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Evaluation of Sound Exposure and Risk of Hearing Impairment in Orchestral Musicians

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This study aimed to assess exposure to sound and the risk of noise-induced hearing loss (NIHL) in orchestral musicians. Sound pressure level was measured in 1 opera and 3 symphony orchestras; questionnaires were filled in. On the basis of that data, the risk of NIHL was assessed according to Standard No. ISO 1999:1990. Classical orchestral musicians are usually exposed to sound at equivalent continuous A*-weighted sound pressure levels of 81−90 dB (10th−90th percentiles), for 20−45 h (10th−90th percentiles) per week. Occupational exposure to such sound levels over 40 years of employment might cause hearing loss (expressed as a mean hearing threshold level at 2, 3, 4 kHz exceeding 35 dB) of up to 26%. Playing the horn, trumpet, tuba and percussion carries the highest risk (over 20%).*

musicians exposure to orchestral noise risk of noise-induced hearing loss

1. INTRODUCTION

Hazardous aspects of music have been extensively investigated for several decades. In particular, exposure to excessive sound (so-called orchestral noise) in professional orchestras has been studied. Professional orchestral musicians are often exposed to sounds at levels exceeding the upper exposure action values from Directive 2003/10/EC [1, 2, 3, 4, 5, 6, 7, 8, 9]. Although industrial workers are at a higher risk of developing hearing loss, musicians can also develop noise-induced hearing loss (NIHL). Furthermore, they can suffer from other hearing symptoms such as tinnitus, hyperacusis or diplacusis, which can affect their ability to work more severely than hearing loss [1, 2, 4, 5, 8, 10, 11, 12, 13, 14, 15].

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 [9]. 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. However, such regulations are still missing in Poland.

Directive 2003/10/EC requires estimating individual risk of NIHL and states that risk arising from exposure to noise should be eliminated or reduced to a minimum [9]. These general requirements are in force in the music and entertainment sectors. Therefore, the aim of this study was to assess exposure to orchestral noise and the risk of NIHL in professional orchestral musicians.

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2. METHODOLOGY

Sound pressure level (SPL) was measured in one opera and three symphony orchestras; a questionnaire was also administered. On the basis of these data risk of NIHL was assessed according to Standard No. ISO 1999:1990 [16].

The study comprised 127 subjects (49 females and 74 males), aged 44 ± 11 years (range: 22−67). All musicians filled in a questionnaire developed to identify 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. Special attention was paid to professional experience, i.e., duration of employment in an orchestra or duration of a musical career or comparable experience, various work activities and instruments in use and duration of daily and/or weekly practice, including individual practice. These data were crucial in evaluating musicians' exposure to orchestral noise.

2.1. Evaluation of Exposure to Orchestral Noise

To assess musicians' exposure to orchestral noise, SPL was measured during rehearsals, concerts and performances. These measurements comprised a diverse repertoire and various venues (for details see Appendix on p. 269). However, for organizational reasons they did not include musicians' individual practice.

Noise measurements were carried out according to Standards No. PN-N-01307:1994 [17] and ISO 9612:2009 [18] using both integrating-averaging sound level meters or personal sound exposure meters (i.e., SVANTEK, Poland, sound analyzers type 912, 912E and 958 as well as the Brüel & Kjær, Denmark, personal logging noise dosimeters type 4443) placed in various instrument groups (Figure 1). Both types of meters were positioned on tripods with microphones close to the players' ears. The distance between the microphones and the ears (0.1–0.5 m) was as short as practically possible (without disturbing the musicians).

Equivalent continuous *A*-weighted SPL ($L_{Aeq,T}$), maximum *A*-weighted SPL with S (slow) time constant (L_{Amax}) and peak *C*-weighted SPL (L_{Cpeak}) were determined in accordance with Standards No. PN-N-01307:1994 [17] and ISO 9612:2009 [18]. Each measurement usually corresponded to the duration of the rehearsal, concert or performance. There were 338 measurement samples (lasting in total ~591 h).

SPL measurements and questionnaire data on musicians' professional experience (i.e., declared time of weekly practice) were used to evaluate exposure to orchestral noise in various groups of players. First, the distributions of equivalent-continuous *A*-weighted SPL ($L_{Aeq,T}$) produced by various groups of instruments were determined. Then, on the basis of the declared time of weekly practice and $L_{Aeq,T}$ levels, the limit values of weekly noise exposure levels ($L_{EX,w,10}$; $L_{EX,w,50}$; $L_{EX,w,90}$) for various groups of players were calculated with the following equations:

$$L_{EX,w,10} = L_{Aeq,T,10} + 10\lg\left(\frac{T_{w,10}}{T_o}\right), \quad (1)$$

$$L_{EX,w,50} = L_{Aeq,T,50} + 10\lg\left(\frac{T_{w,50}}{T_o}\right), \quad (2)$$

$$L_{EX,w,90} = L_{Aeq,T,90} + 10\lg\left(\frac{T_{w,90}}{T_o}\right), \quad (3)$$

where $L_{Aeq,T,10}$; $L_{Aeq,T,50}$; $L_{Aeq,T,90}$—10th, 50th, 90th percentiles of the *A*-weighted equivalent-continuous SPL produced by the respective instrument, in decibels; $T_{w,10}$; $T_{w,50}$; $T_{w,90}$—10th, 50th, 90th percentiles of declared time of weekly practice, in hours, T_o—reference duration, $T_o = 40$ h.

2.2. Assessment of Risk of Noise-Induced Hearing Loss

Standard No. ISO 1999:1990 was used to evaluate risk of hearing impairment due to orchestral noise and age, and due to noise alone in various groups of players [16]. This standard defines the risk of hearing loss due to age and noise as the percentage of the population with

