

Risk of Hearing Loss in Orchestra Musicians:

Review of the Literature

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Abstract—We reviewed 13 papers on noise exposure of orchestral musicians and found that the question of whether orchestra musicians are overexposed does not appear to have a clear answer. To find relevant papers, we researched three databases (Scholar, Scopus, and Medline), which yielded 6, 9, and 17 papers, respectively (including duplicates). A number of papers in the reviewed literature lacked basic descriptions concerning such issues as measurement technique and instrumentation. Rough data and calculation details were often not provided so that the conclusions could not be checked easily. The most serious problem was the estimated time that musicians performed in the orchestra. This information is crucial for the calculation of the normalized noise exposure levels (L_{EX}), and is especially important as orchestra players do not perform year-round nor are they exposed to the same noise levels while performing different pieces of music. *Med Probl Perform Art* 2006;21:164–168.

Musicians playing in orchestras performing classical music—symphonic, ballet, opera, etc.—are exposed to high sound levels and may be at risk of hearing loss. This issue has been the subject of extensive debate, and many papers have been written supporting opposing conclusions. Some authors claim that the excessive sound levels typical of notorious “noisy” composers, such as Wagner or Brahms, are a definite cause for hearing losses. Others insist that due to the limited duration of rehearsals and performances, the resulting noise exposures of the musicians are never high enough to present a hazard to their hearing.

This paper summarizes findings from several different authors and provides suggestions about ways that these kinds of studies should be conducted to obtain scientifically rigorous results. As there are not many studies on this subject, all papers available to these authors, dating from the last 15 years, were included in this review. The following databases were researched and the number of papers found is shown in parentheses: Scholar ($n = 6$), Scopus ($n = 9$), and Medline

($n = 17$). As expected, several papers were found repeated in the different databases.

ASSESSING THE RISK OF HEARING LOSS

Noise Exposure Assessment

It is well known that exposure to high sound levels for extended periods of time is a major contributor to hearing loss. The most common method of assessing the risk of noise exposure is by measuring a person's exposure with either a sound level meter or a dosimeter. (In this paper the words music, noise, and sound are used interchangeably, as their effects on hearing are identical.) This should be done following procedures in such standards as the Canadian Standard Association (CSA) Z107.56 standard¹ or the International Organization for Standardization (ISO) 9612:1997² (now under revision). Calculated results are then used to predict hearing losses using the ISO 1999 standard (Table 1).³

Several issues need to be considered when using this method for assessing the risk of hearing loss to orchestra musicians. Some issues are related to the measurement technique itself, such as the selection of an appropriate instrument, location of the microphone, or the duration of the measurement. Others belong to the very nature of playing in an orchestra, where a musician is subjected to two noise sources: his or her own instrument as well as those of colleagues seated in close proximity.

Another problem, not frequently found in the industrial environment, is the very nature of music, where frequency and sound level change constantly in a non-cyclical manner. Finally, the duration of the exposure changes from day to day. A performance program is rehearsed a number of times, with frequent interruptions and repetitions, and then the piece is performed once, twice (in the case of a symphonic orchestra), or several times (in the case of an opera or ballet). The cycle of rehearsals and performances is then repeated with a completely different program. Therefore, the very concept of a sound exposure, repeated day after day (as commonly found in industry) cannot be easily applied to this case.

To make matters worse, musicians do not play only in the orchestra: they often teach music, play in small ensembles (trios, quartets), and also spend time practicing alone. In other words, their exposure is usually higher than that resulting from the orchestral activities.

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In summary, determining the noise exposure can become a difficult endeavor with musicians.

Hearing Threshold Measurements

Another approach to assessing the risk of hearing loss is by measuring the hearing threshold levels of musicians and then comparing the results with the hearing thresholds of the same age group as predicted by the ISO 1999 standard.³ Any measured increment of the threshold levels could be attributed to excessive noise exposure, which in turn will provide an estimate for risk for the musicians in question.

The problem encountered when using this method is common to all epidemiological studies: it is impossible to clearly separate effects due to “occupational” noise from exposures to other type of noises (environmental or recreational). In our case, the researcher may assume that the hearing loss is due only to playing in the orchestra, while the subject may be involved in other noisy activities or hobbies, such as playing in sound-enforced venues (always with very high noise levels) or in woodworking at home.

