Orchestral Music: An Assessment of Risk

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Abstract: Worldwide, a reasonable number of measurements have been made of the type of sound levels to which Orchestral Musicians are exposed. The conclusions are in conflict when compared in isolation because the previous studies have given little data as to true exposure levels over a longer period. The current study traces the sound exposure at various positions within a Classical Orchestra performing for Opera and Ballet in an orchestra pit. It determines Noise Exposure based on type and length of performance, rehearsal etc. on a daily basis for a full season of works. The results, when compared to industrial criteria for noise exposure, are relatively high as many musicians are often being exposed to levels over 90dB(A). The only person in the orchestra without risk is the conductor. The audience is also not at risk of NIHL.

1. INTRODUCTION

The establishment of the risk of Noise-Induced Permanent Threshold Shift (NIPTS) for orchestral musicians is more difficult than for process workers or other industrial exposures due to the large variation in sound levels and exposure times. This is caused by; the type of performance, the acoustic environment, the performance schedule and the rehearsal time. Also it has been commonly claimed that "music is harmonious and lacks the peaks of industrial noise and is therefore not as harmful".

There are two ways to assess the risk of NIPTS for musicians. The first is by evaluating the working environment of musicians. This is achieved by measuring and analysing the sound levels and then calculating the equivalent continuous sound exposure levels taking into account the musical instrument played by each musician and his position relative to other players during musical performances and rehearsals. The performance and rehearsal schedule also needs to be taken into account . The result obtained can then be compared to ISO 1999 Acoustics - Determination of occupational noise exposure and estimation of noise-induced hearing impairment.

The second method is by evaluating the hearing threshold levels (HTLs) obtained for each member of the orchestral group. A comparison to a non-exposed population can then be made. If the hearing levels for the musicians as a group are no worse than the general public, then the risk of NIPTS could be assumed to be small.

This paper presents the results of the first approach. It shows the results of measurement and determines exposure levels for a season of performance. As a result of the findings a follow-up audiometric study is being carried out. A further paper will be prepared after the conclusion of a four year audiometric study.

2. PREVIOUS STUDIES

Records of the measurement of sound levels produced by musical instruments and orchestras can be traced back to as early as 1931[1]. The whole spectrum peak power and the corresponding percentage of intervals as well as the frequency range containing the maximum peaks, their power and percentage of intervals, were measured and recorded for sixteen instruments ranging from drum to piano, and for 15, 18, 75-piece orchestras as well as a pipe organ. The highest sound levels obtained were from a 36 x 15" bass drum. The lowest levels obtained were from a violin played very softly. These levels were measured over short times at undefined positions and cannot be related to exposure. The sound pressure levels and exposures measured by other researchers are summarised in Table 1

TABLE 1.

Sound Source	S P L	Author
Piano	70 dB	Arnold
Symphony orchestra	70 - 95 dB	Lebo
Symphony orchestra	> 90 dB(A) for 3.51 of 14.4 hours recorded.	Westmore
Symphony orchestra	83 - 92 dB(A) $L_{Aeq,8h}$ = 76.5 - 85.2	Axelsson
Symphony orchestra	88.9 - 93.1 dB(A)	Jansson
Symphony orchestra	82.9 - 89.5 dB(A)	Woolford
Symphony orchestra	83.9 - 95.9 dB(A)	Woolford
Symphony orchestra	79 - 99 dB(A) $L_{Aeq,8h}$ =74.7 - 94.7	Royster

Arnold and Miskolczy-Fodor [2] measured the sound pressure levels (SPLs) of a concert grand piano. Placing the microphone at the level of a pianist, the SPLs obtained were

64 to 93 dB with the piano top raised and 59 to 86 dB with the top lid lowered. It was noted that maximum sound was achieved by repeatedly striking the keys with the sustain pedal depressed until the sound volume reached its maximum value. The authors concluded that the sound level produced by a piano during normal performance was about 70 dB.

Lebo and Oliphant [3] measured the SPLs of a symphony orchestra in an empty concert hall with the microphone positioned at the centre of the orchestra. The SPLs noted were usually below 70 dB and rarely achieved 95 dB, they were also fairly evenly distributed between 500 and 4,000 Hz.

In 1981, Westmore and Eversden [4] recorded the SPLs produced by a symphony orchestra for a total time of 14.40 hours. Their subsequent analysis found that sound levels exceeded 90 dB(A) for 3.51 hours and equalled or exceeded 110 dB(A) for only 0.02 hours. Peaks exceeding 120 dB(A), probably generated by the percussion section, were also measured occasionally.

