A Review of Orchestral Musicians' Hearing Loss Risks

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Summary

This paper reviews the literature concerning the noise exposure and hearing loss of symphony orchestra musicians.

The mean sound level of symphony musicians when normalized to a 40-hour week is 84 dBA. The L_{EX}s of brass and woodwind players are higher while that of stringed instrumentalists are lower. The majority of studies suggest hearing levels in orchestra musicians are not significantly different than a non-exposed population

While conventional hearing protectors are unsuitable for musicians, specialized hearing protectors with uniform attenuation may be appropriate for certain applications. An educational program to inform musicians about the effects of sound exposure, risk of hearing loss, and exposure control options is warranted. The effectiveness of the only two identified physical means for controlling noise (risers and screens) was not reported in the literature and, considering the physical acoustics of the situation, significant benefits are unlikely.

Objectives

An article on hearing problems of symphony musicians and associated sound levels appeared in a 2000 edition of a national newspaper. The article contained obvious inaccuracies but raised questions regarding orchestra musicians' noise exposures and possible risk of hearing loss.

It was decided to review the literature to:

Determine the sound exposure for symphony musicians
Evaluate the risk the sound exposures pose to the hearing of the musicians
Evaluate musicians' hearing loss by comparison with that of non-noise-exposed groups
Examine the effectiveness and practicability of noise exposure control techniques

Noise Exposure

International Standard ISO 1999 (1990) presents in statistical terms the relationship between noise exposures and the "noise-induced permanent threshold shift" (NIPTS) in people of various ages. The NIPTS the standard addresses is progressive and is acquired gradually over a period of several years. The Standard, then, can be applied to the calculation of risk of sustaining hearing handicap due to regular occupational or any daily repeated noise exposure.

The noise exposure descriptor used by ISO 1999 (1990) is the equivalent continuous A-weighted sound level, L_{eq}. The Standard assumes the worker is exposed to noise over an 8 h day, 5 day week. For workers exposed to noise in some other pattern, a related descriptor, L_{EX}, has been devised and is employed in this review. L_{EX} is the steady sound level which, energy-averaged over 8 hours, would give the same average daily noise exposure dose as the varying noise. It is related to the L_{eq} measured by an integrating meter. Thus:

$$L_{EX} = L_{eq} + 10\log_{10}(\text{Average daily shift duration in hours/8 hours})\ \text{dBA}$$

ISO 1999 (1990) excludes from consideration hearing loss due to high-energy impact noise. Instantaneous "peak" sound pressure levels will not be considered since they do not relate to gradual noise-induced hearing loss and which can often be shown to be artifacts in dosimetry. Peak values are frequently confused and often misused when compared to permissible L_{EX} values.

The most comprehensive symphony orchestra noise exposure study was that of Royster et al who obtained 68 dosimeter samples of L_{eq} from the 100-member Chicago Symphony Orchestra (CSO) under rehearsal and performance conditions for a variety of orchestral works. The musicians' mean L_{eq} was 89.9 dBA to which we have applied corrections to obtain L_{EX}. The orchestras in the reviewed papers employ their musicians for 15 hours of "service" per week over an 8 month annual season. Thus, we have applied a total correction of -5.9 dB (= $10\log_{10}$(520 h/y/2000 h/y) to the measured L_{eq} to obtain an annual mean L_{EX} of 83.9 dBA

Royster subdivided the orchestra into four instrumental groups. Members of the brass group have the highest levels, followed by a group most of whose members are traditionally located in front of the brass. The left ear of violinists was exposed to 6 to 8 dB higher sound levels than the right ear depending upon inclination of the players' head.

An extensive study on the Winnipeg Symphony Orchestra (WSO) was carried out by Sabesky and Korczynski who obtained 50 dosimeter samples from the 67-member orchestra in seven surveys covering a variety of venues, musical works under rehearsal and performance conditions. The samples were obtained in accordance with CSA Z107.56-1994 for a total sampling time of over 180 hours. For comparison with Royster, we calculated the mean annual L_{EX} of the WSO musicians (84.0 dBA) from measured L_{eq}s (by private communication from Sabesky).

