



ELSEVIER

Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

SCIENCE @ DIRECT®

Applied Acoustics 66 (2005) 919–931

**applied  
acoustics**

[www.elsevier.com/locate/apacoust](http://www.elsevier.com/locate/apacoust)

## Musicians' noise exposure in orchestra pit

Jason Lee <sup>a,b</sup>, Alberto Behar <sup>a,\*</sup>, Hans Kunov <sup>a,b</sup>, Willy Wong <sup>a,b</sup>

<sup>a</sup> *Sensory Communication Group, Institute of Biomaterials and Biomedical Engineering,  
University of Toronto, 4 Taddle Creek Road, Toronto, Ont., Canada M5S 3G9*

<sup>b</sup> *The Edward S. Rogers Sr. Department of Electrical and Computer Engineering, University of Toronto,  
10 King's College Road, Toronto, Ont., Canada M5S 3G4*

Received 30 April 2004; received in revised form 1 November 2004; accepted 30 November 2004

Available online 19 February 2005

---

### Abstract

Sound exposures of Canadian Opera Company orchestra players were measured to assess the risk of hearing loss of players in orchestra pits. This was done during 18 sessions that included rehearsals, dress rehearsals and actual performances of two operas. Seventy-three noise exposures of musicians were measured using five dosimeters for the entire duration (3 h) of each event. The measured estimate,  $L_{eq}$ , from which the  $L_{ex}$  was calculated using the numbers of hours per year played by the musicians of the Canadian Opera Company. Following the ISO 1999 Standard, results indicate that, playing for the company does not pose risk of hearing loss for the players.

© 2005 Elsevier Ltd. All rights reserved.

*Keywords:* Noise exposure; Hearing conservation; Hearing loss; Musicians; Orchestra pit

---

### 1. Introduction

There is abundant literature that deals with noise exposure of classical orchestra players. Most studies deal with noise exposure levels of orchestra players performing

---

\* Corresponding author. Tel.: +1 416 978 6170; fax: +1 416 978 4317.  
E-mail address: [behar@sympatico.ca](mailto:behar@sympatico.ca) (A. Behar).

in concert halls. However, very little is found regarding musicians' noise exposure when they perform in orchestra pits in operas, ballets and musicals.

Most studies fell into two groups: those where only noise levels or sound exposure levels are measured and those where hearing threshold levels are also tested. In studies belonging to the second group, comparisons are made between hearing thresholds of players and non-exposed people to assess the influence of the noise on the hearing of the players.<sup>1</sup>

After examining an extensive bibliography and also data from 53 members of the Vancouver Symphony Orchestra, Eaton and Gillis [1] concluded that "some noise-induced hearing loss is predicted. However...most studies on musicians' hearing...found threshold levels not significantly different than non-exposed populations".

Obeling and Poulsen [2] conducted a study on musicians from four different Danish orchestras. Sound levels were measured and audiometry performed on the musicians. When compared to the median audiogram from ISO 7029 for the same age and gender they concluded that musicians "cannot expect to suffer a pronounced hearing loss from playing in a symphony orchestra".

Kahari et al. [3] performed pure-tone audiometry on 140 classical orchestral musicians from the Gothenburg Symphony Orchestra and the Gothenburg Opera. They concluded that the results "did not show severe hearing losses that could be attributed to exposure to musical noise".

Similar results were found by the same authors [4] in another study that was a follow-up from a research by Axelsson and Lindgren done 16 years earlier. The study consisted in repeating the audiometric tests done on classic orchestra musicians in Goteborg, Sweden. The study showed no significant change of hearing during this 16 years interval.

It may be assumed that the exposure of musicians playing in orchestra pits, such as in the case with opera or ballet, is different from other types of orchestras. Because of the confined space in the pit, where walls and ceiling are very close, it is to be expected that the exposures will be higher than those of their counterpart, performing in regular music halls. A large study, encompassing both hall and pits players, was performed by Williams [5] on musicians belonging to three orchestras from the Australian Broadcasting Corporation. Measurements were performed using a number of sound level meters (but not dosimeters) in a variety of activities including rehearsals and performances. According to the author "...it can be clearly stated in general that the noise levels in the pit environment will always be louder than in the open area." The study concludes that the orchestras "...do not have a major noise exposure problem...".