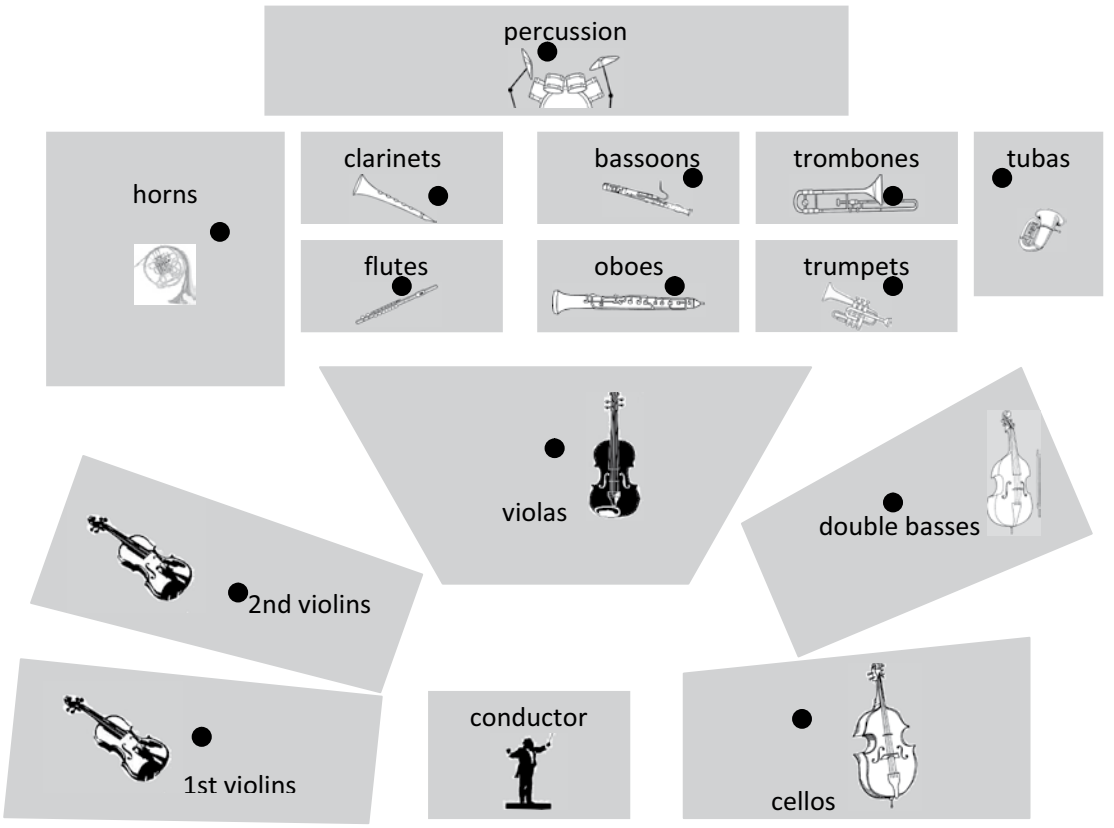


Figure 1. An example of arrangement of musical instruments and measurement points on the stage during rehearsal of Tchaikovsky's Symphony No. 4 in the philharmonic concert hall.

hearing threshold levels (HTLs) exceeding an accepted limit value. On the other hand, risk due to noise alone is defined as the difference between the percentage of noise-exposed population and non-exposed to noise population (otherwise equivalent to the former) with HTLs greater than accepted limit value.

Standard No. ISO 1999:1990 specifies a method for calculating noise-induced permanent threshold shift (NIPTS) of adult populations following exposure to noise [16]. It defines HTL associated with age and noise (HTLAN) as a combination of hearing loss associated with age (HTLA) and occupational exposure to noise (NIPTS). Therefore, it makes it possible to determine statistical distribution of HTLs in a noise-exposed population, and then to evaluate the risk of hearing impairment based on four parameters: age, gender, level of noise exposure and duration of noise exposure.

This study calculated percentages of subjects with HTLAN exceeding the limit value of 25, 35 or 45 dB and the risk of hearing loss due to noise alone for various groups of players (separately for females and males), for the accepted hypothetical period of professional exposure (7–42 years) and age (25–60 years) in 5-year steps. These calculations were performed on the basis of $L_{EX,w,10}$; $L_{EX,w,50}$ and $L_{EX,w,90}$ that were established for the various groups of players.

3. RESULTS AND DISCUSSION

3.1. Exposure to Orchestral Noise

Exposure to orchestral noise depends on many factors, including the repertoire, the venue, the instrument and the players' location within orchestra. Rehearsal format also impacts on SPL to which musicians are exposed. In rehearsal, an orchestra may play all the time, but it may also frequently stop and work on parts of a musical piece with only a few musicians. An orchestra may also spend much time on a particular passage and play through other ones, etc. Figure 2 illustrates the impact of the type of

