NOISE EXPOSURE OF OPERA MUSICIANS

Ewen N. MacDonald, Alberto Behar, Willy Wong, and Hans Kunov
Institute of Biomaterials and Biomedical Engineering, University of Toronto, Toronto, Ontario, Canada M5S 3G9

ABSTRACT

A previous noise exposure survey involving the Canadian Opera Company (COC) orchestra followed several musicians over the course of two operas (Lee, Behar, Wong, and Kunov, 2005) and found that the musicians were not at risk. Since then, the COC has moved to a new building. Thus, a new study was conducted to examine whether the new venue would have an effect on noise exposure. Measurements were taken during three performances of five different operas using five dosimeters attached to music stands located throughout the orchestra pit. While the exposure levels were found to be different across operas and instrument sections, these effects were independent. In general, the exposure levels were slightly lower in the new building for all musicians with woodwinds showing a large decrease. These decreases are likely due to a larger and less enclosed orchestra pit along with fewer brass musicians playing under the pit roof. While the present study did not find evidence for a risk of hearing loss for work performed in the new venue, the musicians engage in a variety of activities outside the COC that when added to their COC work may pose a risk of noise induced hearing loss.

RÉSUMÉ

Une précédente étude sur l'exposition sonore des musiciens de l'orchestre du *Canadian Opera Company* (COC) avait suivi plusieurs musiciens pendant deux opéras (Lee, Behar, Wong et Kunov, 2005). Elle avait conclue que les musiciens ne couraient aucun danger. Depuis, le COC a déménagé dans un nouvel immeuble. Une nouvelle étude a donc été effectuée pour examiner si la nouvelle salle avait une incidence sur l'exposition sonore des musiciens. Les données ont été capturées pendant trois performances de cinq opéras différents en utilisant cinq dosimètres fixés à des lutrins dispersés dans la fosse d'orchestre. Il a été trouvé que les niveaux d'exposition calculés différaient d'un opéra à l'autre et d'un endroit à l'autre dans la fosse; ces effets restaient indépendants. En général, le niveau d'exposition était plus bas dans le nouvel immeuble pour tous les musiciens. Une diminution significative a été remarquée pour les instruments à vent en bois. Cette diminution est principalement attribuée à une fosse plus grande et plus ouverte en plus d'avoir moins de cuivres jouant sous la voûte de la fosse. Même si cette étude n'a pas trouvé d'évidence de risque de perte auditive pour tout travail effectué dans la nouvelle salle, il est à noter que les musiciens du COC jouent aussi dans d'autres salles et que l'ajout des ces activités en plus de leur travail au COC peut créer un risque d'une perte auditive.

1 INTRODUCTION

Perhaps more than any other profession, a professional musician relies on his or her ability to hear to earn a living. Musicians are also clearly passionate about listening to and enjoying music so a loss of hearing would have a more significant impact on both the livelihood and quality of life of a musician when compared to the general public. Many researchers have investigated the risks of noise induced hearing loss faced by musicians due to their occupation. These studies often follow one of two approaches: measurement of musicians' audiometric thresholds or measurement of sound levels during rehearsals and performances.

In a review of studies dealing with noise exposure of orchestra musicians, Behar, Wong and Kunov [1] found that a majority of studies concluded that players were not at risk [2, 3, 4, 5]. However, other studies reviewed in the same paper concluded the opposite [6, 7]. One of the measurement problems identified was the difficulty in properly measuring the noise exposure as well as determining the real length of time musicians are exposed to sound levels due to music playing. Behar et al. also noted problems in several studies including lack of proper measuring techniques as well as inconsistent analysis of the raw data.

Most orchestra players perform in concert halls, where performers are located on a stage in front of or surrounded by the audience. However, in the case of opera and ballet, musicians play in a pit, enclosed by hard, acoustically reflecting surfaces and often located partially below stage overhangs. The sound levels generated in such an environment are expected to be higher than those found in auditoriums.