Contrary to the previous study, Laitinen et al. [6] arrived at the conclusions that most musicians are overexposed in their study. They used dosimeters to measure

---

<sup>1</sup> The expressions "noise" and "noise exposure" are used here as synonyms to "occupational sound" and "occupational sound exposure". Although music is not usually classified as "noise", in this study we are dealing with occupational exposure to sound, therefore the use of the word "noise".

noise exposure levels of players, singers, dancers and auxiliary personnel of the Finnish National Opera. From their results, annual noise exposure levels of different groups of musicians were calculated, assuming that the total duration of the exposure (individual and group rehearsals, and performances) was 1500 h.

One could be puzzled by the apparently contradictory conclusions obtained by different researchers: on one hand, sound levels and noise exposures studies show levels that appears to be in excess of the “safe” limit of 85 dBA, and so the musicians appear to be over-exposed. On the other hand, audiometric test results indicate that the hearing of classical orchestra musicians is similar to that of the non-exposed population. This apparent contradiction could be the result of equating  $L_{\text{eq}}$ , the measured noise exposure level, to  $L_{\text{ex}}$ , that is the noise exposure level normalized for an 8 h workday, repeated 5 days/week for a 40 years period, which is the limit recommended in the ISO Standard [7].

For example, if the  $L_{\text{eq}}$  of a tuba player during the performance of *The Flying Dutchman* is 92 dBA for a 4-h period one night, the corresponding normalized  $L_{\text{ex}}$  for the day is 89 dBA. He could be considered overexposed if only his exposure on that particular day is taken into consideration. However, unless his every day exposure for the entire 250 days/year (8 h/day or 2000 h/year) period is known, he should not be considered as overexposed.

The present study was intended to examine the noise exposures of musicians from the Canadian Opera Company (COC), while rehearsing and performing two operas in the orchestra pit, to assess their risk of hearing loss. Results were then extrapolated to the normalized, whole-year noise exposure using the annual number of hours spent in the orchestra.

## 2. Risk criteria

There is no Federal or Provincial legislation in Canada that sets limits to professional musician’s maximum daily noise exposure. We are not aware of any similar legislation worldwide either. The Ontario Occupational Health and Safety Act [8] that applies to industry in the province of Ontario, specifies that the maximum daily exposure level should not exceed 90 dBA. The limit increases by 5 dB every time the length of the exposure is halved. This criterion is known as the 5 dB exchange rate.

Another widely accepted criterion recommends the use of 85 dBA as the daily 8 h exposure limit and a 3-dB exchange rate (3 dB increase per halving of the exposure duration). In Canada, this criterion is included in the federal legislation, in the corresponding CSA standard [9], and is used in most provinces. Its use is recommended by some institutions in the USA (National Institute of Safety and Health, NIOSH [10], and the American Conference of Governmental Industrial Hygienists, ACGIH [11]), by the International Standard Organization (ISO [7]) and is used in most countries in Europe. This second, more stringent criterion is used in this paper to assess the risk of hearing loss of orchestra players.

### 3. Participants

In total, 67 volunteer musicians participated in the study. Some of them were measured more than once, to test the repeatability of the results. Participants were requested to wear noise dosimeters during an entire activity that was either a rehearsal, a dress rehearsal or an actual performance, all of them in the pit. The duration of each activity was roughly 3 h. Measurements were taken during 18 sessions that included two operas: *The Italian Girl in Algiers*, by Rossini, and *Madama Butterfly*, by Puccini. The first of them required 49 musicians, while the second had 61 players. Both operas are common to the international operatic repertoire, and are considered average in terms of orchestra size.

### 4. Instrumentation and measurement procedures

#### 4.1. Instrumentation setup

Measurements were performed using five Quest Type Q-300 dosimeters. These dosimeters record the exposure level in a per minute basis and calculate the average exposure level over the recording period. In our study, the dosimeters were set to measure  $L_{eq}$ . The dynamic range was set to 70–140 dBA, which provides a linear response within this range. The response time was set to “Slow” to smooth out the noise fluctuations, as according to the CSA Standard [9].

Dosimeters were first calibrated in our laboratory, using the QuestSuite Professional computer program and the Quest Type QC-10 calibrator. The program was also used for setting the dosimeters. Before each measurement the calibration was checked by attaching the calibrator to the dosimeter microphone and ensuring that the sound-level reading of the dosimeter conforms to the calibrator. No additional calibration was needed throughout the study, which spanned approximately two months.