Group No.	**Instruments in Group**	**Annual L_{EX}, dBA (95% C.I.)**		
		CSO	**WSO**	**Both**
1	violin and viola	82.4	82.0	82.2 (1.3)
2	horn, trumpet & trombone	87.2	88.5	87.9 (1.4)
3	clarinet, flute, bassoon & percussion	85.2	86.2	85.9 (1.2)
4	bass, cello, harp and piano	78.9	80.2	79.2 (1.0)
Mean annual L_{EX}, dBA, all orchestral musicians		**83.9**	**84.0**	**84.0 (0.9)**

Table 1. Comparison of Musicians' L_{EX} derived from Dosimetry

There is excellent agreement between the two studies for the annual mean L_{EX} in Table 1. Also shown is the combined data from the two. Due to the large number of samples (N = 118) and the relatively low standard deviation (4.7 dB), the 95 % Confidence Interval is small, 0.9 dB.

Hearing Loss Risk

Table 2 details the expected NIPTS for male musicians, based on three different L_{EX} exposure ranges: 85-89.9, 90-94.9 and 95-99.9 dBA over a 30-year exposure. Also noted is the percentage of musicians who will incur the predicted degree of hearing loss.

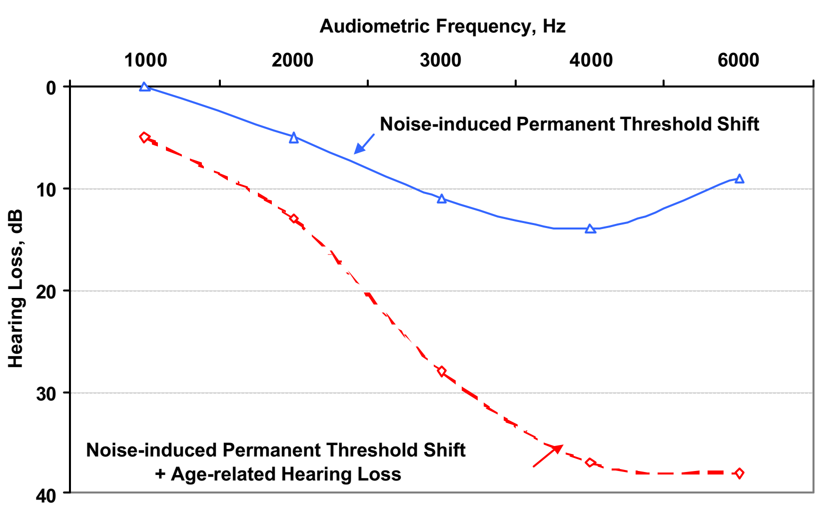
It is well known that median hearing levels increase with each decade of life for non-noise-exposed populations. ISO 1999 provides estimates of the expected age-related hearing loss (ARHL) for a non-exposed population. The expected age-related loss (ARHL) is tabulated separately at the bottom of each table, based on the 50th fractile, Annex B. Table 2 provides the 10th fractile for NIPTS, i.e. 90% of the exposed group will have hearing no worse than the predicted levels.

L_{EX} Range	Noise-induced Hearing Loss, dB					Predicted % Musicians	
dBA	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	In L_{EX} range	With HL
85 – 89.9	0	5	12	13	10	35.5	3.6
90 – 94.9	2	14	25	26	21	12.8	1.3
95 – 99.9	10	27	45	43	36	1.6	0.16
ARHL	**5**	**8**	**19**	**26**	**31**		**50**

Table 2. Predicted Noise-induced Hearing Loss (10th fractile, 50 year old males, ISO 1999:1990) and Expected Rate of Incidence in Population and Orchestra

The Hearing Threshold Level (HTL) of 0 dB is the statistical average normal hearing for young adults with no history of ear disease or significant noise exposure. Hearing thresholds have a range of ± 20 dB, normally distributed around 0 dB. Hearing loss is not considered to be present until HTLs of 20 dB or greater are reached. Thus, in Table 2, a slight noise-induced hearing loss is predicted at 3kHz and above for L_{EX} 90 to 94.9 dBA exposure for the most susceptible 10% of musicians, and the predicted percentage of musicians affected will be 1.3%. For exposures of 95 - 99.9 dBA, a mild to moderate hearing loss is predicted at 2 kHz and above for the most susceptible 10%, which affects 0.16% of the musicians.