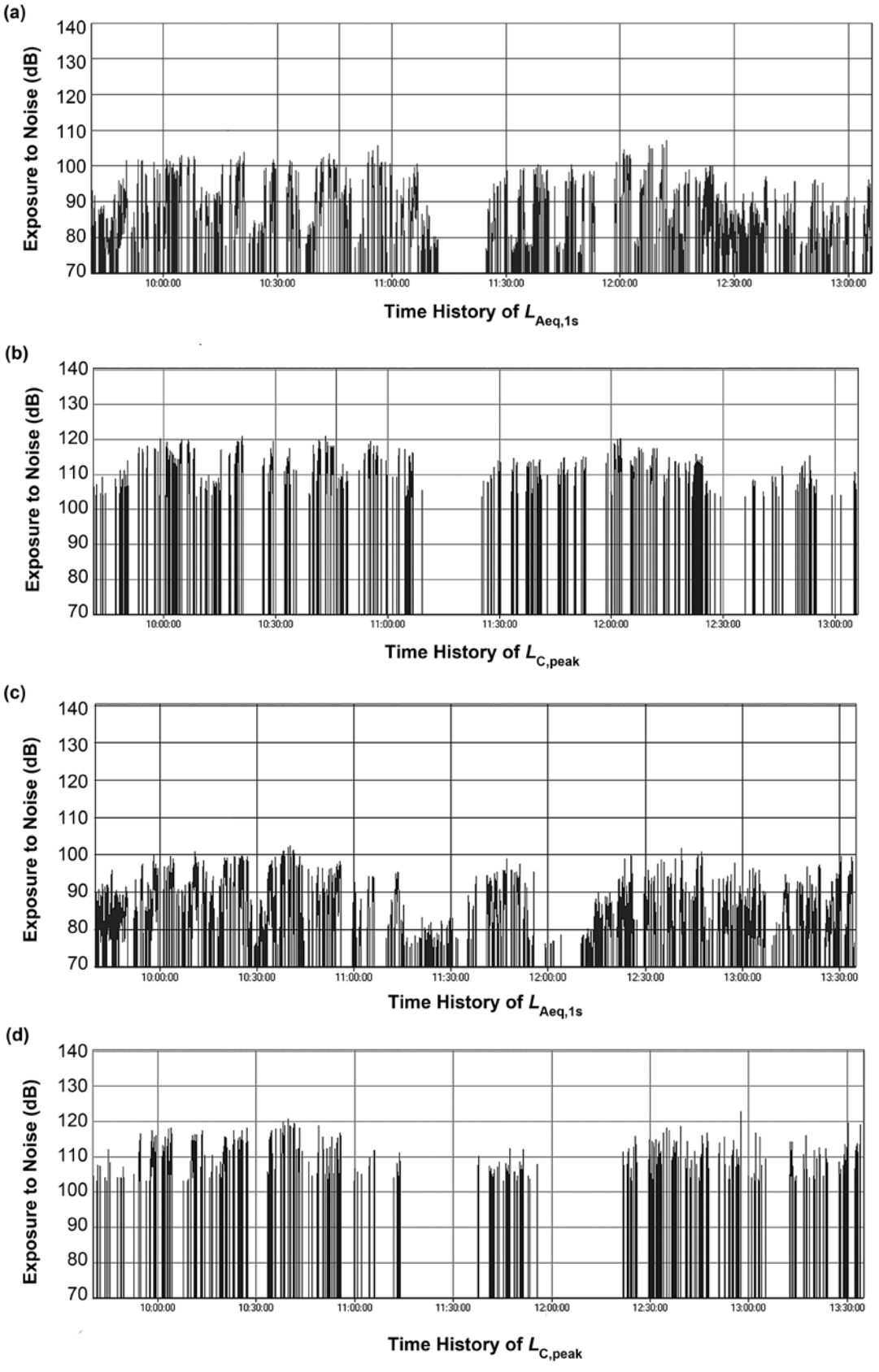


Figure 2. Exposure to (a, b) viola and (c, d) flute during a group rehearsal of a symphony orchestra in a concert hall. *Notes*. Rehearsal programme comprised of Tchaikovsky's Symphony No. 4 and Messiaen's *L'Ascension*. Measurements were carried out with Brüel & Kjær (Denmark) noise dosimeters; time-history of the equivalent-continuous *A*-weighted sound pressure levels ($L_{Aeq,1s}$) and peak *C*-weighted sound pressure levels (L_{Cpeak}) were plotted with 1-s steps.

instrument, the compositions being played and rehearsal format on the sound level variability during group rehearsal. On the other hand, Figure 3 shows variability of exposure due to changes in repertoire.

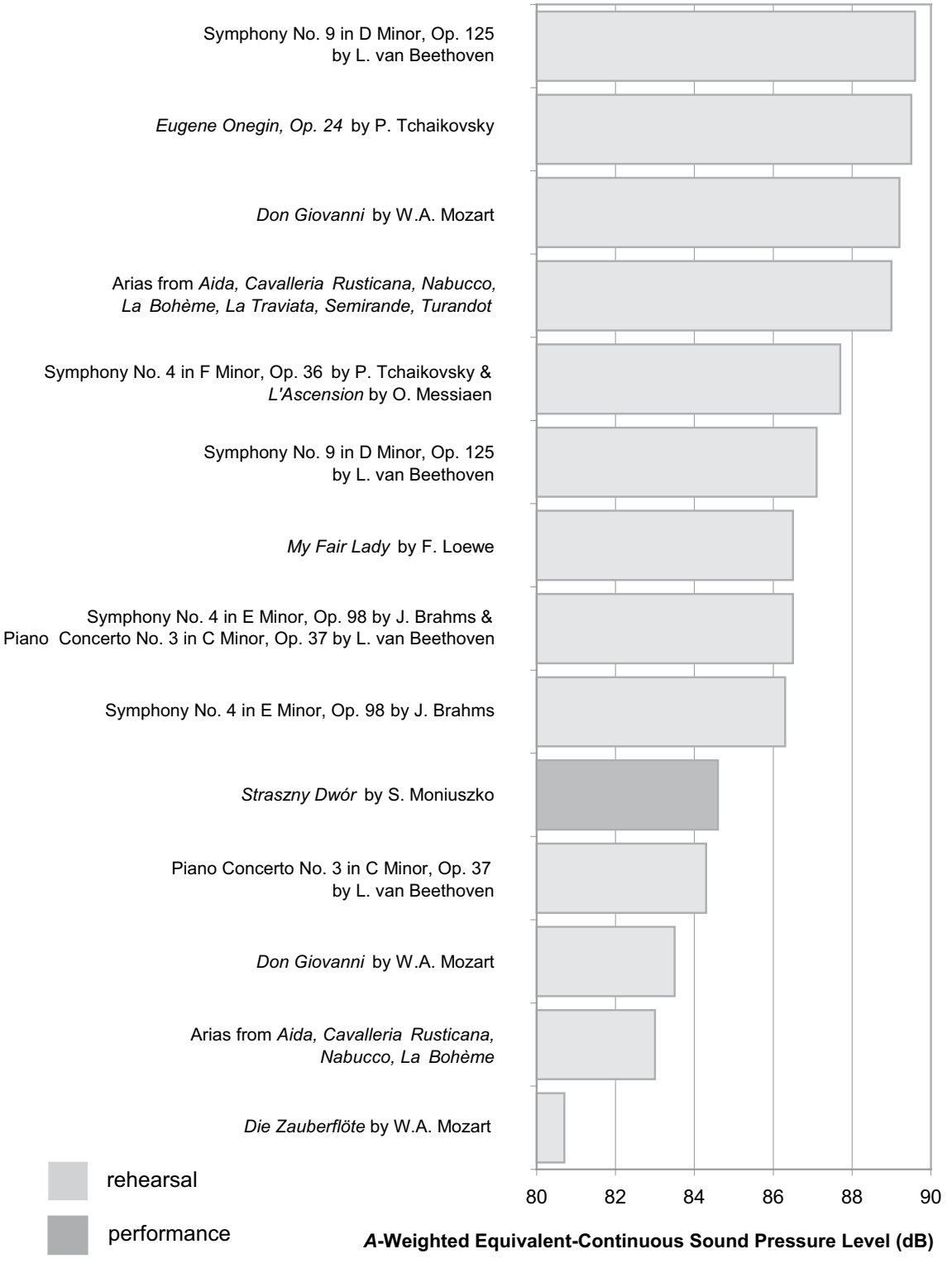


Figure 3. Exposure to a clarinet—*A*-weighted equivalent-continuous sound pressure levels measured during some group rehearsals or performance.

TABLE 1. Results of Sound Pressure Level Measurements Performed During Group Rehearsals, Concerts or Performances in 1 Opera and 3 Concert Halls. No Individual Practice Was Included