To investigate this, a study was performed previously by some of the authors measuring the noise exposure levels of musicians of the *Canadian Opera Company* (COC) in 2003 [5]. At that time the venue of the Company was the *Hummingbird Centre for the Performing Arts*, a multifunctional hall not particularly suitable for opera or for ballet, located in Toronto, Canada. In 2006, the COC moved to a new home, the *Four Seasons Centre for the Performing Arts*, designed specifically for opera and ballet. This venue, which seats approximately 2000, was designed in the traditional horseshoe style with several rows of balconies as opposed to the slightly larger, fan-shaped *Hummingbird Centre* that has only one large balcony on the back of the hall. Thus, it was logical to perform a follow-up study to assess if a change in the architecture of the hall had an effect on the noise exposure of players.

As discussed below, the conditions were not easy to replicate: the operas tested were not the same and the measuring technique had to be modified. However, results indicate that the change in the venue has reduced the noise exposure of the players.

1.1 Risk criteria

To our knowledge, there is currently no country that has legislation setting limits for maximum noise exposure levels for musicians. However, the European Union (EU) is working towards such legislation. Since July 2007, the Ontario Health and Safety Act specifies that the maximum noise exposure level for an 8 hour work day, L_{ex}, should be 85 dBA. This is in line with the European Union legislation for industrial workers, and is recommended by the USA National Institute of Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH).

In the present study, L_{eq} is used to denote the level of a constant sound source that would provide the same total A-weighted acoustic energy as the measured sound source over the same duration as the measurement. Since the musicians in the COC are contracted for 300 hr/year, as opposed to the 2000 hr/year (equivalent to 8 hr/day) that the noise exposure legislation is based on, comparing the measured L_{eq} values to 85 dBA is inappropriate. Instead a criterion of 93 dBA was used for this study. Exposure to this level for 300 hours would result in the same total A-weighted acoustic energy as being exposed to 85 dBA for 2000 hours. Thus, if the average of the Leq measurements is above 93 dBA, the musicians can be considered to be at risk.

Many of the musicians play in other orchestras outside of their work at the COC or teach music. These, along with the other noisy activities of everyday life, may increase an individual musician's risk for noise induced hearing loss. However, as this study was limited to only assess the risk from playing in the COC orchestra, we are forced to assume that the musicians are in a quiet environment outside of the time they spend with the COC. This assumption may or may not be valid for each individual. Based on our measurements it is also possible to develop guidelines for maximum exposure times (based on the provincial limit) that a musician can make use of to help assess his or her own risk.

2 PROCEDURE

Measurements were taken during five operas performed by the COC during the 2007 season: *Faust*, *Lady Macbeth of Mtsensk*, *La Traviata*, *Luisa Miller*, and *Elektra*. Noise exposures were measured during three performances of each opera. All performances were held in the *Four Seasons Centre for the Performing Arts*.

2.1 Measuring instruments

Five Quest Type Q-300 dosimeters were used to measure the exposure level during each performance. The dosimeters were set to measure L_{eq} following the guidelines in CSA Standard Z107.56-94 [8]. The entire study spanned approximately four months. The data from the first two operas (*Macbeth* and *Faust*) were collected over a nine day period at the end of January/beginning of February, 2007, while the data from the last three operas (*La Traviata*, *Luisa Miller*, and *Elektra*) were collected over a ten day period during the month of May, 2007. The dosimeters were calibrated in our laboratory before the first two operas and again before the last three operas. As well, before each measurement, the calibration of each dosimeter was checked as per the manufacturer's instructions using a Quest Type QC-10 calibrator. No additional calibration was needed throughout the study.

2.2 Dosimeter locations

In the previous COC study [5], the dosimeters were worn by each musician with the microphones placed on his/her shoulder following the procedures described in CSA Standard Z107.56-94 [8]. For the present study the musicians were not willing to wear the dosimeters again as they found their use uncomfortable, especially with the microphone cable taped to the back of their shirts. As a compromise, it was decided to affix the dosimeters to the bottom of each music stand with the microphone positioned approximately 1 m above the floor.