A variation on this method is to follow changes in hearing in groups of musicians over a number of years. Although very attractive, this approach is difficult to implement because musicians are a highly mobile work group. Therefore, to have the same population and to be able to measure their hearing periodically can be a very difficult task. In addition, the problem still remains of separating occupational exposure from other type of exposures.

Mixed Procedures

Finally, other researchers have used combinations of noise measurements, exposure measurements, and audiometric tests to obtain as detailed results as possible.

REVIEW OF PAPERS (Table 2)

McBride et al.,⁴ in a paper from 1992, measured noise levels and noise exposure levels during five rehearsals and two concert performances of the City of Birmingham Symphony Orchestra. The data collected were L_{eq} , L_{Peak} , duration, and dose. Musicians were also subject to audiometric test to determine the presence of hearing loss. For that purpose 18 “high-risk” musicians were matched for age and sex to “low-risk” musicians. The two major conclusions of their study were:

- Some musicians are exposed to sound levels in excess of the recommended limit and are therefore at risk. The authors, however, point out that they cannot estimate the total noise exposure due to the fact that most professional musicians have other commitments, such as teaching.
- Applying paired t-test to the results of both groups failed to show significant differences in hearing thresholds at high frequencies (2, 4, and 8 kHz) but did at low frequencies (0.25, 1, and 2 kHz). No explanation of this effect was provided.

TABLE 1. Explanation of Terms Used in this Paper

Terms
L_{Peak} —peak sound pressure: the highest instantaneous sound pressure level, in decibels, that occurs during a given time period.
L_{eq} —equivalent sound level: ten times the logarithm (base 10) of the time integral over a stated time, t hours, of the squared A-weighted sound pressure relative to 20 μ Pa, divided by that time. The equivalent sound level is identical to the sound level of a constant sound of the same total A-weighted acoustical energy as the actual varying sound of interest over the same time period.
L_{EX} —noise exposure level: ten times the logarithm (base 10) of the time integral of the squared A-weighted sound pressure relative to 20 μ Pa for the time actually worked, divided by T hours (usually the standardized shift length of 8 h).
$L_{Aeq,8hs}$ — L_{EX} for 8-h exposure.
Dose—a percentage of the maximum allowable noise energy that a person can be exposed to per day.
Instrumentation
Sound level meter—an instrument to measure the sound pressure level in decibels (dB)
Integrating Sound Level Meter—a sound level meter with the capability of measuring L_{eq} .
Dosimeter—an integrating sound level meter of smaller size intended to be carried by the exposed person during the entire noise exposure period.

For definitions of terms, see ANSI S1.1–1994: Acoustical Terminology.

The study does not provide normalized noise exposure level values (L_{EX}). Because the number of hours the musicians are exposed per year is not known, the real risk of occupational hearing loss cannot be assessed.

Mikl,⁵ in his 1995 report, documented a survey of similar studies of orchestra musician noise exposures going back to 1931. He concluded that there were no determination of $L_{Aeq,8hs}$ except for the day of the measurement and that the long-term exposure cannot be estimated.

Mikl performed a series of measurements during rehearsals and performances of the Australian Opera and Ballet Orchestra during the 1992 winter season (April 1 to October 31). Measurements were taken between four and six positions using a Larson Davis integrating sound level meter and dosimeters. Microphones were suspended from the ceiling at a distance of less than a meter from the monitored ear. The results indicated that the orchestra players can be divided into three groups according to their $L_{Aeq,8hs}$: low risk (<85 dBA), medium risk (85 to 90 dBA), and high risk (>90 dBA). Unfortunately, the paper does not provide the raw numerical results of the measurements or details of the calculations of the $L_{Aeq,8hs}$. There is no clear indication of the adjustment made for the number of hours per year that musicians spent performing or rehearsing—a factor that may significantly alter the risk of hearing loss.