	L_{AeqT} (dB)	L_{ASmax} (dB)	L_{Cpeak} (dB)
Instrument Group (No. of Samples)	***M* ± *SD* (10th/50th/90th percentile)**		
Violin (57)	83.9 ± 2.4 [84.7]* 81/84/87	98.9 ± 3.9 94/99/105	115.8 ± 4.7 109/116/120
Viola (32)	83.8 ± 3.2 [84.5] 80/84/88	97.8 ± 4.2 92/99/102	115.0 ± 4.5 109/116/121
Cello (20)	80.4 ± 3.1 [81.3] 75/82/84	95.0 ± 4.1 89/95/100	113.7 ± 4.8 108/114/120
Double bass (20)	80.8 ± 4.2 [82.3] 74/83/84	97.2 ± 5.6 89/98/103	115.9 ± 6.7 107/117/125
Harp (5)	81.5 ± 2.7 [82.1] 78/82/85	96.8 ± 3.1 92/98/99	119.3 ± 4.7 114/119/125
Flute (19)	86.1 ± 2.8 [86.8] 83/87/89	101.1 ± 3.4 97/101/107	117.8 ± 3.8 113/118/123
Oboe (14)	85.9 ± 2.1 [86.8] 83/86/89	99.8 ± 2.3 97/100/103	119.2 ± 3.6 114/120/123
Clarinet (18)	86.2 ± 2.8 [86.3] 81/87/90	100.4 ± 3.3 96/100/105	119.0 ± 5.1 113/119/127
Bassoon (26)	86.0 ± 3.2 [86.9] 83/86/90	102.0 ± 4.4 96/102/108	120.8 ± 5.7 114/121/129
Trumpet (34)	88.0 ± 2.9 [89.2] 84/89/91	106.2 ± 5.4 101/106/111	124.4 ± 6.7 119/123/133
Horn (43)	87.9 ± 3.1 [87.7] 85/88/92	104.9 ± 4.5 99/105/112	123.3 ± 7.1 115/123/128
Trombone (24)	86.9 ± 2.7 [88.9] 84/87/90	104.3 ± 3.6 99/104/110	123.0 ± 3.8 118/124/128
Tuba (5)	88.6 ± 1.9 [88.9] 87/89/91	107.6 ± 2.2 106/108/110	125.0 ± 3.8 122/125/128
Percussion (21)	85.4 ± 4.8 [87.5] 80/87/91	103.4 ± 6.4 96/104/111	126.9 ± 7.6 117/129/134
total (338)	85.2 ± 3.8 [86.8] 81/86/90	101.1 ± 5.4 94/101/108	119.6 ± 6.7 111/119/128
time of weekly practice (h)	31.2 ± 10.2 (20/30/45)**		

Notes. L_{AeqT}—equivalent-continuous *A*-weighted sound pressure level, L_{ASmax}—maximum *A*-weighted sound pressure level, L_{Cpeak}—peak *C*-weighted sound pressure level; *—an energy average of the number of measurements of the *A*-weighted equivalent-continuous sound pressure level [18], **—data from a questionnaire.

Table 1 summarizes SPL measured in different instruments groups during rehearsals, concerts and performances. Classical musicians are usually exposed to orchestral noise at (a) $L_{Aeq,T}$ of 72–97 dB; (b) L_{Amax} of 86–123 dB and (c) L_{Cpeak} of 105–146 dB. Exposure to $L_{Aeq,T}$ was highest among clarinet, trumpet, trombone, horn, percussion and tuba players.

Several scientists studied musicians' exposure to sound [1, 2, 3, 4, 5, 6, 7, 8]. Recently, O'Brien, Wilson and Bradley recorded noise levels within a professional orchestra over 3 years to provide a greater insight into the orchestral noise environment [7]. They collected 1608 noise samples, comprising a diverse repertoire and various venues, rehearsal formats, orchestral setups as well as personnel variations.

Figure 4 presents our results together with O'Brien et al.'s [7]: mean values of *A*-weighted equivalent-continuous SPL assigned to most instruments (excluding cello and double bass) were similar in both studies (Figure 4a). The relation was similar when median values of *C*-weighted peak SPL were compared (Figure 4b). The best agreement of results was observed for wood-wind and brass instruments. O'Brien et al. obtained a slightly higher median values of L_{Cpeak} (above 90th percentile of our readings) for the viola, cello and percussion.

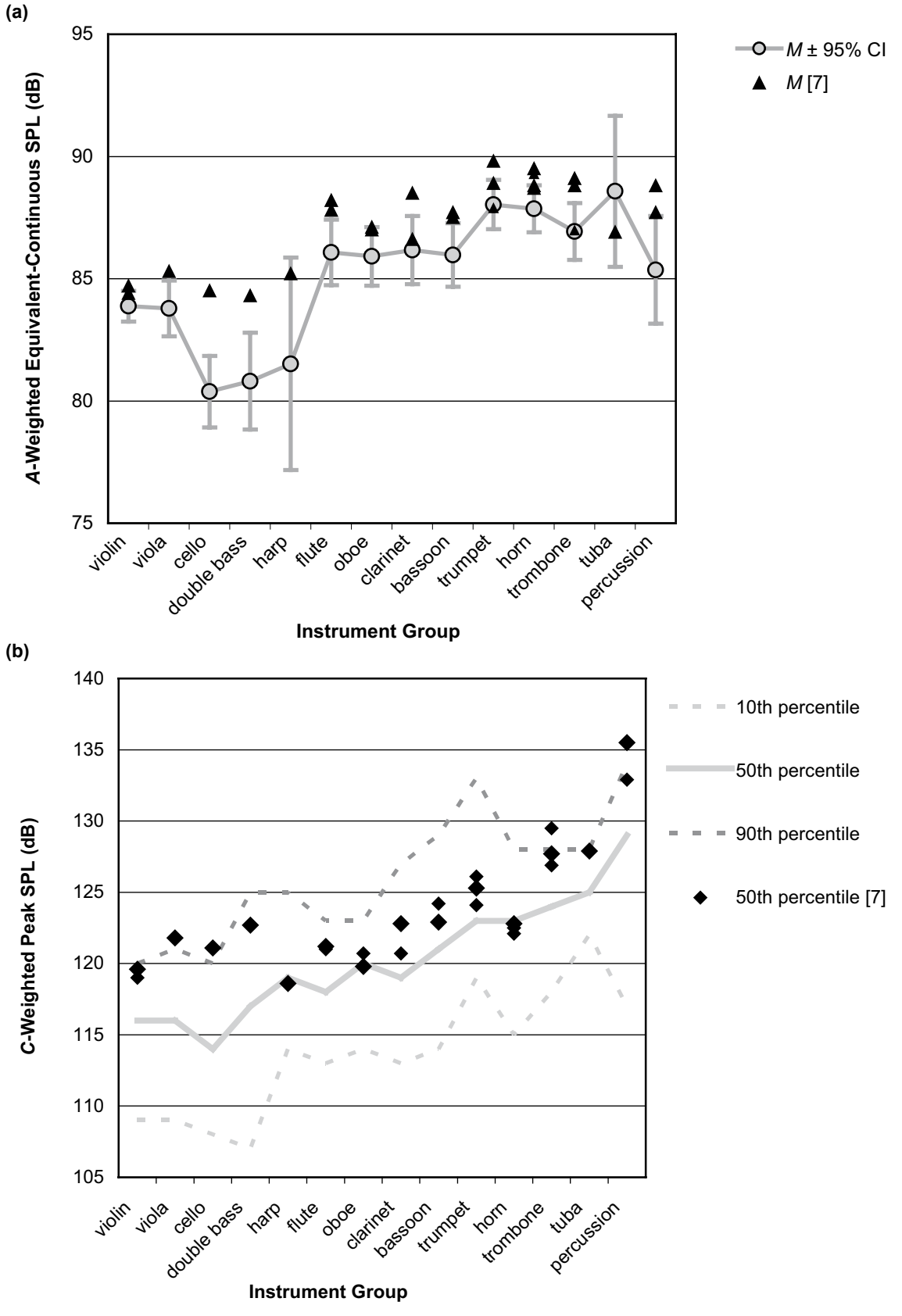


Figure 4. Summary results of orchestral noise measurements together with O'Brien, Wilson and Bradley's [7] data on (a) equivalent-continuous *A*-weighted sound pressure levels and (b) peak *C*-weighted sound pressure levels (SPL) produced by various instruments. *Notes.* Data are given as (a) mean values with 95% confidence intervals or (b) as values of the 10th, 50th and 90th percentile.