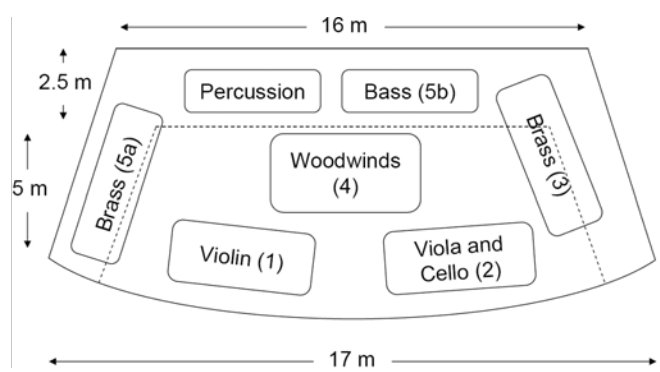

Figure 1. Approximate dosimeter locations used in the study. Each location corresponds approximately to the middle of an instrument section: violin (1), viola and cello (2), brass (3), woodwind (4), brass (5a), double bass (5b). The dimensions of the opera pit are also given.

For each opera, five dosimeters were set up in the orchestra pit. The locations corresponded approximately to the middle of instrument sections (see Figure 1). Four of the five dosimeter locations were common to all operas: violins (1), viola and cello (2), brass (3), and woodwinds (4). In one of the operas (*Faust*), the fifth dosimeter was located with the double bass instruments (5b). In the other four operas, the fifth dosimeter was located in a second group of brass instruments (5a). As the orchestra size varied with the different operas, the exact dosimeter location would vary slightly. However, the relative distribution of dosimeter locations remained the same.

2.3 Measurement procedure

Approximately 15 minutes before the start of each performance, the dosimeters were attached to the stands and the data gathering was started. The start-time for each dosimeter was recorded manually. The majority of the musicians would arrive in the orchestra pit very shortly after the dosimeters were set up and would start warming and tuning up. At the end of the performances, the dosimeters were switched off shortly after the musicians left the orchestra pit for the night (approximately 15 minutes after the end of each performance). The time each dosimeter was stopped along with the measured L_{eq} was also recorded manually.

3 RESULTS AND DISCUSSION

The results of the mean L_{eq} as a function of both opera and instrument section can be seen in Table A in the appendix. The first analysis conducted on the results was to determine if the different operas and instrument sections had an effect on the exposure level and to determine if these effects were independent. To test this hypothesis, an ANOVA was conducted with opera and instrument section as factors on L_{eq}. While a significant main effect for both opera ($F(4,54) = 23.04$, $p < 0.001$) and section ($F(4,54) = 20.73$, $p < 0.001$) was found, the interaction of opera x instrument section was not significant ($F(12,54) = 1.618$, $p = 0.114$). Thus, while the average L_{eq} varied significantly across operas and instrument sections, the effects of both variables were independent.

3.1 L_{eq} and Opera

Across operas, the L_{eq} ranged from 82.2 dBA for *La Traviata* to 89.7 dBA for *Elektra*. The mean L_{eq} for each opera can be seen in Figure 2. One possible explanation for this wide range in exposure levels observed across operas is the difference in the orchestra size, as can be seen Table 1. When the orchestra size is compared the mean Leq in Figure 3, it is clear that as the number of musicians increased, the mean L_{eq} increased as well.

If the number of uncorrelated, equal sound-level sources is doubled the level should increase by 3 dB. Thus, one would expect that the noise exposure level should increase by approximately 3 dB as the number of musicians is doubled. The mean L_{eq} as a function of the $\log_2$ of the number of musicians is plotted in Figure 3. The slope of the fitted regression line suggests an approximate increase of 7 dB as the number of musicians is doubled. Thus, the size of the orchestra does not entirely explain the change in exposure level across operas. Other factors, such as the style and musical choices of the different composers of each opera, are likely involved.