Figure 1. Predicted Hearing Losses (L_{EX} = 90 dBA, 10th Fractile, 50 year-old Males)



ARHL combines with NIPTS, though not in strictly arithmetical fashion (see ISO 1999, paragraph 5.1). Figure 1 provides an example of this, showing the predicted NIPTS at the 10th fractile for a male of 50 years of age with 30 years exposure L_{EX} = 90 dBA. Also shown are the combined NIPTS and ARHL. ARHL is much greater than NIPTS, so the significance of the latter is reduced.

Hearing Loss in Orchestra Musicians

A number of studies which examined the hearing sensitivity of orchestra musicians were reviewed. The methodology typically used is to compare mean or median hearing threshold levels (HTLs) of musicians with HTLs of a non-exposed reference group. The choice of reference group varies across studies, and may be screened for non-occupational noise exposure and ear disease, or unscreened.

Axelsson et al evaluated hearing levels of 139 musicians in Gothenburg, Sweden. The musicians worked an average of 29 hours per week in the orchestra, 35% of whom worked in an orchestra pit, rather than on an open stage. The authors found poorer hearing compared to a non-exposed reference group in bassoon, French horn, trumpet and trombone players. History of firearm use and serving as a military musician were also associated with poorer hearing levels.

Johnson found the effects of instrument type and position on the orchestral stage on the HTLs of 62 members of the Minnesota Orchestra were not significantly correlated with hearing loss. Another finding was that musicians' hearing was not significantly different from an unscreened control group of non-exposed individuals.

A later study by Johnson et al compared hearing sensitivity of 60 orchestra musicians with 30 non-musicians for the conventional audiometric frequencies (0.5-8kHz) and for extended high-frequencies (9-20 kHz.). The musicians had a mean practice/performance time of 33 hours per week and a mean of 31 years at their occupation. The authors found no significant difference in hearing sensitivity for the two groups, nor any ear or gender effect. Both musicians and non-musicians showed an age effect of similar magnitude at the extended high frequencies.

Ostri, B. et al compared median hearing levels of 95 orchestra musicians with the ISO 1999 screened non-exposed population. These musicians worked an average 26 hours per week in the orchestra pit for the Royal Danish Theatre. Median hearing levels of the musicians were slightly poorer than for those of the reference population for all age groups. An additional finding was that violinists had significantly poorer hearing in their left ear at the higher frequencies.

McBride et al compared mean hearing levels of two groups of City of Birmingham Orchestra musicians (n = 63) with different exposure levels: woodwind and brass musicians comprised the higher exposure group, and strings players the lower exposure group. No significant hearing level differences were found between the two groups, when matched for age.

Royster et al compared mean threshold levels (HTLs) of 59 Chicago Symphony Orchestra musicians to age and sex-matched ISO 7029 screened and unscreened non-noise exposed populations. Musicians showed better average hearing than the unscreened non-exposed group, and slightly poorer hearing than the screened non-exposed group. Fifty percent of musicians showed a high-frequency "notch" suggestive of noise-induced threshold shift. Mean age-corrected hearing levels for four different groups of instruments showed differences in hearing ranked as follows from best to worst: a) bass, cello, harp and piano, b) violin and viola, c) horn, trumpet & trombone, d) clarinet, flute, bassoon and percussion.

The authors concluded that a small amount of noise-induced permanent threshold shift is predicted for orchestra musicians with average susceptibility based on a 15-hour/week exposure.

Karlsson et al examined the hearing of 417 musicians from five Swedish orchestras. Hearing levels were tested twice for 123 musicians, 6 years apart. Median HTLs for the musicians did not differ from those of non-exposed (screened and unscreened) reference populations. The only exception to this was flute players, who showed very slightly elevated HTLs. The authors point out that noise-induced hearing loss typically develops most rapidly in the **early** years of exposure. However, in the musicians, the development of hearing loss followed the normal course of presbycusis, i.e. hearing loss accelerating in **later** years. Karlsson concluded the risk of noise-induced hearing loss in symphonic musicians is nil or negligible.