The musicians' long-term exposure was evaluated with SPL measurements and data on duration of their weekly practice gathered from the questionnaires. $L_{EX,w,10}$; $L_{EX,w,50}$ and $L_{EX,w,90}$ corresponding to $L_{Aeq,T,10}$; $L_{Aeq,T,50}$ and $L_{Aeq,T,90}$; and $T_{w,10}$; $T_{w,50}$; $T_{w,90}$ were determined for groups of players. It is worth noting that the $L_{EX,w,50}$ levels for the flute, the clarinet, the percussion and the brass instruments exceeded the Polish maximum admissible intensity value for occupational noise ($L_{EX,w}$ = 85 dB) [19]. Moreover, in almost all cases, excluding the cello, the double bass and the harp, the $L_{EX,w\ 90}$ levels were higher than the exposure limit value ($L_{EX,w}$ = 87 dB) in Directive 2003/10/EC [9].

It has been shown that from the perspective of exposure, individual practice was as important as performances and group rehearsals [2, 5]. Laitinen, Toppila, Olkinuora, et al. investigated sound exposure among the Finnish National Opera personnel [5]. During performances and group rehearsals, $L_{Aeq,T}$ varied between groups from 82 dB for double bass players to 98 dB for flute/piccolo players. For individual practice, the lowest sound level was recorded among double bass players (79 dB), whereas the highest levels were recorded for percussionists and flute/piccolo players (up to 99 dB).

Unfortunately, we did not evaluate personal rehearsals. We assumed that SPL produced by various instruments during solo practice were similar to SPL during group rehearsals or concerts and performances. Therefore, the evaluated weekly noise exposure levels were likely to be overestimated for double bass, bassoon and some other instruments players, whereas they were probably underestimated among percussionists, flute players and some other brass players.

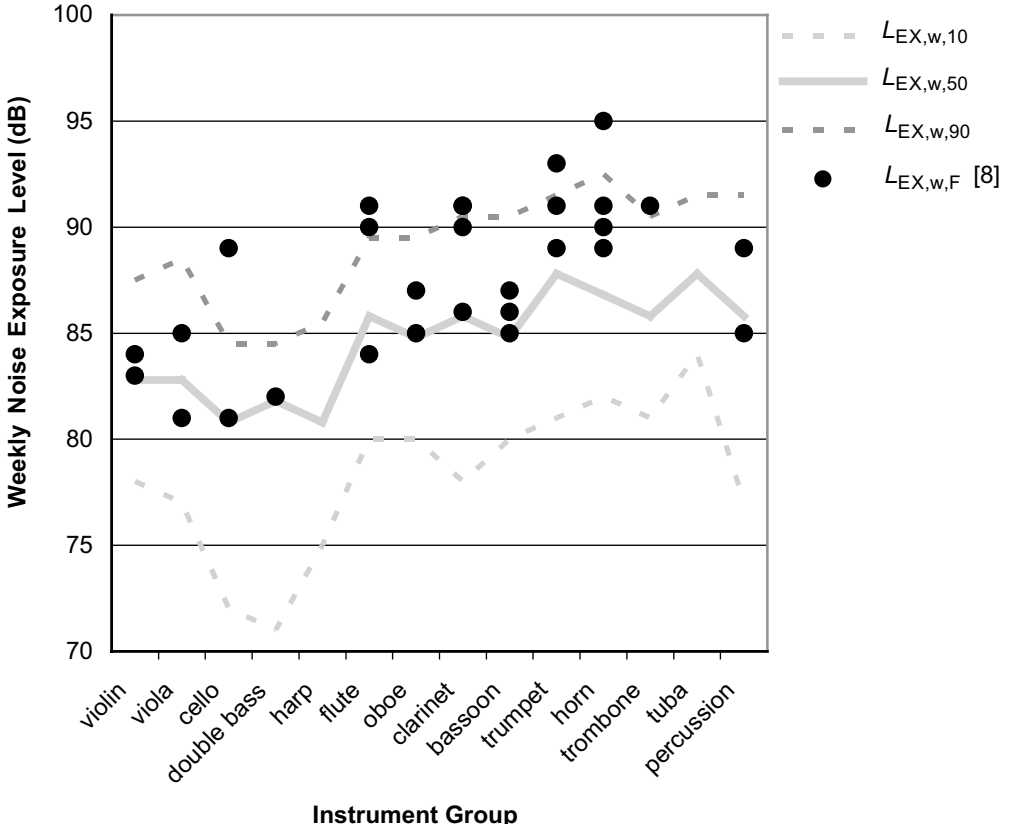


Figure 5. Results of noise exposure evaluation for various groups of players ($L_{EX,w,10}$, $L_{EX,w,50}$, $L_{EX,w,90}$) together with evaluations of weekly noise exposure levels ($L_{EX,w,F}$) in Finnish orchestral musicians from Toppila, Koskinen and Pykko [8]. *Notes.* $L_{EX,w,10}$; $L_{EX,w,50}$; $L_{EX,w,90}$—weekly noise exposure level, corresponding to the 10th, 50th and 90th percentile of the equivalent-continuous *A*-weighted sound pressure level for different instrument groups of the orchestra and the 10th, 50th and 90th percentile of declared weekly time of practice as given in Table 2.

Toppila, Koskinen and Pykko studied 63 musicians from four Helsinki classical orchestras [8]. To compare musicians' actual audiometric HTLs with theoretical predictions according to Standard No. ISO 1999:1990 [16], they used measurements from performances, group rehearsals, and individual practice to evaluate weekly noise exposure levels for various groups of players. Figure 5 illustrates compares Toppila et al.'s results with ours; there is a quite good agreement between them. Thus, limit values of weekly noise exposure level determined for various groups of players (in particular $L_{EX,w,50}$ and $L_{EX,w,90}$) are a reliable basis for assessing risk of NIHL.

3.2. Risk of Hearing Loss

According to Standard No. ISO 1999:1990 [16], the risk of hearing impairment can be evaluated individually for frequencies of 1, 2, 3, 4 and 6 kHz or for a combination of various frequencies. In this study, the risk of hearing loss was calculated as the mean value for (a) 0.5, 1, 2, 4 kHz; (b) 2, 3, 4 kHz and (c) 1, 2, 3 kHz. The latter frequency range corresponds to the most important speech frequency range of the Polish language. Thus, it is considered to be crucial for social efficiency of hearing. Moreover, mean HTL at 1, 2, 3 kHz equal to or higher than 45 dB is the precondition for a diagnosis of occupational hearing loss in Poland [20]. Mean HTLAN for 0.5, 1, 2, 4 kHz up to 25 dB corresponds to grade 0 of hearing impairment. According the World Health Organization's classification, grade 0 (no impairment) stands for no or very slight hearing problems and being able to hear whispers [21]. On the other hand, the frequencies of 2, 3, 4 kHz are considered optimal for early detection of occupational hearing loss [22].