According to the procedures in the CSA Standard Z107.56 –94 [9], the microphone of each dosimeter was located on the shoulder to minimize sound reflections from the head. It is also well known from the practice, that movements of the microphone cable can generate extraneous noise. To avoid this source of error, the microphone, as well as the cable was secured using masking tape. The dosimeter proper was attached either on the belt or on the pants of the wearer.

Noise exposure of the conductor was also measured. In this case, since the microphone could interfere with his motions, it was positioned on the podium.

#### 4.2. Physical environment

All the measurements took place while the musicians played in the orchestra pit of the Hummingbird Centre, a concert hall that seats approximately 3200, located in Toronto, Canada.

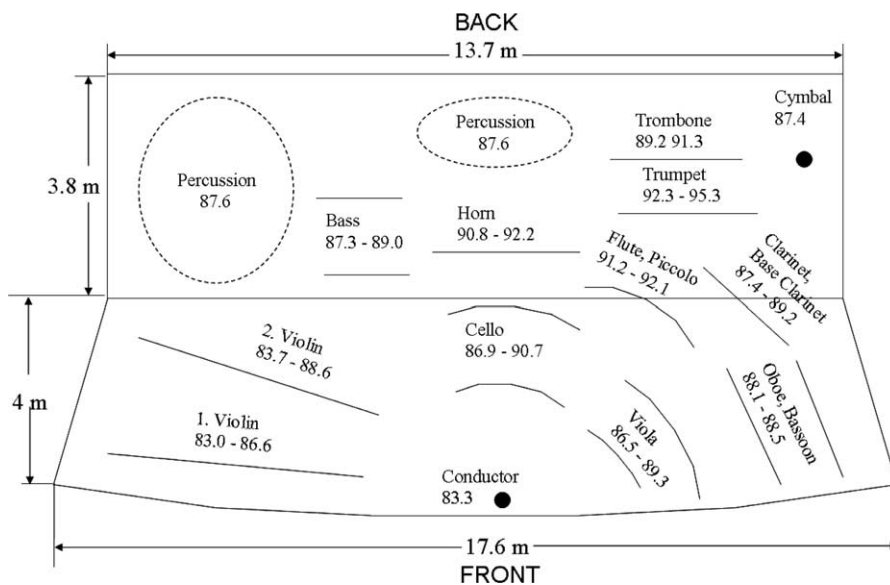


Fig. 1. Instruments location and  $L_{eq}$  ranges in Madama Butterfly (MB), and physical dimensions of the orchestra pit.

Fig. 1 shows the physical dimension of the orchestra pit. It is divided into two sections. The section at the back is under the stage, while the top of the front section is open to the hall. The ceiling for the back section is 2.5 m from the floor, and the front section is about 50 cm elevated from the back. The walls, ceiling and floor are mostly hard and reflective surface. The size of the pit is quite small compared to the size of the orchestra and most musicians sit close to each other.

#### 4.3. Measurement procedure

At the beginning of the study, a meeting of players was called to explain the objectives of the study and the procedures to be followed during the tests. Questions were encouraged and answered. All players were invited to participate in the survey and it was stressed that participation was on a voluntary basis. Since no hearing tests were to be performed, there was no specific requirement for the volunteers for the test, such as minimum hearing threshold, condition of general health, etc. Although not all musicians volunteered, there were enough participants to represent different parts of the orchestra.

For each session, about five players were selected by the Orchestra Personal Manager. The selection criteria were:

- For each event (rehearsal, dress rehearsal or performance) the players are from different instruments, and
- For each opera, there was an attempt to have one instrument player tested in two consecutive events (e.g., for the events A and B the same first violin, for the

events B and C the same clarinet, etc.). This was done to test the repeatability of the measured noise exposures of the same player in different events while performing the same opera. Unfortunately, that was not always achieved for reasons of practicality. However, as discussed further, we did collect enough samples as to conclude that there was an acceptable repeatability.

Each session began with changing the batteries of the dosimeters and checking their calibration. Dosimeters were then attached to the wearers, taking care to tape the microphone wire on their back to avoid any obstruction while executing their instruments. Players were instructed to wear the dosimeters during the entire event and perform their job as usual. They were also asked to prevent from touching and speaking directly at the microphone to avoid measurement error.

At the end of the performance/rehearsal, the dosimeters were collected and the measured  $L_{eq}$  were recorded manually. The data, which includes a per-minute log of  $L_{eq}$ , was also downloaded from the dosimeters to a computer and then stored into separate diskettes for safety purposes.