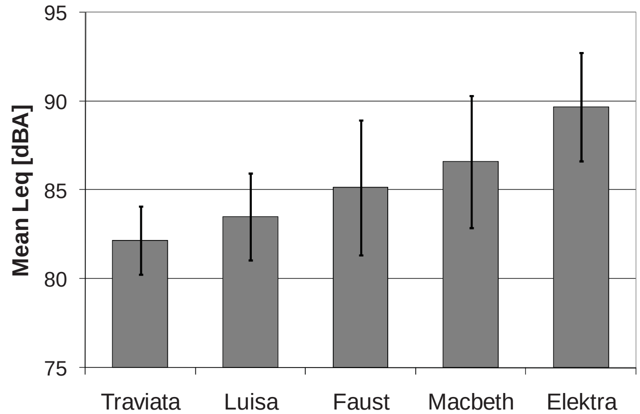

Figure 2. Mean L_{eq} for each opera. The error bars show the standard deviation.

Table 1. Orchestra size for each opera

Opera	Number of Musicians
La Traviata	63
Luisa Miller	63
Faust	64
Macbeth	93
Elektra	109

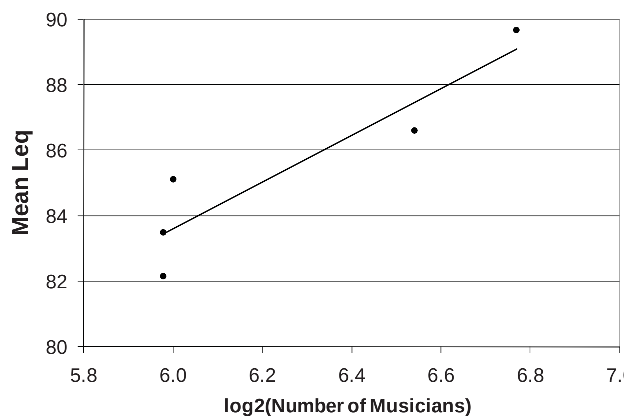

Figure 3. Mean L_{eq} as a function of the $\log_2$ of the number of performing musicians. The plotted regression line was found to have a slope of approximately 7 dB per doubling of the number of musicians.

3.2 L_{eq} and instrument section

Across instrument sections, the L_{eq} ranged from 82.7 dBA for Woodwinds to 87.9 dBA for Brass. The mean L_{eq} for each section can be seen in Figure 4. Several studies have found that the exposure levels are largest for brass musicians when compared to other instrument sections [5, 9]. An ANOVA was conducted and no significant interaction between opera and instrument section was found ($F(12,54) = 1.618$, $p = 0.114$). In other words, the pattern of exposure levels with instrument section was the same across all the operas, so for louder or quieter operas, the change in exposure level was the same for all instruments. As all of the mean Leq were lower than the criteria of 93 dBA described earlier, none of the musicians are at risk of hearing loss due to just their activity in the COC.

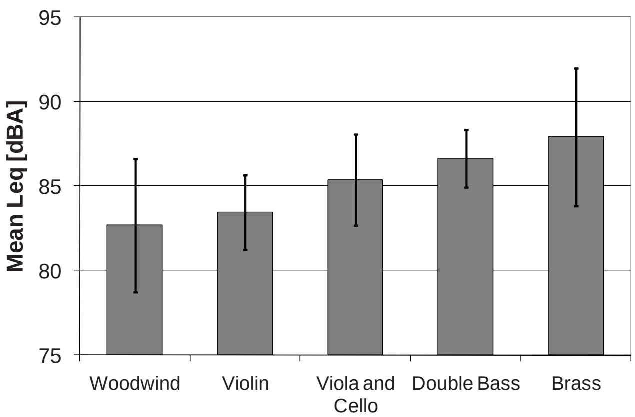

Figure 4. Mean L_{eq} for each instrument section. The error bars show the standard deviation.

3.3 Safe exposure durations

Given the characterization of exposure levels as a function of instrument section, it is possible to calculate exposure times that would equal the exposure from 85 dBA for 8 hr per day/40 hr per week/2000 hr per year as described previously in Section 2. A table of the calculated maximum exposure durations for each instrument section is shown in Table 2. It should be noted that the exposure durations assume that the musician is not exposed to any other significant sound source for the remaining period of time.