Tables 2–3 summarise the results of assessing the risk of hearing impairment due to orchestral noise and age, as well as due to exposure to noise alone, in 60-year-old musicians playing various types of instruments after ~40 years of employment. On the other hand, Figure 6 shows the results of assessing risk as a function

TABLE 2. Risk of Hearing Impairment Due to Age and Exposure to Orchestral Noise in 60-Year-Old Musicians After ~40 Years of Employment

	Subjects (%)					
	Mean HTL at 0.5, 1, 2, 4 kHz > 25 dB		Mean HTL at 2, 3, 4 kHz > 35 dB		Mean HTL at 1, 2, 3 kHz > 45 dB	
Instrument Group	Females	Males	Females	Males	Females	Males
Violin	9/10/14*	18/19/24	4/6/13	18/21/29	0/0/0	0/0/1
Viola	9/10/16	18/19/25	4/6/15	18/21/32	0/0/0	0/0/1
Cello	8/9/11	18/18/21	4/5/7	18/19/23	0/0/0	0/0/1
Double bass	8/9/11	18/19/21	4/5/7	18/20/23	0/0/0	0/0/1
Harp	8/9/12	18/18/21	4/5/9	18/19/25	0/0/0	0/0/1
Flute	9/12/17	18/22/27	5/9/18	19/26/34	0/0/0	0/1/2
Oboe	9/11/17	18/21/27	5/8/18	19/24/34	0/0/0	0/1/2
Clarinet	9/12/19	18/22/29	4/9/21	18/26/38	0/0/1	0/1/3
Bassoon	9/11/19	18/21/29	5/8/21	19/24/38	0/0/1	0/1/3
Trumpet	9/15/21	18/24/31	5/14/26	19/30/40	0/0/1	0/1/3
Horn	10/13/25	19/23/34	6/11/29	20/27/44	0/0/2	0/1/4
Trombone	9/12/19	18/22/29	5/9/21	19/26/38	0/0/1	0/1/3
Tuba	11/15/21	20/24/31	8/14/26	22/30/40	0/0/1	0/1/3
Percussion	9/12/21	18/22/31	4/9/26	18/26/40	0/0/1	0/1/3
all instrument groups	9/11/19	18/21/29	4/8/21	18/24/38	0/0/1	0/1/3
non-exposed population**	8	17	4	18	0	0

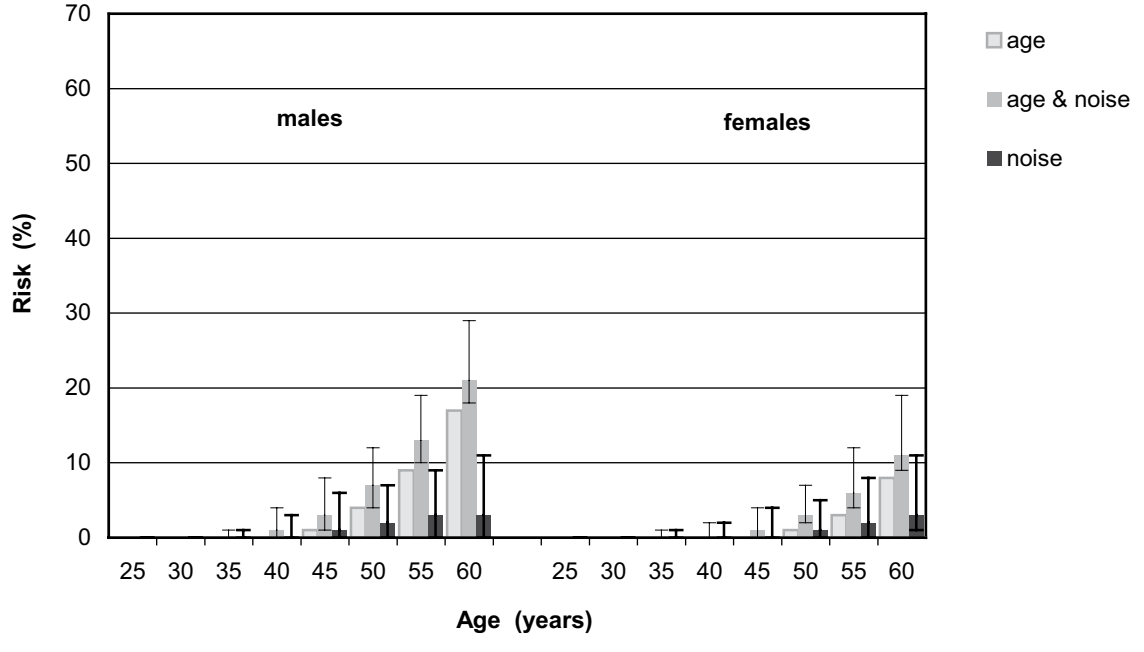
Notes. HTL—hearing threshold level; *—calculations performed according to Standard No. ISO 1999:1990 [16] on the basis of weekly noise exposure levels $L_{EX,w,10}/L_{EX,w,50}/L_{EX,w,90}$ corresponding to the 10th/50th/90th percentile of the equivalent-continuous *A*-weighted sound pressure level for different instrument groups of orchestra and the 10th/50th/90th percentile of declared weekly time of practice as given in Table 2; **—an ontologically normal population ("highly screened").

TABLE 3. Risk of Hearing Impairment Due to Noise Alone in 60-Year-Old Musicians After ~40 Years of Employment

	Risk of Hearing Loss (%)					
	Mean HTL at 0.5, 1, 2, 4 kHz > 25 dB		Mean HTL at 2, 3, 4 kHz > 35 dB		Mean HTL at 1, 2, 3 kHz > 45 dB	
Instruments Group	**Females**	**Males**	**Females**	**Males**	**Females**	**Males**
Violin	1/2/6*	0/2/6	0/1/8	0/3/11	0/0/0	0/0/1
Viola	1/2/7	0/2/8	0/1/11	0/3/13	0/0/0	0/0/1
Cello	0/1/3	0/0/3	0/1/3	0/1/5	0/0/0	0/0/0
Double bass	0/1/3	0/1/3	0/1/3	0/2/5	0/0/0	0/0/0
Harp	0/1/4	0/0/4	0/1/4	0/1/7	0/0/0	0/0/0
Flute	1/4/9	0/4/9	0/5/14	0/7/16	0/0/0	0/0/1
Oboe	1/3/9	0/3/9	0/4/14	0/5/16	0/0/0	0/0/1
Clarinet	1/4/11	0/4/11	0/5/17	0/7/19	0/0/1	0/0/2
Bassoon	1/3/11	0/3/11	0/4/17	0/5/19	0/0/1	0/0/2
Trumpet	1/7/13	1/7/13	1/9/21	1/12/22	0/0/1	0/1/3
Horn	2/5/16	1/5/17	1/7/25	2/9/26	0/0/2	0/0/4
Trombone	1/4/11	1/4/11	1/5/17	1/7/19	0/0/1	0/0/2
Tuba	3/7/13	2/7/13	3/9/21	4/12/22	0/0/1	0/1/3
Percussion	1/4/13	0/4/13	0/5/21	0/7/22	0/0/1	0/0/3
all instrument groups	1/3/11	0/3/11	0/4/17	0/5/19	0/0/1	0/0/2

