch, i.e., an increase in hearing loss at the 6 kHz frequency when compared to the adjacent 4 and 8 kHz frequencies, was found. This is a sign of noise induced hearing loss also linked with musicians' noise exposure (Chasin 1998; Kähäri et al. 2001a, b; Backus & Wiliamon 2009; Lund et al. 2010). Please note that headphones used were properly placed on musician's head and have no known artefacts that could have increased thresholds at 6 kHz.

Analysis of calculated average hearing thresholds per frequency for all instrument groups tested at the Academy from 2007-2010 indicated notches at 6 kHz especially in the left ear where thresholds at 6 kHz were higher than those at 4 and 8 kHz. Most 'intense' notches, i.e. where highest differences between 4-6 and 6-8 kHz were calculated, were found for guitarists (both ears, amplified music exposure?), followed by those for string players (left ear), musical theatre singers (left ear), piano and jazz players (left ear), voice and brass (left ear).

Figure 3 shows a significant notch at 6 kHz for string players with higher thresholds at 6 kHz compared to those at 4 and 8 kHz at the left ear. A similar notch is apparent in the right ear, however with smaller differences in hearing thresholds between 4-6 and 6-8 kHz. When comparing string players thresholds to those of brass, although the 6 kHz notch is apparent in the brass players left ear, hearing thresholds at 8 kHz continue to increase at the right ear indicating a higher amount of hearing loss at high frequencies for brass players. The same, but not so significant, trend is apparent for both wind and percussion/timpani players.