Hearing test results from 53 members of the Vancouver Symphony Orchestra (VSO) were evaluated by the authors of this paper. Median hearing levels for male and female musicians were similar to the expected age-related hearing loss (ARHL) per ISO 1999 Annex B, unscreened 50^{th} fractile) as shown in Figures 2.A and B. Mean hearing levels (males and females combined) for the four instrument groups outlined in Table 1 showed differences in hearing ranked as follows from best to worst: a) cello, bass, harp b) violins, violas c) clarinet, flute, bassoon & percussion and d) horn, trumpet, trombone, tuba (see Figure 2.C). This ranking follows the predicted noise exposure rankings for the four instrument groups.

Age-corrected mean hearing levels were established by subtracting the appropriate ISO 1999 expected age-related hearing loss from each musician's hearing levels prior to determining the mean. Age-corrected mean hearing levels for the four instrument groups were not ranked by predicted noise exposure. The age-corrected means were clustered around 0 dB HL except for the brass group, which showed slightly poorer hearing (see Figure 2.D).

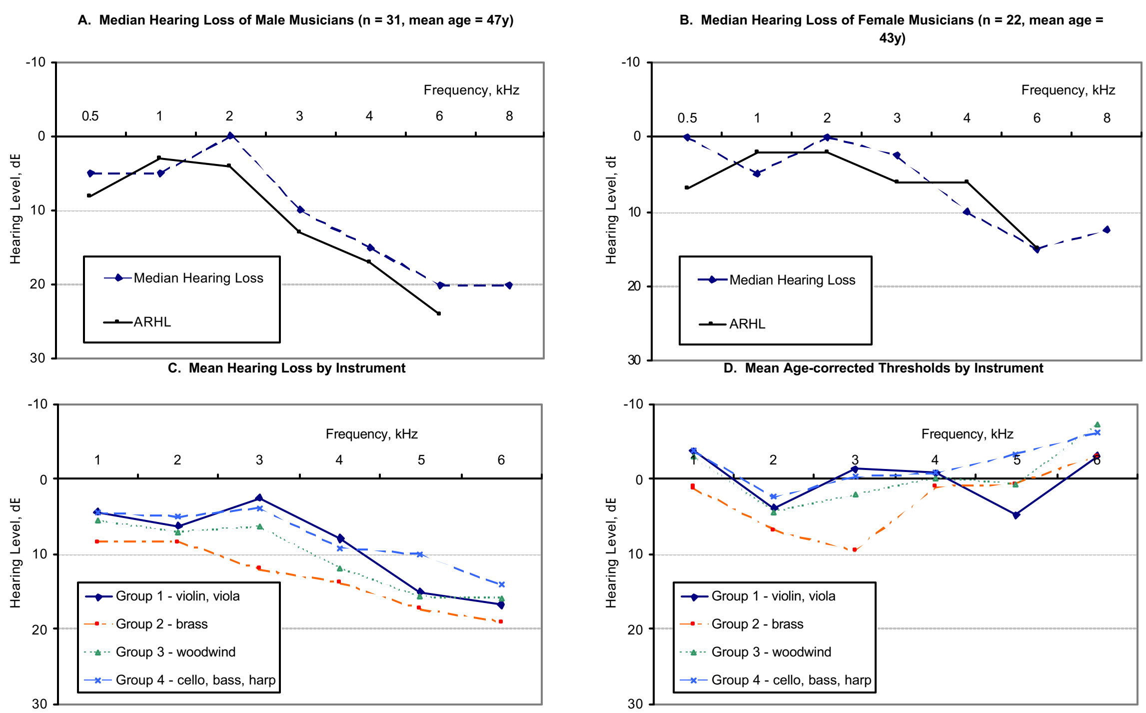


Figure 2. Hearing Levels for Vancouver Symphony Orchestra Musicians

Thirteen of the 53 musicians (24.5%) had a high-frequency "notch" in the audiogram, suggestive of noise damage. A notch was defined as a drop of 15 dB centered at 3000, 4000, or 6000 Hz. with recovery of 15 dB at a frequency above the drop, in either ear. No significant left/right ear differences were found for any of instrument groups, in contrast to the finding of Royster et al that violinists and violists had significant left ear asymmetries at 4000 Hz.

47% of VSO musicians reported regular use of hearing protection, with most using CSA Class A earplugs. Interestingly, musicians in the instrument group with the highest estimated noise exposure (horn, trumpet and trombone) reported the lowest percentage (10%) regular use of hearing protection.