## 5. Results and analysis

In total, 73 measurement results were performed: 41 from *Madama Butterfly* (MB) and 32 from *Italian Girl in Algiers* (IG). The noise exposure readings were obtained from 66 musicians playing different instruments and from the conductor. Seven measurements were from repeated tests.

### 5.1. Equivalent sound level

#### 5.1.1. $L_{eq}$ per instrument

Table 1 shows the number of tests performed per each instrument (N) and opera, the average  $L_{eq}$  and, within brackets, the range of the measured  $L_{eq}$ . Figs. 1 and 2 provide a floor plan of the instruments locations.

For both operas, the highest noise exposures were found among the brass instruments, followed by the woodwinds, and then the strings. In general, the measured noise exposure decreases with the distance from the brass and woodwinds. For example, among the strings in *Madama Butterfly* (MB), the noise exposure of viola, cello and double bass players were higher than the first and second violins, which are farther away from the brass and woodwinds.

Noise exposures obtained from the conductor were substantially lower than most of other musicians. This is probably due to the fact that the conductor was above the musicians and larger distance from the brass and woodwinds.

#### 5.1.2. $L_{eq}$ of the two operas

The  $L_{eq}$  for all instrument groups were higher in MB than in IG, except for the second violins. This can be explained by the different number of players and different

Table 1  
Average  $L_{eq}$  of instrument groups

Instrument	Madama Butterfly		Italian girl in Algiers	
	<i>N</i>	$L_{eq}$ (dBA)	<i>N</i>	$L_{eq}$ (dBA)
Violin 1	5	84.8 (83.0–86.6)	5	82.8 (80.3–84.9)
Violin 2	6	85.7 (83.7–88.6)	8	86.5 (84.6–88.1)
Viola	3	88.3 (86.5–89.3)	4	85.8 (84.1–88.2)
Cello	3	88.7 (86.9–90.7)	3	81.4 (81.0–81.8)
Double Bass	2	88.2 (87.3–89.0)	2	83.7 (82.0–83.3)
Trumpet	3	93.7 (92.3–95.3)	3	91.4 (88.7–92.7)
Trombone	3	90.3 (89.2–91.3)	0	
Horn	4	91.7 (90.8–92.2)	1	89.9
Piccolo/Flute	2	91.7 (91.2–92.1)	1	87.4
Clarinet/Bass Clarinet	4	88.6 (87.4–89.2)	1	86.8
Oboe/Bassoon	3	88.3 (88.1–88.5)	2	84.6 (84.6–85.2)
Percussion	1	87.6	1	79.8
Cymbal	1	87.4	0	
Conductor	1	83.3	1	81.3
All instruments	41	89.3 (83.0–95.3)	32	86.4 (79.8–92.7)

Note. Range of  $L_{eq}$  within brackets.

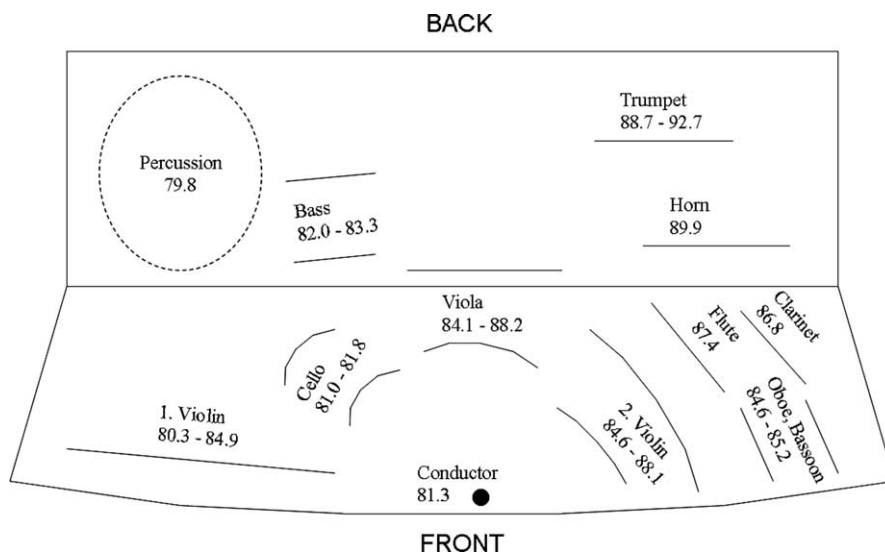


Fig. 2. Instruments location and  $L_{eq}$  ranges in Italian Girl in Algiers (IG).

positioning of the instruments in the two operas. In IG, the second violins were in front of the woodwinds on the right (see Fig. 2), while in MB they were located on the left side of the pit, opposite to the brass and woodwinds (see Fig. 1).