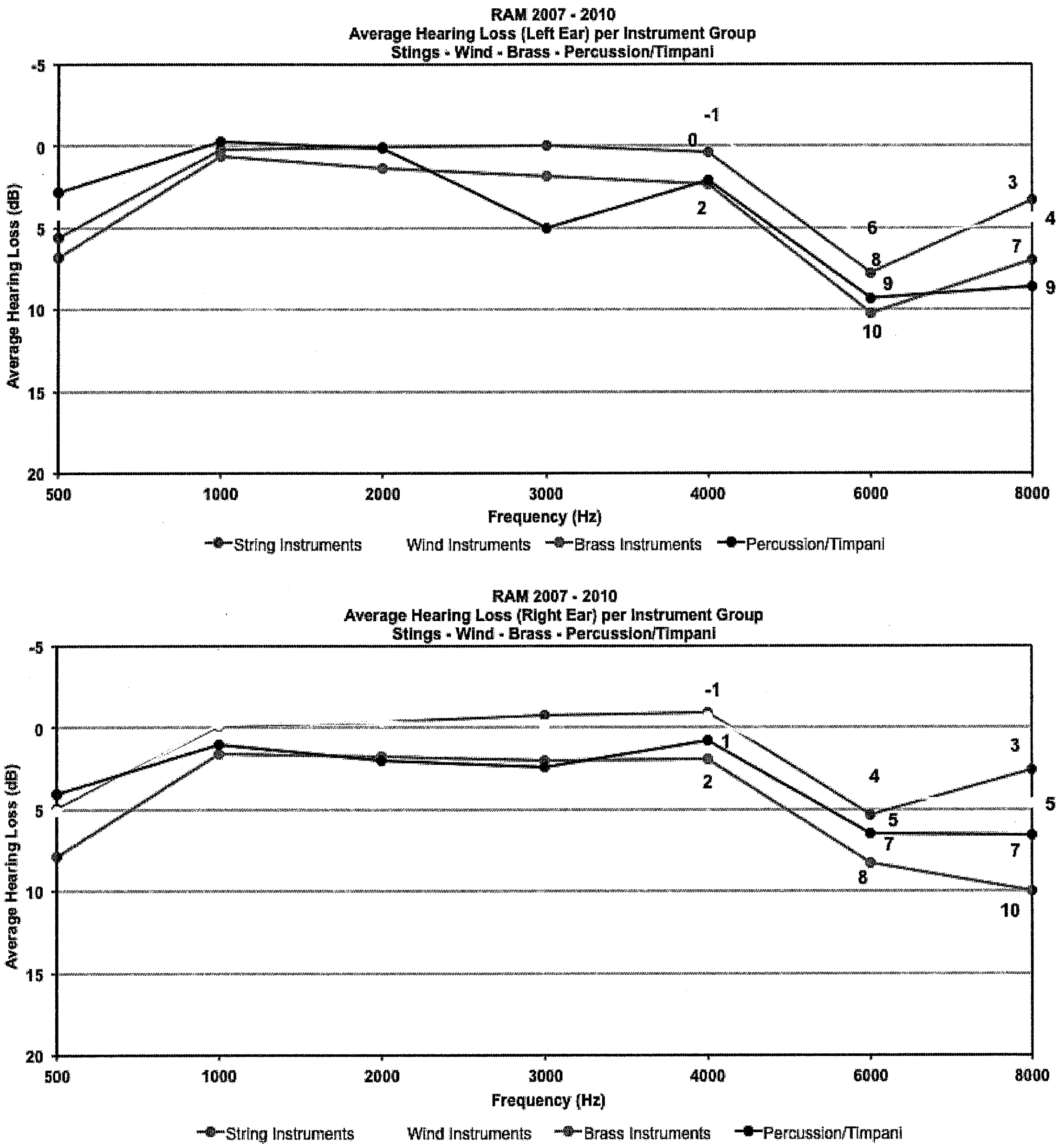

Figure 3: Average hearing loss per frequency for Stings, Wind Brass, and Percussion/Timpani

CONCLUSIONS

Since 2007, the Royal Academy of Music has been following a management policy to assess the hearing acuity of the musicians at the start of their career. Results of almost 1,300 hearing tests revealed that music students have excellent hearing and less hearing problems than those of general population and same age despite their, already accumulated, hearing exposure. Highest incidence of students with mild hearing impairment or poor hearing was found among string players with highest hearing loss recorded at their left ears. However, highest percentages of hearing loss calculated within each instrument group were found for brass students indicating the fact that these musicians are at a higher risk of developing hearing loss. Finally, averaged hearing thresholds per frequency for each instrument group showed a significant threshold notch at 6 kHz, especially in the left ear, indicative of noise-induced hearing loss.

Hearing health surveillance at the Royal Academy of Music will be repeated each year for all new first year students with students to be re-tested at the end of their studies. A statistically significant amount of re-tests, combined with questionnaires assessing the students noise exposure, etc. during their studies, will reveal any rapid changes in the students hearing health that can be associated with music related noise exposure.

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Hearing loss in professional orchestral musicians

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INTRODUCTION

According to several studies, professional orchestral musicians are often exposed to sounds at levels exceeding the upper exposure action values from the 2003/10/EC noise directive (Royster et al. 1991; Obeling & Poulsen 1999; Laitinen et al. 2003; O'Brien et al. 2008; Toppila et al. 2011). It has been also shown that players can develop noise-induced hearing loss (NIHL) and suffer from other hearing symptoms such as tinnitus, hyperacusis, ringing in the ears, which can influence their work abilities more severely than hearing loss. 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 (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. 2010).

The aim of this study was to assess hearing status in 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.

MATERIALS AND METHODS

Study group

Participants were 85 professional musicians (38 females and 47 males), aged 24−67 years (mean ± SD: 42.9±11.5 years, median: 41.75 years) from two opera and three symphony orchestras. The study group comprised musicians playing violin (21), viola (11), cello (8), trombone (7), oboe (6), flute (6), bassoon (5), horn (4), trumpet (4), double bass (3), clarinet (3), percussion (2), tube (2), guitar (1) and piano (1).

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

Questionnaire inquiries

All musicians were interviewed according to a questionnaire developed to enable identification of occupational and non-occupational risk factors of NIHL. 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: (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. 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).

Hearing examinations

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

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 6,000 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.

Evaluation of exposure to orchestral noise

Musicians' exposures to orchestral noise were evaluated based on data concerning sound pressure levels produced by various group of instruments. These data were collected during measurements performed with the measuring equipments placed in various instrument groups during rehearsals, concerts and performances including diverse repertoire. In general, results of 338 measurement samples (lasting in total approx. 591 hours) were collected (for details see Pawlaczyk-Luszczynska et al. 2011).