In the conclusions, the author states that concert patrons and the conductor are not at risk. However, the placement of

TABLE 2. Summary of Published Studies

Author	Year of Publication	Method	Conclusion
McBride et al. ⁴	1992	SL/dose/audio	No conclusions
Mikl ⁵	1995	Dose	High risk
Mikl ⁶	1995	Sound power	No conclusions
Williams ⁷	1995	SLM	No significant hazard
Obeling, Poulsen ⁸	1999	SL/audio	No significant hazard
Kahari et al. ⁹	2001	Audiometry	No hearing loss
Kahari et al. ¹⁰	2001	Audiometry follow-up	No significant changes
Beale ¹¹	2002	Dosimeters	No significant overexposure
Eaton, Gillis ¹²	2002	Biblio/SL/audio	No hazard
Boasson ¹³	2002	L _{ex}	No risk except for horns
Laitinen et al. ¹⁴	2003	Exposure	Overexposed
Lee et al. ¹⁵	2005	Exposure	No hazard
Fleischer, Muller ¹⁶	2005	Audiometry	No risk of hearing loss

the performers in the orchestra, coupled with a tight schedule, contributes to a significant risk of noise-induced hearing loss for orchestra musicians.

In another study, **Mikl**⁶ attempted to assess the risk of hearing loss by calculating the sound power from different instrument groups in the orchestra. To do so, the author used 10 microphones located on a hemisphere around selected groups, each with three musicians, all located within 3 m from the center of the hemisphere. For each instrument group, representative segments of the opera *Tosca* by Puccini were selected by the conductor and designated as “soft,” “medium,” and “loud.” The musicians were also asked to play the “loud” selections at the maximum possible level. The sound power of each group of instruments was measured and corrected for the reverberation time of the room and the number of players within the group. The overall sound power was then calculated using the total number of players in each group.

The study concluded that the highest overall noise power comes from the brass and percussion sections. However, the paper does not provide the raw data or details of calculations. This study is clearly aimed at the calculation of the sound power of groups of instruments, rather than to assess the risk to the musicians. The artificial setting of the physical locations of the players and the methodology used allow for a rigorous measure of sound power contributed by the instrument, but it cannot be used directly to assess the risk of hearing loss.

A large study, encompassing both hall and pit players, was performed by **Williams**⁷ on musicians belonging to three orchestras from the Australian Broadcasting Corporation. Measurements were performed using a number of sound level meters (but not dosimeters) during 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.” However, the study concluded that the orchestras “do not have a major noise exposure problem.”

Obeling and Poulsen,⁸ in their 1999 report, studied musicians from four Danish orchestras. Sound levels were measured and audiometric tests performed on the musicians.

When compared to the median audiogram from ISO 7029 for the same age and gender, these musicians, the authors concluded, “cannot expect to suffer a pronounced hearing loss from playing in a symphony orchestra.”

In their 2001 study, **Kahari et al.**⁹ performed pure-tone audiometric tests on 140 classical orchestral musicians from the Goteborg Symphony Orchestra and the Goteborg Opera. They concluded from the results that the musicians “did not show severe hearing losses that could be attributed to exposure to musical noise.”

Kahari et al.¹⁰ performed another study that followed up research by Axelsson and Lindgren (unpublished data) done 16 years earlier. Their study consisted of a repetition of the audiometric tests done on classical orchestral musicians in Goteborg, Sweden. The study showed no significant change in musicians’ hearing during this 16-year interval.

In his research reported in 2002, **Beale**¹¹ performed noise exposure measurements on musicians from the Sydney Opera House. He used Larson Davis, Bruel & Kjaer, and CEL noise dosimeters mounted on tripods located at 0.3 m from the ears of selected players. Noise doses (%) were measured having as a base 1 DND (daily noise dose) equivalent to $L_{Aeq,8hs} = 85$ dBA. Data were collected during the performances of 18 operas. The report included only data from some wind instruments, and no mention was made if the data were from a single performance or an average of several performances.

The summary data indicated that the 1 DND has been slightly exceeded by only the trumpet section (103%) and horns (107%). The author claimed that musicians in the pit had higher noise exposure than their colleagues on stage, although it did not state by how much. This statement, that in theory appears to be valid, was not supported by his data or by bibliographic references.