The measured  $L_{eq}$  of cello, double bass and percussion players, compared to the other instruments, are substantially lower in IG. This may be due to the distance from the brass and woodwind. These instrument groups are very close to the horns in MB, while in IG they are far from the brass and woodwinds.

The average  $L_{eq}$  for each opera was calculated by calculating the energy average from all instruments. The resulting average  $L_{eq}$  from MB, was 89.3 dBA, compared to 86.4 dBA in IG. Comparing each instrument group between the two operas, the  $L_{eq}$  of each group were within 3 dB, except Cello, Double Bass and Percussion.

### 5.1.3. Repeated measurements

As mentioned above, the exposure of some of the players were measured on two different occasions, to evaluate the repeatability of the results and, therefore, the reliability of the study. Measurements were repeated for three players in MB and four in IG. The results of the measurements are shown in Table 2. The difference between the repeated measurements from each player is within 1.5 dB. The differences are well within the measurement error, estimated to be  $\pm 2$  dB (from experience); hence the variation between different performances and rehearsals of the same opera is not significant.

### 5.2. $L_{eq}$ and $L_{ex}$

To evaluate the risk of hearing loss of the musicians, the  $L_{eq}$  of each instrument group was first averaged between the two operas. According to the Personnel Manager, the musicians play for 300 work hours per year for the Canadian Opera Company, including performances and rehearsals.

Table 3 shows the average  $L_{eq}$  and the normalized yearly noise exposure level ( $L_{ex}$ ) of the instrument groups. It was calculated using the following formula:

$$L_{ex} = L_{eq} + 10 \log t/T,$$

where  $t = 300$  and  $T = 2000$ , the yearly equivalent to a daily work period of 8 h.

The  $L_{ex}$  of all instrument groups are below 85 dBA the safety limit adopted in this study. Consequently, the musicians are not at risk of noise induced hearing loss from playing in the COC alone.

Table 2  
 $L_{eq}$  in repeated measurements

Instrument	Opera	1st measurement (dBA)	2nd measurement (dBA)
Trombone	MB	90.0	91.3
Horn	MB	92.2	90.8
Bass Clarinet	MB	89.2	88.6
Violin 2	IG	86.5	87.9
Violin 2	IG	87.1	86.4
Violin 2	IG	86.4	86.7
Trumpet	IG	91.9	92.7

Table 3  
Average  $L_{eq}$  and normalized yearly  $L_{ex}$

Instrument	Average $L_{eq}$ (dBA)	$L_{ex}$ (dBA)
Violin 1	83.9	75.7
Violin 2	90.0	81.8
Viola	87.3	79.1
Cello	86.4	78.2
Double Bass	86.3	78.1
Trumpet	92.7	84.5
Trombone	90.3	82.1
Horn	90.9	82.7
Piccolo/Flute	90.0	81.8
Clarinet/Bass Clarinet	87.8	79.6
Oboe/Bassoon	86.9	78.7
Percussion	85.2	77.0
Conductor	82.4	74.2
All instruments	88.1	79.9

### 5.3. Result discussion

Our finding of the musicians not being at risk is contrary to Laitinen et al. [6]. One major difference between the studies is the exposure time. First, this study does not account for individual practice. Secondly the exposure time from performance and rehearsals are considerably shorter in our study (300 h vs 800 h). This difference can lead to an increase of 4.3 dB and many musicians in our study will exceed the limit. Another difference is the different operas involved in the studies. According to the musicians, MB and IG is regarded as “average” and “light” in terms of loudness respectively.

Since activities outside the COC are not included in this study, the musicians can be overexposed with the addition of these activities (e.g., playing for another orchestra). They have to be accounted for to assess the total risk of the musicians. However, activities outside COC differ between musicians and it is difficult to estimate noise exposure from these activities; Moreover, it is outside the scope of this study.