Axelsson and Lindgren [5] measured sound levels during seven performances conducted in a concert hall and an orchestra pit by placing microphones on tripods near players. The L_{Aeq} obtained were 83 to 92 dB(A). The $L_{Aeq,8h}$ was estimated to be 68.5 to 86.4 dB. The data also revealed that the sound levels were slightly higher in the orchestra pit.

Jansson and Karlsson [6] obtained performance L_{Aeq} of 93.1 and 88.9 dB(A) at "exposed" and "normal" positions respectively with the microphones placed beside the musician at ear level during orchestral performances.

Woolford [7,8] measured SPLs with microphones mounted at head level. Eight microphone positions were used within the orchestra and included the conductor's podium. Measurements were taken of 66 to 85 musicians performing in a large studio for just over one hour. The L_{Aeq} recorded ranged from 82.9 dB(A) at the conductor's podium to 89.5 dB(A) at the point between the French horn and woodwind section as well as in front of the timpani. Seven locations showed maximum peak levels exceeding 115 dB with a maximum of more than 125 dB at a point located in front of the trumpet and bassoon and near the percussion section. The remaining position located between the double bass and cello recorded a sound level of 112 dB.

Woolford [7,8] took one hour samples of various orchestral musicians. Results were reported for:

An 18-piece brass choir performing in a recording studio with the measurements taken at the conductor's podium. The performance L_{Aeq} was 93.1 dB(A) with a maximum peak of 120 dB. At a corner of a large recording studio fenced with acoustic screens, the L_{Aeq} produced by 3 trombones, 3 trumpets, and 1 tuba, was 83.9 to 95.9 dB(A) with L_{peak} of 115 dB.

A 45-piece orchestra on a confined stage of 7.6 by 11.6 m and with the microphone placed in front of the brass and percussion instruments. The L_{Aeq} generated was 95.5 to 93.5 dB(A). The peak sound levels noted exceeded 125 dB. During a performance of the ballet Swan Lake in a theatre pit, the measured sound levels L_{Aeq} were:

95.9dB(A) with peak levels exceeding 125dB in front of the trombones for 1.27 hour;

93.9dB(A) and exceeding 125dB in front of percussion and tuba's for 0.6 hour;

94dB(A) and exceeding 125dB in front of drums and trombones for 0.52 hour;

93.4dB(A) and exceeding 119dB in front of French horns and piccolos for 1.17 hour; and

92.8dB(A) and in excess of 125dB in front of French horns and piccolos for 0.7 hour.

Measurement of SPLs were carried out during a performance in a hall of 11m *x* 20m *x* 4.3m high. All surfaces were hard and sound-reflecting except that one side was covered with a curtain to separate one quarter of the long side which was not in use. Woolford reported on four locations which gave L_{Aeq} 88 to 91.6 dB(A) and peak levels of 116 to 122dB over measuring times of 0.2 to 1.2 hour.

In a recent study, Royster, Royster and Killion [9] obtained 68 dosimetry samples from 23 violins and violas (group 1), 13 horns, trumpets and trombones (group 2), 17 clarinets, flutes, bassoon, and percussion (group 3), and the remaining 15 samples from bass, cello, harp and piano (group 4). Microphones were clipped onto the collars of the selected musicians on the side with higher noise exposure and the corresponding dosimeters were mounted around the musicians' waist or near the hip. The SPLs recorded are given in Table 2. The daily equivalent 8-hour exposures were calculated based on a 15-hour week.

TABLE 2. (Values in dB(A))

	L_{Aeq}	Peak	Max	$L_{Aeq,8h}$
Mean	89.8	124.9	106.4	85.5
S.D.	4.7	6.4	5	4.7
Median	90	124	106.8	85.7
Minimum	79	112	95.5	74.7
Maximum	99	143.5	115.5	94.7

The L_{Aeq} ranged from 79 to 99 dB(A) with a mean value of 89.8 dB(A). Groups 2 and 3 appeared in the upper portion of the overall range. The L_{Aeq} values for group 1 (violins and violas) were evenly distributed throughout the entire range, while group 4 (bass, cello, harp and piano) fell in the lower portion of the range. 82 % of the samples had a maximum peak level of 130 dB or below, and two samples (3 %) had peaks exceeding 140 dB throughout the period of measurement. 76 % of the samples had a maximum RMS equivalent sound level of 110 dB(A) or below. The highest measured peak was 115.5 dB. The mean $L_{Aeq,8h}$ was 85.5 dB(A).

This summary of the literature shows the variation in methodology and the lack of any determination of $L_{Aeq,8h}$ except for the day of measurement. The long term exposure has not been calculated for any orchestra. The SPLs reported ranged over 70-110dB(A). Prolonged exposure at these levels is capable of causing hearing damage.

