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Noise exposure and hearing loss in classical orchestra musicians

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ABSTRACT

Noise exposure and hearing loss was assessed in different instrument groups of a professional ballet orchestra. Those instrument groups experiencing the highest levels of exposure also had the highest pure tone thresholds. Critically, we found that thresholds were not uniform across instrument groups. The greatest difference in thresholds was observed at test frequencies above 2000 Hz, peaking at 4000 Hz where the average difference between groups was as high as 15 dB. The differences could not be accounted for on the basis of age, years of playing, or years of playing professionally, and are thus most likely due to differences in occupational noise exposure. Nonetheless, measured losses for all instrument groups did not approach clinically significant levels.

Relevance to industry: By combining noise exposure and hearing loss assessment, this study provides information that extends current understanding of the occupational risks faced by professional musicians playing in orchestras. This information may be particularly useful in the design and implementation of hearing conservation programs.

1. Introduction

The passages marked quadruple forte (ffff) in Berlioz's "Symphonie Fantastique", exciting though they may be for the audience, seem likely to pose some occupational risk for the performing musician. Nonetheless, in a review of some 32 papers, Behar et al. (2006) were hard-pressed to reach general conclusions about the occupational risks faced by musicians because of the inconsistency in methods across studies (both instrumentation and procedures) and variability in reported playing time. A number of studies have focused on exposure in the context of performance (Axelsson and Lindgren, 1981; Kahari et al., 2003; Royster-Doswell et al., 1991; Schmidt et al., 2011; Westmore and Eversden, 1981), while others have focused on exposure during practice, which can involve sub-optimal acoustic conditions such as those often faced in standard classrooms (Chesky, 2010; Phillips and Mace, 2008; Walters, 2009).

Quian et al. (2011) conducted a noise exposure survey on musicians in the Canadian National Ballet Orchestra. This was done using dosimeters that run continuously for the whole duration of rehearsals as well as during performances. On the basis of measured levels and contractual limitations on playing time (360 h/year), the authors determined that there was no risk of hearing loss associated with playing in the orchestra. However, the authors acknowledged that assessment of noise exposure might not be sufficient to make conclusions regarding risk to hearing health because other types of noise exposure have not been taken into account. Given the challenge of fully accounting for all possible types of noise exposure, another valuable way to address the occupational risks faced by orchestra musicians is to perform audiometric tests (Ostri et al., 1989; Toppila et al., 2011). Zhao et al. (2010) have argued that disagreement and speculation about the risk of hearing loss in musicians stems in part from insufficient audiometric evidence.

In the current study, we conducted audiometric tests on musicians from the same orchestra that took place in the noise exposure survey conducted by Quian et al. (2011) allowing us to assess the correspondence between measured hearing loss and noise exposure in the same population. The musicians were also asked to complete a questionnaire to obtain information about basic demographics and extra-occupational factors that might impact measured hearing thresholds (Appendix). Our aim was to gather all information necessary to predict hearing loss according to the ISO 1999 standard (International Organization for Standardization, 1990). Predicted and measured levels of hearing loss were compared.

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2. Methods

2.1. Participants

Fifty two orchestra musicians from the National Ballet of Canada Orchestra took part in the study.

2.2. Questionnaire

In addition to basic demographic questions, musicians were asked about instruments played (some played more than one), number of years playing, number of years playing professionally, and exposure to other non-occupational sources of noise.

Participants were fully informed about the objectives of the study and were assured about the confidentiality of their responses. The issue of confidentiality was important to the musicians, given professional sensitivities about hearing loss. Indeed, confidentiality was a pre-condition for many musicians to even consider taking part in the study. Thus, names were neither requested nor attached to our questionnaire.

For data analysis purposes, musicians were grouped as follows: (1) Violins; (2) Violas/Cellos; (3) Woodwinds; (4) Percussion/(Double) Basses; and (5) Brasses. Our grouping was determined on the basis of timbre and location on the orchestra floor (see Fig. 1). Although there is greater heterogeneity in Group 4 relative to the other groups, it is important to note that percussion and bass instruments both generate sound with a high concentration of low-frequency energy.

2.3. Audiometry

All musicians received a complete audiometric evaluation from one of the authors (MC), who is a qualified audiologist. This included pure tone testing (air conduction and bone conduction), speech testing (word recognition scores and speech reception thresholds), and admittance measures (tympanometry and acoustic reflexes). All measurements were conducted in a sound treated audiometric booth that was in accordance with the American National Standards Institute (ANSI) standard ANSI S3.1-1999 (R2003) and with appropriate calibration of the audiometric (ANSI S3.6, 2004) and admittance (ANSI S3.39, 1987 (R2002)) equipment. Because a temporary threshold shift is known to occur within 16–18 h after an exposure to loud noise (or music), the audiometric assessments were carried out in the morning prior to any practice or scheduled rehearsals.