From this study, however, we are unable to determine the effect of the opera pit on noise exposure. Comparing our result to other studies in concert hall setting is not feasible because of the different musical pieces and personnel. Noise exposure obtained from rehearsals of the same opera in different environments (e.g., opera pit vs rehearsal hall) will be included in future study.

The measurement errors in this study include accidental touching and movement of the microphone and cables. The slow response time used should render them negligible if they are occasional and instantaneous. We also examined the time course of exposure to ensure data integrity. In addition, results in Section 5.2 shows that measurement errors between different events are insignificant.

## 6. Conclusions and recommendations

### 6.1. Conclusions

The calculated  $L_{\text{ex}}$  shows that there is no risk of hearing loss for the COC musicians from *only* their activities with the orchestra. However, rehearsing and/or performing with other orchestras will add to the noise exposure, possibly reaching a level that may present a risk.

Another factor that has to be taken into account is that of the individual susceptibility to noise-induced hearing loss. As explicitly mentioned in the ISO Standard 1999 [7], data shown here are of statistical nature and should not be applied to individuals. The Standard even goes to the extent of predicting occupational noise-induced hearing loss (called the Standard Noise-Induced Permanent Threshold Shift – NIPTS) for different percentages of the exposed population. For example, according to the Standard, 10% of a population exposed to  $L_{\text{ex}} = 90$  dBA, will experience a loss of 19 dB or more at 3 kHz, while 90 % will have a loss of 9 dB or more at the same frequency. Therefore, the noise hazard varies greatly with the individual player and any prediction should be taken with precaution.

### 6.2. Noise controls

Engineering controls are the first choice for reducing hazardous noise levels. In essence, there are three basic methods to achieve the goal. The first is to reduce the sound energy generated by the source. The second consists of cutting the path of the sound energy from the source to the receiver and the third is to isolate the receiver from the source. In the case of the orchestra, the sources are the musical instruments, while the receivers are the musicians.<sup>2</sup> It is obvious that the sound energy of the source – the musical instruments in our case – cannot be silenced since robust sound production is precisely what is needed, especially during the louder passages of the music.

Sound energy that reaches the ears of a musician originates from the instrument he/she is playing as well as from the instruments surrounding him. Another source of energy is the sound reflected from the limiting surfaces: walls, ceiling and floor. Because of the proximity of the surrounding instruments, the relevance of the reflected energy is probably minimal. Therefore, attention should be given to ways of insulating the players from noise generated by instruments nearby. The use of risers to locate musicians that sit on the rear is a common practice in symphony orchestras. It has the advantage that the rear instruments can project their sound towards the audience, without affecting too much players located in front of them, which are sitting lower on the stage. Unfortunately, because of the limited space and the low ceiling in orchestra pits the use of risers is not practical in such an environment. In the case of

---

<sup>2</sup> One could argue that the people in the audience are also receivers. That is obviously true and there are many studies dealing with the hearing hazard in amplified pop and rock music concerts. However, this issue is outside the scope of this study.

the pit of the COC the situation is even worse, as the instruments at the back of the pit are at a lower level than those at the front.

Another potential solution is the use of barriers that shield the players from instruments located behind them. Attractive as it may appear, barriers are only effective if they break the line of sight between source and receiver. That, in the case of the orchestra may make it difficult for the musicians to see the conductor. Also, there are the problems of available space and obstruction of the mobility of the musicians while entering or exiting the orchestra pit. The use of Plexiglas barriers has been suggested. While they have the advantage of being visually transparent, they are acoustically highly reflective, and thus, can increase the sound affecting the musicians that are behind the barrier.

A type of barrier with non-reflective materials was developed and successfully employed in Australia [12]. It is used in all Australian Broadcasting Corporation orchestras, army bands, some conservatories, the Australian Youth Orchestra and the New Zealand Symphony Orchestra [13]. It appears as something similar to a music stand, where the upper part (used to support the music in a stand) is replaced by a barrier. The barrier is constructed with a combination of insulating and sound absorbing materials, and it shields the individual's head from the instruments situated behind the player. Tests at the National Acoustic Laboratories indicate an average attenuation of 8–10 dB for the shielded player and almost no reflection for the player behind the barrier [12,14].

The authors are not aware of any other successful use of noise barriers in orchestras, symphony or otherwise. Also, the practicality of their use in the crowded environment of the orchestra pit is doubtful.