Table 2. Maximum exposure durations based on provincial limit.

Section	Hours/ Day	Hours/ Week	Hours/ Year
Woodwind	13.7	68	3417
Violin	11.4	57	2846
Viola and Cello	7.4	37	1838
Double Bass	5.5	28	1373
Brass	4.1	20	1022

NOTE: The number of hours per day/week/year of exposure for an Lex of 85 dBA assuming the rest of the day/week/year is spent in quiet. Exposure without hearing protection for durations longer than those given in the table would exceed the risk criterion given by ISO 1999 [11] while exposure for shorter durations would comply with provincial occupational noise regulations.

The maximum exposure durations assume the musician is in a quiet environment for the remaining hours of the day/week/year. As many of the musicians engage in other potentially noisy activity (playing in other orchestras, teaching, rehearsing, etc), it is impossible to assess their total risk unless the exposure levels (L_{eq}) and durations of these other activities are known. However, based on the data in Table 2 and similar data published for other activities (e.g., Behar et al. [10]) a musician can get a rough estimation of whether he or she is overexposed.

3.4 Comparison of L_{eq} between venues

One of the main goals of this study was to examine differences in noise exposure between the two venues. Using the data from the previous study, the mean L_{eq} for each instrument section was calculated. The mean L_{eq} as a function of instrument section for both venues is plotted in Figure 5.

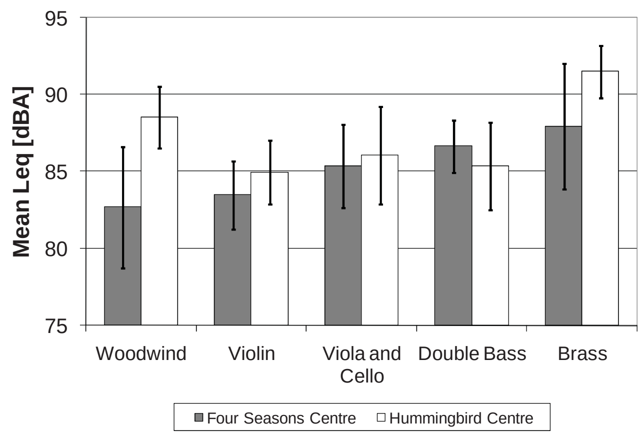

Figure 5. Mean L_{eq} for each instrument section for the *Four Seasons Centre* and *Hummingbird Centre*. The error bars show the standard deviation.

In general, the exposure levels in the *Hummingbird Centre* are higher than those in the *Four Seasons Centre*. It is tempting to conclude that the smaller orchestra pit in the *Hummingbird Centre* leads to an increase in the exposure levels. However, as discussed earlier, the techniques used when performing both measurements were slightly different: in the first study, the microphones of the dosimeters were attached to the players; in the present study, they were attached to the stands. As well, the two operas measured in the previous study (*Madame Butterfly* and *The Italian Girl in Algiers*) are different from those in the present study. Therefore it cannot be concluded if the overall differences in exposure levels between venues are only due to differences in architecture, the measurement technique, or the differences in the operas performed. However, the pattern of exposure levels for each instrument section is different between the two venues. In the previous study, the woodwinds were found to have the second highest mean L_{eq}, whereas in this study they were found to have the lowest.

An ANOVA was conducted with building and instrument section as factors on L_{eq}. A significant main effect for both building ($F(1,133) = 11.592$, $p = 0.001$) and instrument section ($F(4,133) = 17.416$, $p < 0.001$) was found. Importantly, a significant interaction of building x instrument section was also found ($F(3,133) = 4.049$, $p = 0.004$). This confirms that the pattern of results for the instrument sections is different between the two venues. Since no interaction was found between opera and instrument section for the data from the *Four Seasons Centre*, this suggests that the interaction with instrument section is due to differences between the venues as opposed to the different operas played at each venue.