After completing an audiological history and otoscopic examination a full audiometric battery including middle ear assessment was performed. Air conducted and bone conducted audiograms were obtained at the following test frequencies: 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz, and 8000 Hz. The results of the test were explained to each musician and a range of hearing loss prevention strategies, including the use of uniform attenuation earplugs was discussed. Where significant audiometric asymmetries and/or otologic symptoms were noted, the musician was referred for a full otolaryngological assessment. All participants tested within the normal range for speech tests and admittance measures.

3. Results

3.1. Noise exposure

Occupational noise exposure levels, $L_{eq,\ 360}$ (dB) for each group were calculated using the L_{eq} data from Quian et al. (2011), adjusted for the 360 h musicians are contracted to play per year, while 2000 is the number of hours that is typically used to determine noise exposure for an industrial worker (i.e., 8/hr day). Consequently, the corrected noise exposure for the orchestral musicians studied here is equal to $L_{eq} - 7.5$ dBA.

$$L_{eq,360}(\mathrm{dB}) = L_{eq} + 10\log(360/2000) = L_{eq} - 7.5\ \mathrm{dBA}$$

As shown in Fig. 2, brasses had the highest level of exposure, followed by woodwinds and percussion/basses. Violins and violas/cellos had the lowest levels of exposure. This pattern of noise exposure by instrument is consistent with a recent study of two orchestras conducted by Schmidt et al. (2011), in which the highest levels of exposure was also found to be in the brasses.

3.2. Questionnaire

Forty-four of the 52 orchestra musicians completed the questionnaire (85%). Twenty-one of the 44 respondents were female (48%). The average age of males was 51.7 years (SD = 11.1), while the

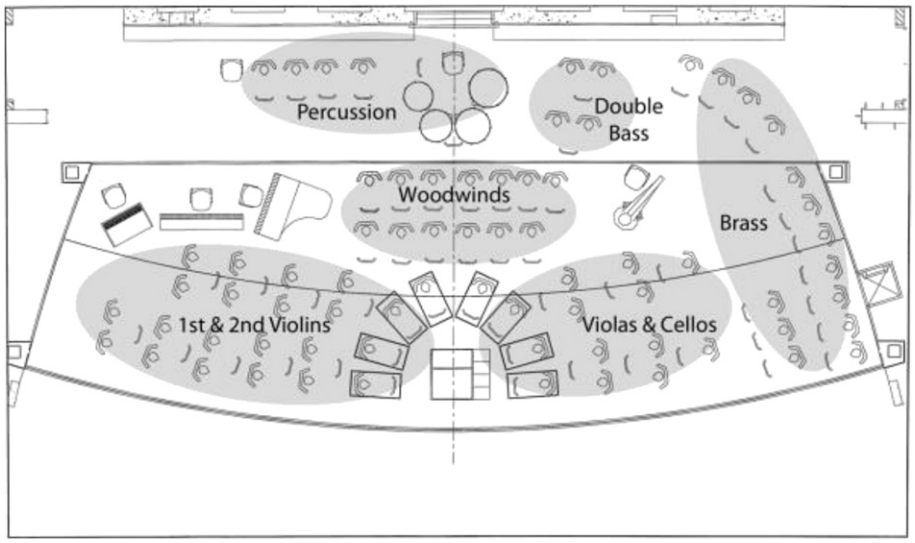

Fig. 1. Location of the instrument groups on the orchestra floor.

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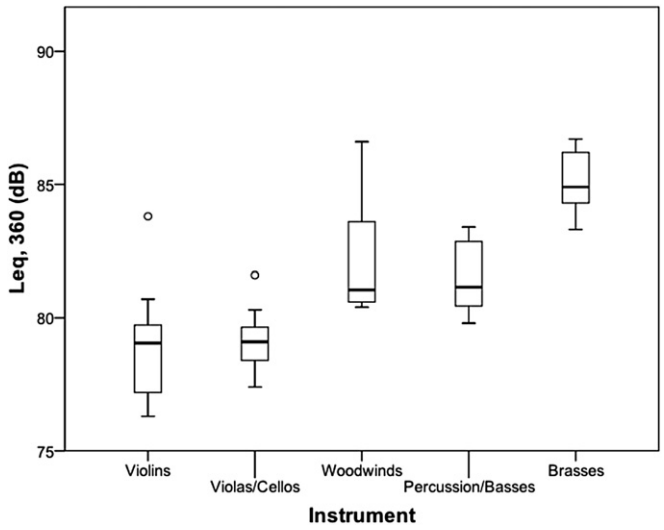

Fig. 2. Boxplots of noise exposure levels in each group. Outliers are shown as small circles.

average age of females was 48.7 (SD = 9.9). As shown in Table 1, the average age of participants was reasonably matched across the five groups.