### 6.3. *Hearing conservation program*

Implementing a Hearing Conservation Program<sup>3</sup> in any workplace has proven to be the most effective way for reducing the risk of hearing loss. It is an administrative document that provides guidelines as to what should be done, when and where, and more importantly, who is responsible for each individual action.

The program includes issues such as:

- (i) Raising the awareness of the effect of excessive noise and the risk of hearing loss.
- (ii) Instituting the use of hearing protectors for the reduction of the risk. Although the conclusion of this study is that there is no risk of hearing loss for the orchestra musicians, some members of the orchestra have expressed their desire to be “on the safe side” and to protect themselves. Management should make protectors of the “musician earplug” type available to the musicians. These earplugs offer an approximately flat frequency response (i.e., they do not

---

<sup>3</sup> An excellent guide for hearing conservation programs is the Hearing Conservation Manual [15].

significantly “colour” the music), and do not excessively attenuate the music. Proper usage and care of the plugs should be explained and all users should be trained during hands-on sessions.<sup>4</sup>

- (iii) Performing audiometric tests and follow-ups. The only way of knowing if the environment affects noise-exposed people is by performing periodic (once every two years) audiometric tests. They should be of the screening type that is, using air-conduction and pure-tones (as opposed to other, more complex, diagnostic tests).

### **Acknowledgements**

The authors acknowledge Graham Greenland, Elaine Lui and Gerry Fung from the Institute of Biomaterials and Biomedical Engineering for their assistance in collecting data. Ian Cowie, the personnel manager of the COC, was very instrumental with the organization of the tests and in making this study happen. Finally, they thank the musicians that wore the dosimeters during the tests. Without their enthusiasm, this study could not have been performed.

### **References**

- [1] Eaton S, Gillis H. Review of orchestra musicians’ hearing loss risks. *Can Acous* 2002;30(2):5–12.
- [2] Obeling L, Poulsen T. Hearing ability in Danish symphony orchestra musicians. *Noise Health* 1999;1(2):10–27.
- [3] Kahari KR, Axelsson A, Hellstrom PA, Zachau G. Hearing assessment of classical orchestral Musicians. *Scand Audio* 2001;30(1):13–23.
- [4] Kahari KR, Axelsson A, Hellstrom PA, Zachau G. Hearing development in classical orchestral musicians. *Scand Audio* 2001;30(3):141–9.
- [5] Williams W. Noise exposure of orchestra members. National Acoustic Laboratories (Chatswood, Australia), Report No. 109; 1995.
- [6] Laitinen HM, Toppila EM, Olkinuora PS, Kuisma K. Sound Exposure Among the Finnish National Opera Personnel. *Appl Occup Environ Hygi* 2003;18(3):177–82.
- [7] ISO 1999. Acoustics – Determination of occupational noise exposure and estimation of noise-induced hearing impairment. International Organization for Standardization, Geneva; 1990.
- [8] Ontario Ministry of Labour: Occupational Health and Safety Act and Regulations for Industrial Establishments. Regulation 851, Section 139; 1990.
- [9] CSA Standard Z107.56 –94. Procedures for the measurement of occupational noise exposure. Canadian Standard Association; 1994.
- [10] Criteria for a Recommended Standard: Occupational Noise Exposure. Revised Criteria 1998. DHHS (NIOSH) Pub. No. 98—126, National Institute for Occupational Safety and Health, Cincinnati; 1998.
- [11] TLVs for Noise, in TLVs and BEIs: threshold limit values for chemical substances and physical agents and biological exposure indices, American Conference of Government Industrial Hygienists (ACGIH), ISBN: 1-882417-36-4; 2003. p. 112.

<sup>4</sup> The CSA Standard Z94.2-02 [16] contains abundant material regarding the implementation of hearing protectors.

- [12] Presbury J, Williams W. Occupational noise exposure management in an orchestral setting. *J Occup Health Safety Australia New Zealand* 2000;16(4):337–42.
- [13] Denis D, personal communication. Symphony Australia. Available from: danielsd@symphony.net.au.
- [14] Williams W, personal communication. National Acoustic Laboratories (Chatswood, Australia). Available from: warwick.williams@nal.gov.au.
- [15] Suter A. Hearing conservation manual. Milwaukee, WI: The Council for Accreditation in Occupational Hearing Conservation (CAOHC); 2002.
- [16] CSA Standard Z94.2-02. Hearing protection devices – performance, selection, care, and use. Canadian Standard Association; 2002.