ISO 1999:1990(E) requires that "daily noise exposure level shall be determined for a sufficient number of days for the individuals under consideration to allow the determination of the average exposure to noise for the years or decades under consideration with an overall uncertainty appropriate to the particular noise problem." It was therefore concluded that an estimation of risk for the Australian Opera and Ballet Orchestra could not be made based on the available literature. However the literature did indicate a significant number of high level measurements, from these it may be inferred that the probability of risk was significant.

The question of risk of NIHL however must be addressed by a combination of level and exposure. It is insufficient to extrapolate from a number of level measurements without taking into account the variation of exposure between performances. The only way to resolve this issue is to measure actual performance exposure and relate this to normal work practices and rosters. Therefore a long term measurement programme was undertaken.

3. MEASUREMENT OF SOUND PRESSURE LEVELS

A series of measurements of the Australian Opera and Ballet Orchestra were taken during performances and rehearsals throughout the 1992 winter opera season which extended from April 1 to October 31 1992. The recordings were limited to a representative sample of each performance. The L_{Aeq} of the performances of each opera were measured once. The L_{Aeq} of selected rehearsals of several events performed in the orchestra pit and at the Opera Centre were obtained and were used to estimate the L_{Aeq}'s of the rehearsals not recorded. The frequency spectrum was also recorded for later comparisons to industrial spectra. Measurements were taken at between 4 to 6 positions. The L_{Aeq} of a performance in the Concert Hall of the Sydney Opera House was also taken for comparison purposes.

Larson Davis 700 integrating sound level meters / dosimeters were used to measure the sound pressure levels. The computer capability of these instruments allowed a complete time history of sound levels during the measurement period to be recorded and statistically analysed.

The microphones were suspended from the ceiling in positions ranging from 100mm but always less than 1m from the musicians' ears in accordance with the Australian Standard 1269-1989 Acoustics - Hearing Conservation. The ceiling of the orchestra pit is low, varying from 1.8 to 2.3 metres. The relationships between microphone position and musician varied to a small degree from performance to performance depending on the number of musicians in the pit. The only unacceptable variation between performances occurred with the double bass in front of the trumpets. This microphone was therefore moved between positions 1 and 1a to retain proximity to the double bass. For calculation purposes the positions 1 and 1a were considered equal to the Double Bass exposure.

To establish the validity of fixed area sampling one microphone was fixed onto a musician's shoulder near the ear. The L_{Aeq} thus obtained was in agreement with that obtained with the fixed microphone used to monitor that position. It was concluded that the fixed microphones gave a valid reading of personal exposure due to the rest of the orchestra. Naturally for certain instruments such as the violin the exposure of the ear nearest the instrument may be higher. The figures used in this report are from microphones which were suspended from the ceiling or fitted to fixed positions during recording throughout the opera season.

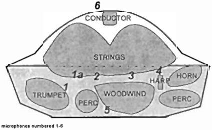

Figure 1. Typical layout of microphones during a performance.

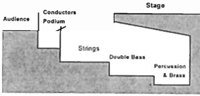

Figure 2. Cross section of orchestra pit.

Figure 1 and Figure. 2 show the plan and elevation views of the orchestra pit at the Australian Opera House Opera Hall together with approximate musician positions. Microphone positions are detailed in Table 3.

TABLE 3

Position number	Description of placement in the orchestra pit
1	Double bass in front of trumpets (full orchestra)
1a	Double bass in front of trumpets (reduced orchestra)
2	Double bass in front of percussion
3	Woodwind
4	Harp
5	Above contrabassoon, between percussion
6	Behind conductor

The L_{Aeq} was sampled on a regular basis by the dosimeters. These were then downloaded into a computer program and the sound exposure histories were plotted. One type of graphical output is shown in Fig 3 and this demonstrates the Equivalent Sound Level for each minute, $L_{Aeq,1m}$ and the maximum SPL (slow time weighting) achieved during that minute L_{Amax}.

The L_{Aeq},1m values were used to determine the exposure and the L_{Amax} values were compared to 115 dB(A), (the New South Wales maximum allowable industrial SPL).