Notes. HTL—hearing threshold level; *—calculations performed according to Standard No. ISO 1999:1990 [16] on the basis of weekly noise exposure levels $L_{EX,w,10}/L_{EX,w,50}/L_{EX,w,90}$ corresponding to the 10th/50th/90th percentile of the equivalent-continuous *A*-weighted sound pressure level for different instrument groups of orchestra and the 10th/50th/90th percentile of declared weekly time of practice as given in Table 2.

(a)



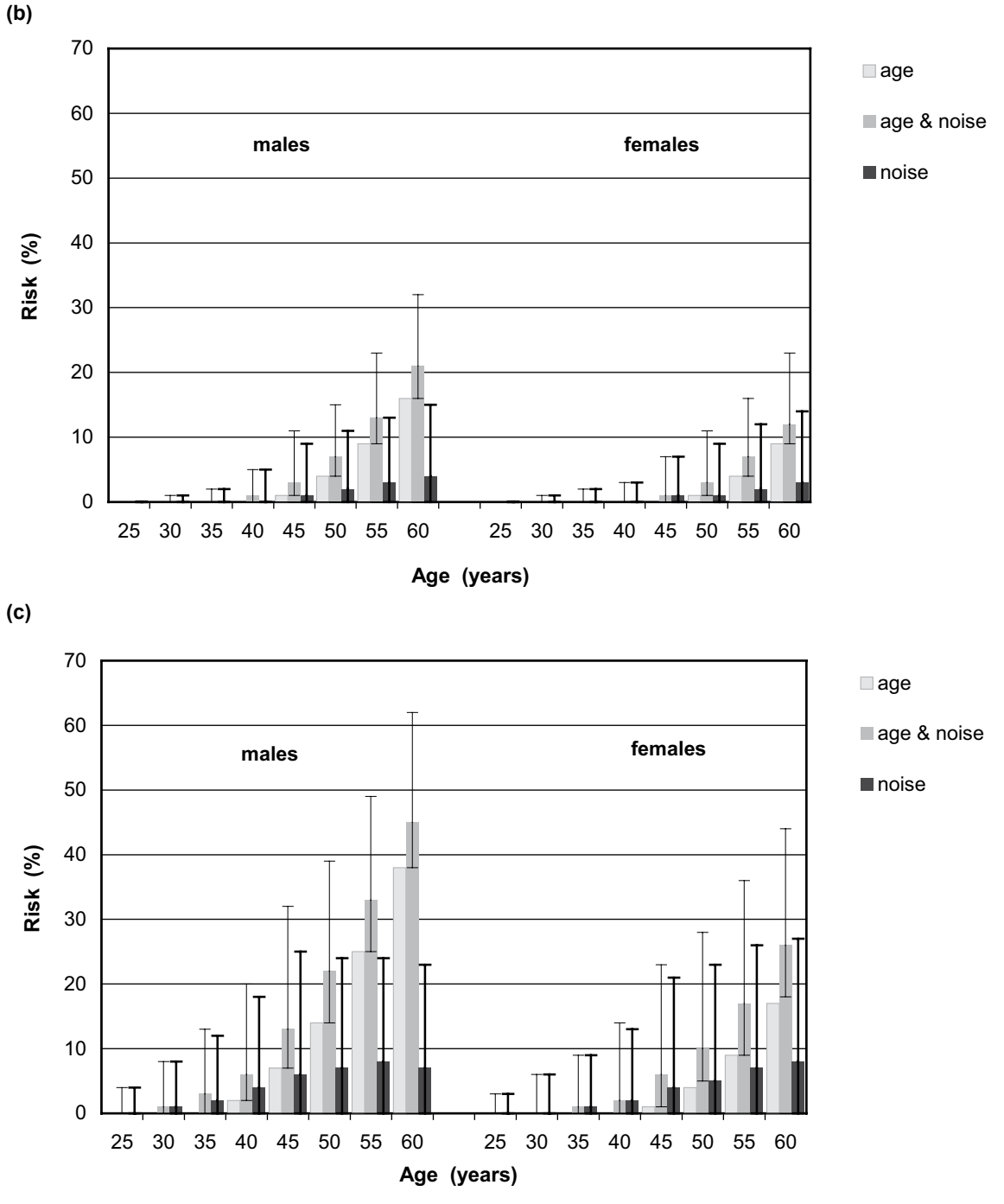


Figure 6. Risk of hearing impairment due to orchestral noise (noise) by age, time of exposure and gender in comparison to the percentage of non-exposed (age) and exposed to orchestral noise (age & noise) populations with an accepted limit value of 25 dB for mean hearing threshold level at (a) 0.5, 1, 2, 4 kHz; (b) 1, 2, 3 kHz and (c) 2, 3, 4 kHz. *Notes*. Calculations were performed according to standard ISO 1999:1990 [16] on the basis of the limit values of weekly noise exposure level ($L_{EX,w,10}$/$L_{EX,w,50}$/$L_{EX,w,90}$) determined for all instrument groups in the orchestra. Bars—risk assessment (%) for weekly noise exposure level $L_{EX,w,50}$ corresponding to the 50th percentile of the equivalent-continuous *A*-weighted sound pressure level and weekly time of practice; whiskers—risk assessment (%) for weekly noise exposure level $L_{EX,w,10}$ and $L_{EX,w,90}$ corresponding to the 10th and 90th percentile of the of the equivalent-continuous *A*-weighted sound pressure level and weekly time of practice.

of age (and exposure in years) on the basis of noise exposure data for all groups of players. It is important that according to Standard No. ISO 1999:1990 the results of risk assessment lower than 5% are unreliable and should be considered as approximations [16].

As can be seen in Figure 6, the risk of hearing loss due to noise and age or due to noise alone depends on the frequency range. The greatest values were obtained for mean HTL at 2, 3, 4 kHz, while the lowest ones for mean HTL at 0.5, 1, 2, 4 kHz. Regardless of the frequency range, in the initial period of exposure the risk of hearing loss (due to noise alone) increases with time and is similar to risk associated with age and noise (Figure 6). After ~20–30 years of exposure (i.e., at the age of 40–50 years), the impact of noise exposure begins to diminish and age starts to dominate.