After examining an extensive bibliography and also data collected from 53 members of the Vancouver Symphony Orchestra, **Eaton and Gillis**¹² 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.”

In a 2002 study, **Boasson**¹³ performed measurements at the Netherlands Ballet Orchestra. This orchestra performs yearly at about 18 different venues. Depending of the venue, the size of the orchestra varies between <65 musicians to >80. Details about the measurement, such as instrumentation used, microphone location, and duration of the measurement were not included in the paper.

From the measurement data, the author calculated the sound exposure per type of performance (so-called “project”) per year. This he calls $L_{EX,PROJECT}$, and it is the noise exposure average over 260 days (the implicit duration of the musicians’ annual activities). He concluded that, with the exception of the horns, all groups’ noise exposures were at or below the limit of 85 dBA. (The noise exposure level from the horns was 87 dBA). From the calculated data, the author predicted the hearing loss at 2, 3, 4, and 6 kHz that the different groups of musicians will incur after playing for 30 years in the same environment. This was done using the ISO 1999 standard.³

In their 2003 study, **Laitinen et al.**¹⁴ concluded that most musicians are overexposed. They used dosimeters to measure 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.

Lee et al.¹⁵ performed measurements on orchestra players from the Canadian Opera Company during 18 sessions that included rehearsals, dress rehearsals, and actual performances of two operas. Seventy-three noise exposures of players of different instruments were measured using five dosimeters for the entire duration (3 h) of each event. L_{EX} was calculated, from the measured L_{eq} , using the numbers of hours per year played by the musicians in that orchestra (300). The results, compared to the ISO 1999 standard,³ indicated that there is no risk of hearing loss for the players.

This finding is in line with that by **Fleischer and Muller**,¹⁶ who in 2005 examined the hearing of 187 orchestra musicians aged between 21 and 70 years (average, 44 yrs). They found that the hearing of 83.4% of the musicians was better than that predicted by the ISO 1999 standard.³ On this basis, the authors supported the theory that a high noise level may indeed build resistance to hearing loss, something that could explain their findings.

DISCUSSION AND CONCLUSIONS

Our examination of the literature regarding hearing loss among orchestral players tends to show that the risk can be quantified as minimal or nonexistent. However, a close examination of the different papers shows that several issues have not been properly addressed. The most significant are:

a) The description of the measurement technique, such as measurement details or location of the microphone, is often incomplete or missing altogether.

- b) Raw data are often not supplied, nor are the calculations explained. This information is necessary to check how the results from short-term exposure measurement from performances or rehearsals are used to calculate the long-term noise exposure.
- c) Some conclusions are based on inconsistent analysis of data.

Determining the noise exposure of musicians in an orchestra, for the purpose of estimating the risk of hearing loss, is not an easy task. Many variables are involved and their influence is difficult to assess. For example, there are variations between the noise levels from the different pieces being played and changes in the exposure from surrounding instruments due to seating arrangement, and finally, there is the assessment of the effective exposure duration, which includes playing at home and at other venues, something that is an almost impossible task. Furthermore, to arrive at meaningful conclusions, noise exposure measurements should be linked to audiometric tests as recommended by current hearing conservation programs.¹⁷

Some recommendations can be offered for future studies on noise exposure in musicians, as well as in workers involved in non-traditional occupations where exposure durations and noise characteristics are randomly distributed throughout the year:

- a) Measurements should be performed during the whole exposure period, preferably using sound integrating instruments (integrating sound level meters or noise dosimeters).
- b) All measurement details, such as location of microphones, description of activities, duration of measurements, sound source, etc., are important and should be reported.
- c) Explanation of the calculations used to arrive to conclusions should be included, as well as the raw data. This helps to verify how results from short-term measurements are used for the calculation of long-term noise exposure.
- d) Hearing loss is the result of long-term exposure to high noise levels. Therefore, the measured exposure levels should be normalized over a long period, preferably over a year. The result will then be $L_{AX, year}$.
- e) Whenever possible, measurement results should be linked to the musicians’ audiometric tests and the results compared to the predictions in ISO 1999.³

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