Table 2 list the average number of years of playing and years of professional experience in each group. Analyses-of-variance (ANOVA) determined that the groups did not differ with respect to years of playing, F (4, 38), = 1.20, n.s., or years of playing professionally, F (4, 38) < 1, n.s.

When asked about the device used for listening during leisure time, 40 participants reported listening through loudspeakers, 21 reported listening through insert earphones (earbuds), and 5 reported listening through circumaural headphones. The small sample did not permit statistical analyses but there were no obvious trends suggesting that instrument groups varied in device used for listening during leisure time. It is also worth noting that most musicians used more than one type of listening device.

Only 9 of the 44 respondents reported involvement in noisy extra-occupational activities. Although these 9 individuals appeared to be randomly distributed across the instrument groups, there is some question surrounding this finding in that a proper definition of "noisy activities" was not provided. Examples of extra-occupational activities identified by the respondents included woodworking, hunting, and use of gas-powered landscape equipment.

3.3. Hearing loss

Fig. 3 plots the audiometric pure tone average thresholds for each group collapsed across ears. As may be seen in the figure, there is a consistent mid- to high-frequency sensory-neural hearing loss with poorest sensitivity in the 4000–6000 Hz region. This pattern of sensitivity is consistent with early stage hearing losses resulting from other types of noise exposure.

An ANOVA was conducted with frequency as the within subjects variable, and with instrument group as the between subject variable. The main effect of frequency was highly significant, F (6, 282) = 51.78, $p < .001$. Although the main effect of instrument group was only marginally significant, F (4, 47) = 2.1, $p < .1$, the interaction between frequency and instrument group was significant, F (24, 282) = 1.68, $p < .05$. The greatest difference between instrument groups was observed at 4000 Hz. In this region, percussion/basses and brasses showed losses of approximately 25 dB, while other instrument groups showed losses of approximately 10 dB. Consistent with the profile of noise exposure, brasses had the greatest loss, peaking at 6000 Hz. However, it must be acknowledged that the measured hearing losses are small and the differences between instrument groups are less than the measurement error (±5 dB) at some test frequencies.

Table 1
Average age (years) of participants.

	Violins ($n = 8$)	Violas/cellos ($n = 8$)	Woodwinds ($n = 11$)	Perc./basses ($n = 8$)	Brasses ($n = 9$)
Average	46.0	48.6	56.9	51.1	46.6
St. dev.	10.8	9.2	5.1	12.5	12.5

Table 2
a) Years playing the instrument. b) Years playing professionally.

	Violins	Violas/cellos	Woodwinds	Perc./basses	Brasses
a					
Avg.	41.8	35.6	40.4	38.6	32.5
St. dev.	11.7	5.9	6.0	11.8	12.8
b					
Avg.	26.0	23.9	31.5	29.9	22.8
St. dev.	12.6	10.8	6.0	14.1	14.2

3.4. Measured and predicted hearing loss

The ISO 1999 Standard (International Organization for Standardization, 1990) predicts the distribution of hearing loss at different frequencies for males and females, according to age and the number of years of exposure at a given noise level. Application of the standard was based on averages drawn from across the instrument groups. We elected to use a uniform noise exposure estimate of 85 dBA to depict the worst-case scenario. This estimate is just below the corrected level of noise exposure for the loudest instrument group (brasses). The value of the predicted hearing loss at each frequency was then determined by averaging the 50th percentile value for males and females of 50 years. This approach is justified by the average age of our sample (50.3 years) and the nearly equal ratio of men to women (23:21).

Fig. 4 shows the predicted and measured hearing losses for the orchestra musicians. It may be observed that there are essentially no differences between predicted and measured hearing losses at 3000, 4000, and 8000 Hz and that the predicted hearing losses were underestimated at lower frequencies. Although the underestimate at 500 Hz may be due in part to background noise in the audiometric booth, the underestimates at 1000 and 2000 Hz cannot

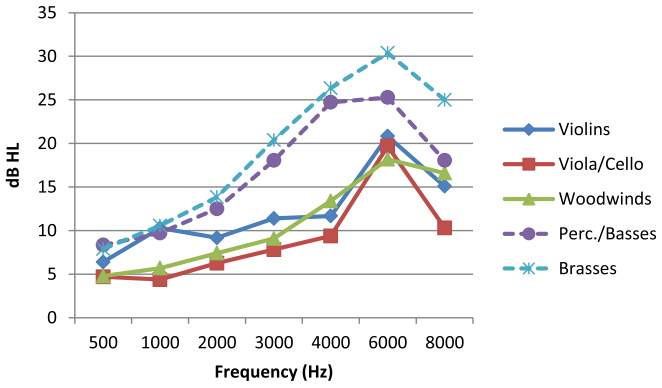

Fig. 3. Average hearing loss per group.