For various groups of players the weekly A-weighted noise exposure levels ($L_{EX,w}$) were calculated basing on the median values of equivalent-continuous A-weighted sound pressure levels produced by the respective instrument (e.g. violins or trumpets) and declared time of weekly practice.

Prediction of noise-induced hearing loss

The musicians' actual hearing threshold levels were compared with the theoretical predictions calculated according to ISO 1990:1990. 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 (Sliwińska-Kowalska et al. 2006):

$$SHTL = 1.282 \times (HTL - PHTL_{Q50})/(PHTL_{Q10} - PHTL_{Q50}) \quad \text{for } HTL \geq PHTL_{Q50}$$

$$SHTL = 1.282 \times (HTL - PHTL_{Q50})/(PHTL_{Q90} - PHTL_{Q50}) \quad \text{for } HTL < PHTL_{Q50}$$

Where:
HTL – is the actual hearing threshold, in dB HL,
$PHTL_{Q50}$ – is the median value of predicted HTL in dB HL,
$PHTL_{Q10/Q90}$ – is the fractile Q10/ Q90 of predicted hearing threshold level, in dB HL,

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.

Statistical analysis

A 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)AIADH 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 or lower-exposed on the basis of assigned theme values of the weekly noise exposure level. 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 subjects as younger and older ones.

The 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. The standardized hearing threshold levels were analyzed using t-test for dependent samples.

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.

RESULTS

Questionnaire inquiries

Musicians under study were employed in orchestras from 1 to 44 years (mean ± SD: 19.5±11.4 years, median: 18.3 years). They were exposed from 7 to 70 hours a week (mean ± SD: 28.8±10.7 h, median: 30 h) to music at the A-weighted equivalent continuous sound pressure levels varying from 73 to 92 dB (Table 1). The weekly noise exposure levels calculated from this data ranged between 81−88 dB (mean ± SD: 84.0±2.0 dB, median: 82.8 dB) (Figure 1).

Generally, almost all subjects (97.7 %) assessed their hearing as good. However, about one quarter of them (23.8 %) noticed hearing impairment, including difficulty in speech intelligibility in noisy environment (40.9 %) and hearing whisper (18.2 %). Nearly every tenth musician complained of tinnitus while one third of them reported hyperacusis.

Table 1: Sound pressure levels produced by various groups of instruments (Pawlaczyk-Luszczynska et al. 2011)

Instrument/ Equivalent continuous A-weighted sound pressure level (10th/ 50th/ 90th percentile) [dB]					
Violin	81/ 84/ 87	Flute	83/ 87/ 89	Horn	85/ 88/ 92
Viola	80/ 84/ 88	Oboe	83/ 86/ 89	Trombone	84/ 87/ 90
Cello	75/ 82/ 84	Clarinet	81/ 87/ 90	Tuba	87/ 89/ 91
Double bass	74/ 83/ 84	Bassoon	83/ 86/ 90	Percussion sect.	80/ 87/ 91
Harp	78/ 82/ 85	Trumpet	84/ 89/ 91	Total	81/ 86/ 90

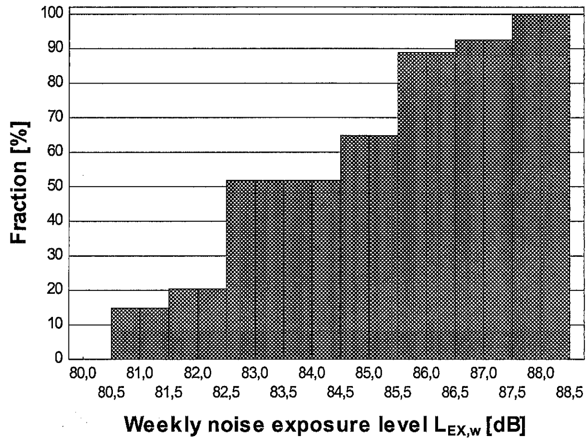

Figure 1: Cumulative distribution of the weekly noise exposure level in study group

Musicians examined using the (m)AIADH obtained mean total score of 90.9 % of maximum value, which suggests no substantial hearing difficulties in subjects under study (Table 2). Relatively low scores were frequent only in the subscale evaluating intelligibility in noise (22.2 % of subjects scored below 70 % of maximum value). The (m)AIADH scores were significantly affected by age ($p<0.05$). As expected older subjects obtained lower scores than younger ones. Neither gender nor exposure had impact on the (m)AIAHD scores ($p>0.05$).