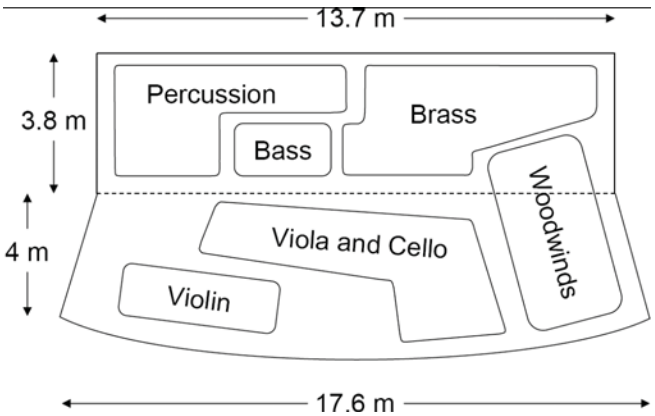

Figure 6. General layout of the orchestra and dimensions of the orchestra pit in the *Hummingbird Centre* (adapted from Lee et al. [5]).

A diagram of the general orchestra layout along with the dimensions of the orchestra pit in the Hummingbird Centre can be seen in Figure 6. From a comparison of Figures 1 and 6 it can be seen that the general layout of the orchestra is slightly different between the two venues. In the *Four Seasons Centre* the woodwinds have been shifted from the one side to the middle of the orchestra pit. As well, some of the brass musicians have been shifted forward along the sides. The previous study suggested that musicians' exposure level is related to their proximity to the brass instruments. In the present study the strings are closer to some of the brass than they were in the previous study but the noise exposure levels in the current study are lower. Further, the proximity of the woodwinds to the brass is about the same in both studies but the noise exposure levels of the woodwinds in the current study are significantly lower. Inspection of the dimensions of the *Four Seasons Centre* orchestra pit shows that it is both larger and is less enclosed than it's counterpart in the *Hummingbird Centre*. It is likely that a combination of these two factors along with fewer brass musicians playing under the enclosed part of the pit is the cause for the observed reduction in exposure levels for other musicians.

4 CONCLUSIONS AND RECOMMENDATIONS

Two conclusions can be drawn from this study: The first is that, assuming they remain in a quiet environment outside of their COC activities (performances and rehearsals), musicians are not at risk of hearing loss in their new venue. However, if they perform for more than the times shown in Table 2 they could exceed provincial occupational noise limits. Since even these limits allow some hearing loss, the musicians should be educated about the meaning of Table 2 and the precautions they should be taking to protect their hearing. The second conclusion is that the exposure levels were generally lower in the new building compared to the older venue with the level of the woodwind section showing the largest decrease. The decrease in exposure level is likely due to a less enclosed pit with fewer brass musicians playing under the roof of the pit. However, the decrease could also be due to the different microphone location.

COC musicians report that they frequently perceived the noise levels as too loud and feel that their hearing has decreased. As well, some mentioned that they have acquired tinnitus which they attribute to performing in the orchestra. While the present study did not find evidence for a risk of hearing loss, these concerns raised by the musicians should not be ignored. As previously mentioned, the musicians engage in a variety of activities outside the COC that when added to their COC work may pose a risk of noise induced hearing loss.

Thus, it is recommended that musicians should undergo periodic audiometric testing, probably every two years, to provide a longitudinal record of their hearing status. An audiogram may not be sensitive enough to pick up the initial stages of a noise induced hearing loss (i.e., the loss of some of the outer hair cells) but it is currently the only accepted standard for documenting a change in an individual's hearing. The use of distortion product otoacoustic emission (DPOAE) tests may be more sensitive as these tests directly measure outer hair cell function. However, their use for documenting occupational hearing loss is not well accepted and requires further study.

The use of "linear" or "musicians" ear plugs has long been advocated for musicians. These earplugs attenuate all frequencies equally to maintain the balance of harmonics that reach the ear and don't "color" the music. Ear plug should both reduce the perception of the sound levels as being excessive as well as reduce the risk of hearing loss. Unfortunately, few musicians accept their use, citing reasons such as discomfort, feeling of fullness in their ears, and a change of perception of their or their partners instruments' sound.