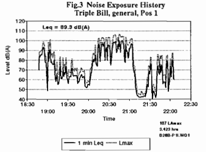

Figure 3. Example of plotted test results downloaded from dosimeters

Because of the extreme variability of performances it was necessary to sample operas over the entire operatic season to enable the determination of a realistic assessment of the overall level of risk. A graphical summary is shown in Figure 4. It demonstrates the relationship between the positions and the different types of performance. The documented levels are for the full performance including intervals and encores. The time of exposure varies with the length of the performance and is used in the next analysis. It can be seen that performances of the *Triple Bill* generate significantly higher outputs for the Bass in front of the Trumpets than say *Figaro, Alcina* and *L'Italian*. *Fiddler on the Roof* has a generally higher output for the rest of the orchestra, mainly due to the introduction of a modern drum kit. Analysis of all the dosimeter outputs showed no L_{max} in excess of 113 dB(A) slow, therefore no further analysis of maximum levels was carried out.

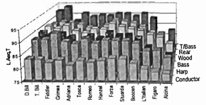

Figure 4. Comparison of noise exposure for complete performances of each Opera.

4. DETERMINATION OF EXPOSURE

After examining the data accumulated for the various Opera performances and rehearsals it was felt that to estimate the risk to musicians the simple taking of levels during an Opera was insufficient to establish long term exposure. It was also felt that, although many exposures were intense their duration may be short and their overall energy when averaged over the day may not be as critical as the spot measurements would indicate. It was therefore decided to calculate an $L_{Aeq,8h}$ for the musicians exposed.

Because not every performance was measured, several assumptions had to be made regarding the validity of extrapolating a single performance measurement to all performances of the same programme. The assumptions used were:

1. The variation between levels for the same performance was not significant. Two measures of Peter Grimes gave the same result. The further extrapolation of this result is valid because the Conductor, Musical Director and the whole Opera Company strive to give a constant, historically accurate and polished performance.
2. Variations between rehearsal, stage orchestral, dress rehearsal, sitzprobe (rehearsal with orchestra and singers) etc would reflect the mood of play and the differing surroundings rather than the opera itself and therefore the variation between rehearsal in the studios and the performance at the Opera House would be the same for each performance.
3. Excessive noise outside the opera was not included. Only Australian Opera and Ballet Orchestra work was included.

The schedule was broken up on a day by day, performance by performance basis and the $L_{Aeq,8h}$ was calculated for each day.

The daily exposure was determined by combining the $L_{Aeq,T}$ from each performance, practice and sitzprobe in accordance with the rehearsal and performance schedule. Each performance was measured directly and estimates for each rehearsal, sitzprobe and audition were made by correlation with a full set of measured results for *Peter Grimes* in which performance, rehearsals, sitzprobe, stage orchestral, general rehearsal and auditions at the Opera Centre and the Opera House were monitored. By this computation it was possible to establish an estimate of exposure due to employment by the AOBO.

Fig. 5 shows the relationship between performance position, the performance schedule and the daily $L_{Aeq,8h}$. The shadings used show the level of hearing damage risk.

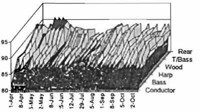

Figure 5. Representation of Noise exposure variation over the Opera Season.

Bottom Dark Grey: is an $L_{Aeq,8h}$ of less than 85dB(A). This is a low risk area. The only person with this low exposure is the conductor.

Middle Light Grey: is the area with $L_{Aeq,8h}$ between 85 and 90 dB(A). This is a level of significant risk. For continuous weekly exposure this level has been shown to cause hearing damage.

Top Dark Grey: level highlights an $L_{Aeq,8h}$ of greater than 90 dB(A) and will need to be avoided.

It can be seen that significant sections of the orchestra have a risk of hearing loss if this schedule is a true representation of normal exposure. The area of high exposure in May is due to two performances of the *Triple Bill* in the one day. This type of scheduling should be avoided. There are however some compensating factors which will reduce the apparent risk. These are:

- Not all members of the orchestra are present for the whole performance
- Not all members perform for each performance
- Each musician has a break of at least one opera in each season.

There are also factors contributing to risk which were not measured. These were:

- Extramural musical activities
- Practice at other venues
- Other noise exposures
- The close coupled output from the musicians own instrument.

The contribution of each of these factors could not be ascertained in this study.

5. CONCLUSIONS

This report has, by its long term nature, demonstrated some clear facts which were previously only conjecture. These are:

1. operagoers, ballet enthusiasts and the conductor are not put at risk of NIHL by these performances
2. the placement of the orchestra in the pit coupled with a tight performance schedule contributes to a significant risk of NIHL for the players.

Steps are currently being undertaken to modify the size and layout of the pit together with modifications to improve the acoustic coupling between the orchestra and the audience. In the meantime the orchestra are utilising hearing protection in the extreme portions of the loudest operas and ballets. Audiometric testing by air conduction and oto-acoustic emission has been started to establish whether the predictions, based on long term exposure, are valid for orchestral performers who typically have shorter exposure times and longer breaks.

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