Table 2: Musicians' self-assessment of hearing ability in the (m)AIADH scores

Score/ Mean ± SD/ 10^{th}/ 50^{th}/ 90^{th} percentile					
Total	Subscale I	Subscale II	Subscale III	Subscale IV	Subscale V
76.4±7.1* 65/ 78/ 84	23.1±1.4* 22/ 24/ 24	13.4±1.9* 10/ 14/ 15	12.4±2.2* 10/ 13/ 15	13.5±1.9* 11/ 14/ 15	14.0±1.4* 12/ 15/ 15

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

Results of PTA and TEOAE

Audiometric hearing threshold levels determined in 85 professional orchestral musicians (165 ears) are shown in Figure 2.

A significant main effect of age on the HTLs was observed in the frequency range from 1,000 to 8,000 Hz (Figure 2b). Generally, older subjects showed higher reduction of hearing threshold level than younger ones. Similar relation was observed between males and females in the in the high frequency region from 3,000 to 8,000 Hz (Figure 2a). There was also a significant main effect of noise exposure on the HTLs at frequencies of 1,000 and 8,000 Hz. Contrary to our expectations higher-exposed subjects ($L_{EX,w}$>82.8 dB) had lower (better) HTLs compared to lower-exposed individuals ($L_{EX,w}$≤82.8 dB) (Figure 2c). However, the latter result is not surprising since the study subjects were generally exposed to sounds at relatively low levels ($L_{EX,w}$≤88 dB).

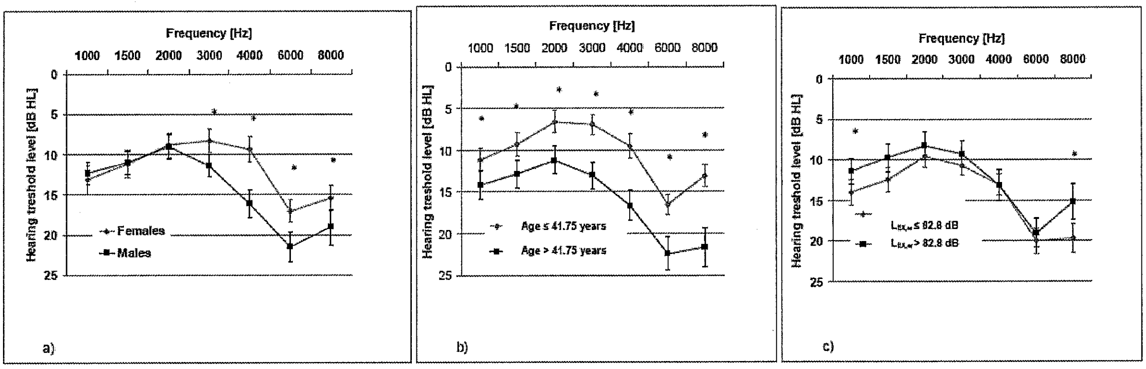

Figure 2: Audiometric hearing threshold levels (mean ± 95% CI) in various subgroups of musicians, i.e. females and males (a), younger and older subjects (b), and lower- and higher-exposed subjects (c). Significant differences between subgroups were marked (*)

Typical NIHL notches at 4,000 or 6,000 Hz of at least 15 dB depth relative to the best preceding threshold (from 1,000 Hz) were observed in 36.0 % of audiograms. Most of them (82.8 %) occurring at 6,000 Hz. The portion of total population with bilateral notching at any frequency was 17.1 %.

In the majority (95.2 %) of cases a mean value of the hearing threshold level for 500, 1,000, 2,000 and 4,000 Hz was lower than 25 dB, which corresponds to grade 0 of hearing impairment (WHO 2011). Only 4.8 % of the measured audiograms corresponded to grade 1 of hearing impairment. Moreover, all of them were found in the older musicians.