Acknowledgements

The authors would like to thank Mr. Ian Cowie, Personnel Manager of the *Canadian Opera Company*, who helped organize the measurements. As well, the authors would like to thank all the COC musicians for allowing the investigators to set up the dosimeters just before the performances. Along with the authors, the following members of the Sensory Communication Group at the Institute of Biomaterials and Biomedical Engineering (University of Toronto) helped conduct the measurements: Lisa D'Alessandro, Sheena Luu, Colin Li, Faranak Farzan, Cheng Qian, Kristen Fortney, Andrea Dickinson and Gurjit

Singh. Funding for this study was provided by the Natural Sciences and Engineering Research Council of Canada.

REFERENCES

[1] Behar A, Wong W, Kunov H. 2006. Risk of hearing loss in orchestra musicians: Review of the Literature. Medical Problems of Performing Artists, 21(4), 164–168.

[2] Williams W. 1995. Noise Exposure of Orchestra Members. Report 109. National Acoustic Laboratories, Chatswood, Australia.

[3] Obeling L., Poulsen T. 1999 Hearing ability in Danish Symphony Orchestra musicians. *Noise Health*; 1(2), 10–27.

[4] Eaton S, Gillis H. 2002 Review of orchestra musicians' hearing loss risks. Canadian Acoustics, 30(2), 5–12

[5] Lee J, Behar A, Kunov H, Wong W. 2005. Musicians' noise exposure in orchestra pit. Applied Acoustics, 66, 919–931.

[6] Mikl K. 1995. Orchestral music: an assessment of risk. Acoustics Australia, 23(2), 51–55.

[7] Laitinen HM, Toppila E.M., Olkinuora P.S., Kuisma K. 2003. Sound exposure among the Finnish National Opera personnel. Applied Occupational and Environmental Hygiene, 18(3), 177–182

[8] CSA Standard Z107.56-94. 1994. Procedures for the measurement of occupational noise exposure. Canadian Standards Association.

[9] Boasson A. 2002. A one year noise survey during rehearsals and performances in the Netherlands Ballet Orchestra. In Proceedings of the Institute of Acoustics 2002; 24(4), 33–34.

[10] Behar A., MacDonald E., Lee J., Cui J., Kunov H. et al. 2004. Noise exposure of music teachers. Journal of Occupational and Environmental Hygiene, 1, 243–247

[11] ISO 1999. Acoustics – Determination of occupational noise exposure and estimation of noise-induced hearing impairment. International Organization for Standardization, Geneva, 1990.

APPENDIX

Table A. Mean L_{eq} for each section across the five operas.

In the section column, the dosimeter location is given in parentheses (See Figure 1 for where these locations are in the pit). For the other columns, the mean L_{eq} are expressed in dBA with the standard deviation in parentheses.

Section (Dosimeter Location)	Traviata	Luisa	Faust	Macbeth	Elektra	Overall
Violin (1)	80.9 (0.7)	81.9 (0.5)	82.9 (0.7)	85.2 (0.6)	86.5 (0.3)	83.5 (2.2)
Viola and Cello (2)	83.3 (3.1)	84.1 (2.7)	85.0 (0.5)	85.8 (0.9)	88.6 (2.9)	85.4 (2.7)
Brass (3)	83.1 (2.1)	86.0 (3.1)	90.0 (2.0)	90.8 (0.8)	92.2 (3.1)	88.4 (4.0)
Woodwind (4)	80.7 (1.4)	81.1 (0.6)	81.2 (4.8)	82.1 (4.9)	88.2 (0.5)	82.7 (4.0)
Brass (5a)	82.8 (0.3)	84.3 (0.9)	-	89.1 (0.6)	92.8 (1.9)	87.3 (4.2)
Double Bass (5b)	-	-	86.6 (1.7)	-	-	86.6 (1.7)
Overall	82.2 (1.9)	83.5 (2.4)	85.1 (3.8)	86.6 (3.7)	89.7 (3.1)	85.4 (4.0)