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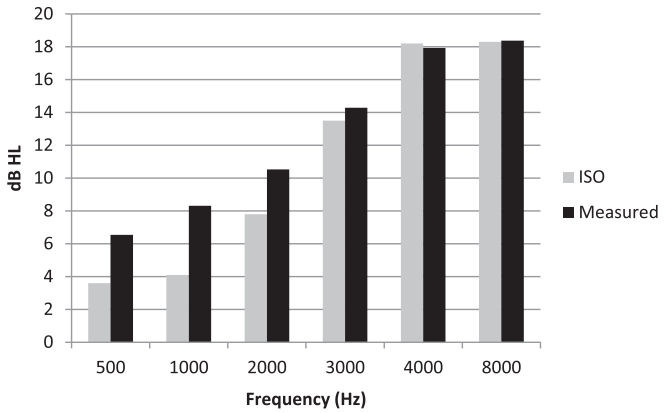

Fig. 4. Predicted hearing losses as per ISO 1999 and measured hearing losses (collapsed across groups).

be so easily dismissed. One possible explanation for these underestimates concerns the slope of the long-term average spectrum (LTAS). The slope of the LTAS is quite variable for industrial noise, whereas it tends to be consistently negative for music (Borch and Sundberg, 2002; Russo and Pichora-Fuller, 2008). It is possible that this negative slope leads to greater losses in the lower frequencies than would be expected on the basis of the ISO standard. However, this explanation is somewhat speculative given the small size of our population and the wide variety of spectral and temporal factors that distinguish industrial noise from music. In addition, the differences between predicted and measured losses do not exceed the limits of measurement error.

4. Discussion

Pure tone audiometry showed that threshold varied as a function of instrument group and frequency region. Brasses and percussion/basses had the highest thresholds, bordering on clinically significant losses in the 4000–6000 Hz region. These differences across groups could not be explained by age, years of playing, or years of playing professionally, and are thus most likely due to differences in occupational noise exposure. Brass players also had the highest level of noise exposure (10 dB or greater than strings and woodwinds between 4000 and 8000 Hz). These findings are consistent with previous noise-exposure surveys (Schmidt et al., 2011) and audiometric investigations (Jansen et al., 2009), which raises some concern about long-term hearing health of brass players. Nonetheless, it is important to acknowledge that at the time of testing, none of the groups had hearing loss that would be considered outside the limits of normal hearing.

Noise exposure levels in the orchestra were below the hazard limit of 85 dBA with the exception of the brasses. However, orchestras with longer playing times will be at greater occupational risk. On the basis of these findings, it seems reasonable to recommend that orchestras comparable to the orchestra studied here adopt a hearing conservation program (e.g. NIOSH, 1998), and that flat attenuation earplugs be considered for those orchestra members that are exposed to higher noise levels. On the basis of the current study, it appears that such interventions may be most necessary among brass players.

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Appendix A. Noise exposure questionnaire

1. Introduction

A noise exposure survey was conveyed on National Ballet Orchestra players in 2009. The objective was to assess the risk of hearing loss due to the exposure to only the sound levels generated by the orchestra. Exposures to other sources (such as playing in other orchestras/ensembles, individual practice, teaching, etc.) were not taken into account. To test the effects of the noise exposure, a series of hearing tests (audiometries) was performed on the same group of musicians. This is a sort of "flash photograph", since it shows the present state of hearing loss. Unfortunately, there are no comparable records from 5, 10 or 15 years ago, to assess the progress of hearing loss (if there is any). However, data on past exposures could help explain the origin of any observed hearing loss. At this point in time, that data can only be obtained through a questionnaire regarding past exposure history.

2. The questionnaire

These questions are related strictly to past history of noise exposure: sources, daily duration and overall length of exposure. It is not necessary to fill out the entire questionnaire but the most important part is age and gender, since the ISO standard to which we will be comparing the results needs those data. Remember that the results of the questionnaire will remain anonymous. Thank you for participating – please put your completed questionnaire in the ballot box in the orchestra lounge.

What is your age? _____years
Male/Female

Instrument (optional): _____
How long have you been playing? ____years
Professionally? ____years
What percentage of your working time is spent
Playing in the NBO? _____%
Playing in other orchestras? _____%
Playing in ensembles? _____%
Teaching? _____%
Practicing? _____%
Is there any other "noisy" activity that you do regularly, e.g. woodworking?
Yes No

Instrument group (circle one)
Violin Viola/cello
Woodwind Percussion/bass Brass
What percentage of your working time is spent playing this instrument?
_____%

When you listen to music do you
Wear headphones? Yes No
Wear earbuds? Yes No
Listen through a speaker system? Yes No
Do you tend to listen to music at high volume or normal range?
High volume Normal

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