It is worth noting that 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 repeat words spoken in normal voice at a distance of 1 meter, but hearing aids may be needed (WHO 2011).

Summary results of TEOAE testing are shown in Figure 3. A significant main effect of gender on TEOAE amplitude, signal to noise ratio (SNR) as well reproducibility (excluding frequency band of 1 kHz) was noted (Figures 3a, 3d and 3g). Generally, females showed better results of TEOAE testing compared to males. On the other hand, age and noise exposure were found to significantly affect the reproducibility of TEOAE in the frequency range from 1 to 1.5 kHz (Figures 3e and 3f). As expected, greater reproducibility was observed in case of younger than older musicians while the opposite relation occurred between lower- and higher-exposed to noise subjects

In almost all cases (96.8 % of ears) the reproducibility of the total response of TEOAE was above 60 %. Signal to noise ratio higher than 6 dB was observed in the 69.4 % of cases.

A weak but statistically significant linear relationship was noted between PTA results and the total score of (m)AIADH 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) (Pearson's correlation coefficient r varied from -0.45 to -0.25, $p<0,05$). The linear relationships were also noted between musicians' self-assessment of hearing ability in the (m)AIADH scores and the TEOAE results ($0.22 \leq r \leq 0.45$, $p<0.05$). The highest values of correlation coefficient were noted between score of subscale III and SNR at 4 kHz as well as HTL at 6,000 Hz.