The risk of NIHL that was evaluated on the basis of $L_{EX,w,50}$ and $L_{EX,w,90}$ for various groups of instruments ranged from 1 to 17%, when the limit value for mean HTL at 0.5, 1, 2, 4 kHz was set at 25 dB (Table 3). This risk increased to 26% when the combination of the frequency of 2, 3, 4 kHz and the limit value of 35 dB were selected. Regardless of the assessment criteria, the highest risk (due to noise alone) was related to playing the horn (up to 17 or 26%) as well as the trumpet, the tuba and the percussion (up to 13 or 22%) (Table 3).

The estimated risk of permanent hearing threshold shift that suffices to diagnose occupational hearing loss in Poland ranged from 0 to 4% for various instrument groups of players. In particular, HTLs (mean values for 1, 2, 3 kHz) exceeding 45 dB might occur in a small percentage of males (maximum 3–4%) and females (up to 2%) playing the clarinet, the bassoon, brass instruments and the percussion. On the other hand, the percentage of females and males with mean HTLAN at frequencies of 2, 3, 4 kHz above 35 dB remained within the range of 4–29% and 18–44%, respectively (Table 2).

The method in Standard No. ISO 1999:1990, which is to assess risk of NIHL in orchestral musicians, is primarily based on data collected with essentially broadband steady non-tonal industrial noise. It also gives unreliable results for tails of predicted statistical distributions of HTLA, NIPTS and HTLAN. Thus, caution should be exercised when interpreting findings presented here. Especially as according to some earlier observations orchestral noise deteriorates hearing less than Standard No. ISO 1999:1990 would suggest [4, 8]. Moreover, that standard does not discuss 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, skin pigmentation, gender and age [23, 24, 25]. It does not discuss the protective effects of hearing protective devices, either.

There are no ototoxic chemicals or vibrations in musicians' working environment. To assess the incidence of other NIHL risk factors, musicians filled in a questionnaire. According to the responses, about one-quarter of them frequently used noisy tools (25%) or listened to music through headphones every day (24%). However, only 12% declared using hearing protective devices at present or in the past, whereas 51% intended to use hearing protective devices in the future. Nearly every fifth musician reported elevated blood pressure. Moreover, ~22% of musicians declared smoking at present, while 30% smoked in the past. The responses indicated that extra NIHL risk factors were not very frequent in orchestral musicians; therefore, they were not considered in this study.

To sum up, the results confirmed that professional orchestral musicians were often exposed to intensive sounds at levels exceeding the upper exposure action value in Directive 2003/10/EC [9]. Therefore, a special conservation program should be developed for this professional group.

4. CONCLUSIONS

- Professional orchestral musicians are usually exposed to sound at $L_{Acq,T}$ of 81–90 dB (10th–90th percentiles) for 20–45 h per week (10th–90th percentiles).
- Such exposure to orchestral noise for over 40 years of employment might cause hearing loss (expressed as mean hearing threshold at 2, 3 and 4 kHz exceeding 35 dB) of up to 26%. The highest risk is posed by playing the horn (up to 26%) as well as the trumpet, the tuba and the percussion (up to 22%).
- Permanent hearing threshold shift that suffices for diagnosing occupational hearing loss in Poland might occur in a small percentage of males (~3–4%) and females (~1–2%) playing the clarinet, the bassoon, the brass instruments and the percussion.
- Further research is necessary to verify whether the method in Standard No. ISO 1999:1990 is appropriate for assessing risk of NIHL in professional orchestral musicians.
- Findings presented in this paper confirm the need to implement hearing conservation program for this occupational group.

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APPENDIX

Selected Data on Circumstances of Measurements of Orchestral Noise

Repertoire

L'Endimione by João de Sousa Carvalho (1745–1799)
Don Giovanni by Wolfgang Amadeus Mozart (1756–1791)
Symphony in C, No. 41, *Jupiter* by Wolfgang Amadeus Mozart (1756–1791)
Die Zauberflöte by Wolfgang Amadeus Mozart (1756–1791)
La Morte di Semiramide by Marcos António da Fonseca Portugal (1762–1830)
Piano Concerto No. 3 in C Minor, Op. 37 by Ludwig van Beethoven (1770–1827)
Symphony No. 5, in C Minor, Op. 67, by Ludwig van Beethoven (1770–1827)
Leonore Overture, No. 3, Op. 72b by Ludwig van Beethoven (1770–1827)
Symphony No. 9 in D Minor, Op. 125 by Ludwig van Beethoven (1770–1827)
Symphony No. 1 in E Flat Major, Op. 11 by João Domingos Bomtempo (1775–1842)
Guillaume Tell by Gioachino Rossini (1792–1868)
Semiramide by Gioachino Rossini (1792–1868)
Symphony No. 4 in D Minor, Op. 120 by Robert Schumann (1810–1856)
Aida by Giuseppe Verdi (1813–1901)
La Traviata by Giuseppe Verdi (1813–1901)
Nabucco by Giuseppe Verdi (1813–1901)
Straszny Dwór by Stanisław Moniuszko (1819–1872)
Akademische Festouvertüre, Op. 80 by Johannes Brahms (1833–1897)
Symphony No. 4 in E Minor, Op. 98 by Johannes Brahms (1833–1897)
Piano Concerto No. 2 in G Minor, Op. 22 by Camille Saint-Saëns (1835–1921)
Yevgeniy Onegin, Op. 24 by Pyotr Ilyich Tchaikovsky (1840–1893)
Symphony No. 4 in F Minor, Op. 36 by Pyotr Ilyich Tchaikovsky (1840–1893)
Cello Concerto in B Minor by Antonín Dvořák (1841–1904)
La Boda de Luis Alonso by Gerónimo Giménez (1854–1923)
La Bohème by Giacomo Puccini (1858–1924)
Turandot by Giacomo Puccini (1858–1924)
Images pour Orchestre, No. 2, *Ibéria* by Claude-Achille Debussy (1862–1918)
Cavalleria Rusticana by Pietro Mascagni (1863–1945)
Piano Concerto No. 4 in G Minor, Op. 40 by Sergei Rachmaninoff (1873–1943)
Alborada del Gracioso by Maurice Ravel (1875–1937)
My Fair Lady by Frederick Loewe (1901–1988)
Fantasia Para un Gentilhombre by Joaquin Rodrigo (1901–1999)
L'Ascension by Olivier Messiaen (1908–1992)
Contemporary film music

Venue

Rehearsal halls (n = 113)
Rehearsal studios (n = 12)
Concert hall stages (n = 189)
Orchestra pits (n = 25)

Activity

Group rehearsals (n = 306)
Concerts (n = 22)
Performances (operas) (n = 11)