It should be noted that only the exposure resulting from the orchestra rehearsals and performances is reported in the studies we reviewed. However, it is recognized that musicians have additional exposure through solo practice, teaching and other performing. The hearing threshold studies would reflect the impact of the cumulative exposures, from all sources, for the musicians.

Noise Exposure Control

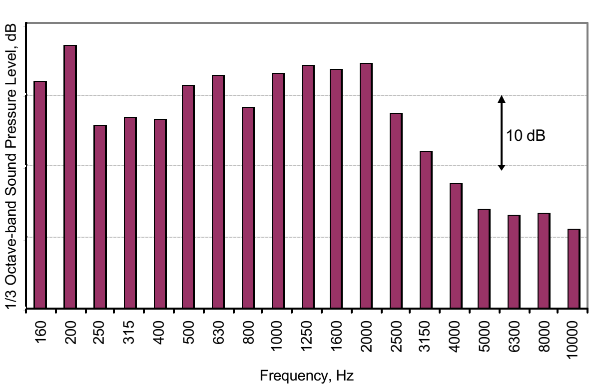
Engineering Controls

References to "engineering" noise control for orchestral musicians are scant in the literature. Indeed, the concept is recognized as counterproductive since the orchestra exists to generate sound, and interference with the perception of the sound may well be unacceptable to experienced, professional musicians. Engineering controls must reduce sound at the musicians' ears without causing unwanted redistribution of the sound.

Transparent screens have been suggested as means to reduce sound levels for musicians playing near loud instruments. Presbury and Williams, of Australia's National Acoustic Laboratory (NAL), after contacting sixteen orchestras around the world commented: "Often the 'acoustic performance' of the barriers is either unknown or inappropriate, given the circumstances. Indeed …most of the sound barriers used by orchestras had never been subjected to any form of performance–based testing". The authors noted that while personal "acoustic shields" may reduce noise from adjacent musicians they can also generate spurious reflections and elevate levels for surrounding musicians. The authors relate the development of acoustic shields at NAL; in which laboratory attenuations were only partly realized in practice due to the diffuse sound field of the orchestra environment. They noted a "cultural resistance" to the shields by the musicians.

Williams reports Camp and Horstmann concluded "freestanding clear plastic shields provide little protection downstream from a sound-generating source". Williams also reports Rosser's remark: "It was interesting to note that the perspex screens were not effective in the new rehearsal studio. This was probably due to multiple reflections and high levels of reverberation in this studio".

Figure 3. Time-Averaged Brass Section Spectrum



Chasin and Chong (1994 and 1995) conjecture that situating the brass section on risers should reduce noise for "downwind" players by taking advantage of the instruments' directional radiation properties. The trumpet's sound directivities (see their

1995 reference) are weak; for example, the sound intensity radiated at 3 kHz is only 5 dB less at 30° than the on-axis level.

A frequency analysis, Figure 3, of a recording of “Trumpet Voluntary” reaches a broad peak at 2 kHz, then decreases at about 18 dB/octave with increasing frequency. The suggested control technique of using directivity with risers will therefore be ineffective as the dominant mid-frequency components of the brass have weak directivities, while the more strongly directional high frequency components are insignificant contributors to the overall sound level.

Hearing Protection

Conventional hearing protectors are often unsuitable for musicians due to their frequency-dependant attenuation characteristics, and the occlusion effect. Conventional protectors attenuate high frequencies more than lows, resulting in distortion of the music. The occlusion effect (an enhancement of low frequency bone-conducted sound due to plugging the ear canal) causes an “echoey” perception of sound unacceptable to musicians.

For musicians, the most effective hearing protection would be ear plugs such as:

- Etymotic Research’s ER plug series (ER9, ER15, ER25), which gives a fairly flat insertion loss (of about 9, 15 and 25 dB respectively) across the audio-spectrum. The plug is available as a custom-molded earplug with an add-on filter. The filters are interchangeable, so if a user tries one level and finds it unsatisfactory, then a different filter can be substituted without remaking the entire ear plug. The occlusion effect can be reduced if the custom-molded earplug is fabricated with deep insertion (a long ear canal).
- E-A-R’s UltraTech plug series (Ultra Tech 12 and 16) which has the same acoustical filter as the ER series in a pre-molded, triple flanged body.