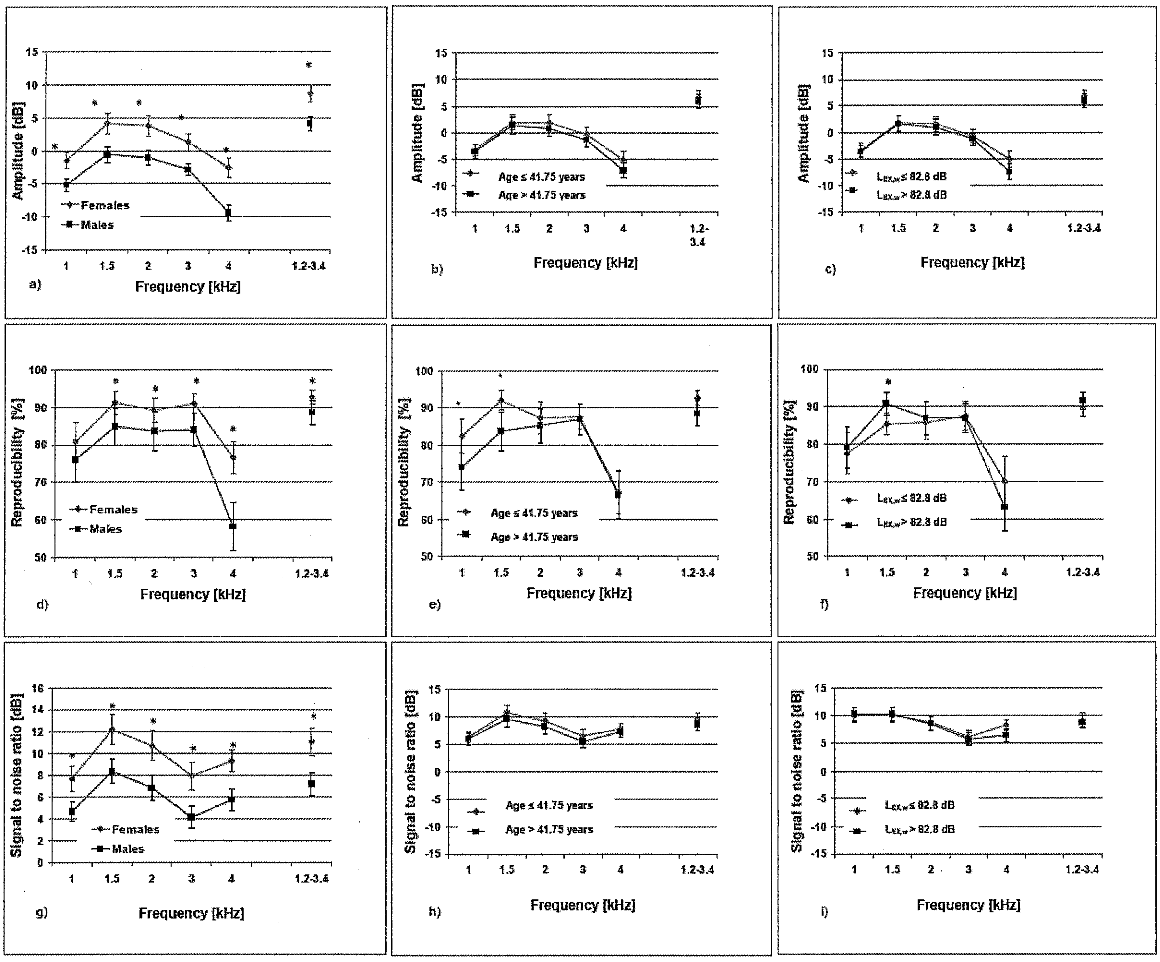

Figure 3: TEOAEs (mean ± 95% CI) in various subgroups of musicians, i.e. females and males (a, d, g), younger and older subjects (b, e, h), and lower- and higher-exposed subjects (c, f, i). Significant differences between subgroups were marked (*)

Comparison of actual and predicted hearing threshold levels

Figure 4 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. On the other hand, the positive values of SHTLs indicate that actual hearing threshold levels are higher than predicted.

Comparing the musicians to non-noise-exposed population revealed that their hearing loss corresponded to the expected hearing loss at frequencies of 3,000 and 4,000 Hz ($p>0.05$). On the other hand, the actual hearing threshold levels were lower (better) than expected for 3,000; 4,000 and 8,000 Hz ($p<0.05$), with an expected values at 2,000 and 6,000 Hz ($p>0.05$), when compared to equivalent population exposed to industrial noise. Thus, findings presented here are in line with some earlier observation that music deteriorates hearing, but less than what ISO 1999:1990 predicted (Obeling & Poulsen 1999; Toppila et al. 2011).

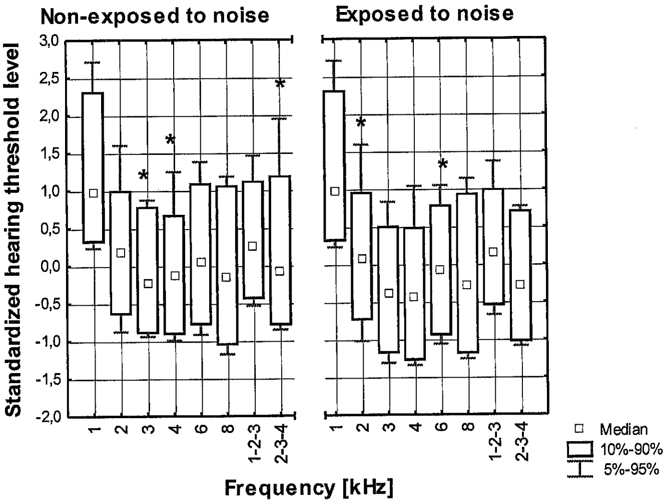

Figure 4: Comparison of the musicians' hearing loss to that of non-noise-exposed and noise-exposed populations. Standardized hearing thresholds which do not significantly differ from 0 were denoted (*)

CONCLUSIONS

- Almost all musicians had hearing threshold levels corresponding to grade 0 ("no impairment") of hearing impairment according to the WHO classification. However, high frequency notched audiograms typical for noise-induced hearing loss were found in 36 % of ears.
- Significant main effects of age and gender on hearing test results were observed. Both PTA and TEOAE showed a tendency toward better hearing in females vs. males, younger vs. older subjects. Moreover, weak but statistically significant linear relationships were noted between musicians' self-assessment of hearing ability in the (m)AIADH scores and the audiometric hearing threshold levels as well as TEOAE results.
- Measured audiometric HTLs at 3,000; 4,000 and 8,000 Hz were lower (better) than theoretical predictions according to ISO 1990:1990. Thus, music deteriorates hearing, but less than expected from exposure to orchestral noise.

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