Experience has shown that even the special hearing protectors described above are not readily accepted by musicians, due to difficulty monitoring their own playing and that of other musicians in ensemble performance. This points to the necessity of a strong educational program for musicians, to inform them of the risks of hearing loss, the implications of even a mild loss to their profession, and the application of available hearing protection options.

Conclusions

The noise exposure data of Royster et al and Sabesky and Korczynski combine for a mean L_{EX} = 84 ± 1 dBA (95% C.I.) normalized to a 15h/week and 8 month year. About 42% of musicians will have L_{EX} greater than 85 dBA; 10% will have L_{EX} greater than 90 dBA and 1% will have L_{EX} greater than 95 dBA.

Based on the exposures established for musicians, some noise-induced hearing loss is predicted. However, most studies of musicians’ hearing found threshold levels not significantly different than non-exposed populations. This finding is interesting, since we know musicians typically have additional sound exposure outside their orchestra work, from solo practice, teaching and other performing which will elevate noise exposure. However, several studies reported high-frequency “notches” suggesting minimal noise damage in some musicians, possibly the more susceptible individuals or those with higher exposures, such as the brass section. Asymmetries in hearing were found for violinists and flutists in some studies, which could be attributed to asymmetrical sound exposure.

Screens as noise barriers seem to be impracticable and risers will not offer significant attenuation of the brass instruments' sound due to the latter's weak directional effects at their most contributory frequencies.

While conventional hearing protectors are unsuitable for musicians, specialized hearing protectors with uniform attenuation have been suggested for certain applications. An educational program to inform musicians about the effects of sound exposure, risk of hearing loss, and exposure control options is warranted.

References

Axelsson, Al, Lindgren, F., Sanden, A., Hearing in Classical Musicians, Acta Otolaryngologica Suppl. 377, 1981, p. 3-74.

Karlsson, K. Lundquist, P. and Olaussen, T., "The hearing of symphony orchestra musicians", Scand Audiol 12:257-264, 1983

Johnson, D. W., Sherman, R.E., Aldridge, J. and Lorraine, A., "Effects of instrument type and orchestral position on hearing sensitivity for 0.25 to 20 kHz in the orchestral musician", Scand Audiol 14:215-221, 1985

Johnson, D., Sherman, R., Aldridge, J., Lorraine, A., Extended high frequency hearing sensitivity – a normative threshold study in musicians, Ann. Otol. Rhinol. Laryngol. 1986, 95, p. 196-202.

Ostri, B., Eller, N., Dahlin, E. and Skylv, G., "Hearing impairment in orchestral symphony orchestra musicians", Scand Audiol 18:243-249, 1989

ISO (1990). "International Standard ISO 1999 second edition: Acoustics - determination of noise exposure and estimation of noise-induced hearing impairment"

Royster J.D., Royster L.H. and Killion M.C., "Sound exposures and hearing thresholds of symphony orchestra musicians"J.A.S.A. 89(6), June 1991

McBride, D., Gill, F., Proops, D., Harrington, M., Gardiner, K. and Attwell, C. "Noise and the classical musician" BMJ 305:1561-1563, 1992

Canadian Standards CSA Z94.2-94 "Hearing Protectors"

Canadian Standards CSA Z107.56-94 "Procedures for the Measurement of Occupational Noise Exposure"

Williams W. (1994) " ABC Symphony Orchestras – Noise Exposure of Orchestra Members", National Acoustic Laboratories Commissioned Report No. 109, January 1995

Chasin M. and Chong J. (1994) "Musicians and the prevention of hearing loss", JSLPA 18(3) September 1994

Chasin M. and Chong J. (1995) “Four Environmental Techniques to Reduce the Effect of Music Exposure on Hearing”, Medical Problems of Performing Artists, 10(2)

Sabesky I.J. and Korczynski R.E. (1995) “Noise Exposure of Symphony Orchestra Musicians”, J. of Applied Occupational & Environmental Hygiene (10)2

Williams W. (1995) “Orchestral Noise?”, Australian Acoustical Society Conference

Presbury J. & Williams W. “Occupational Noise Exposure Management in an Orchestral Setting”', J. Occup. Health Safety, Aust NZ 2000, 16(4): 337-342