

REVIEW OF ORCHESTRA MUSICIANS' HEARING LOSS RISKS

Stuart Eaton and Heather Gillis

Workers Compensation Board of BC, P.O. Box 5350, Stn. Terminal, Vancouver, BC V6B 5L5

ABSTRACT

This paper reviews the literature concerning the noise exposure and hearing loss of symphony orchestra musicians and reports new data on 53 members of the Vancouver Symphony Orchestra (VSO).

Musicians' noise exposures reported in three studies were analyzed. The mean equivalent sound level, L_{eq} , of 146 symphony musicians was 90 dBA. Brass and woodwind players have higher L_{eq} values than stringed instrumentalists. Eight studies which examined hearing sensitivity of orchestra musicians were reviewed. Most studies suggest musicians' hearing levels are not significantly different than a non-exposed population. However, several studies identified high-frequency notches suggestive of noise-induced threshold shift. In addition, elevated hearing levels for certain instrument groups (woodwind, percussion and brass) were observed. No conclusive evidence for the effectiveness of risers and screens (the only two physical means proposed for controlling noise exposure) emerged in the review, and, considering the physical acoustics of the situation, significant benefits by these means are unlikely.

Evaluation of hearing test results for 53 members of the VSO indicate median hearing levels similar to age-expected levels for non-exposed populations. Age-corrected mean hearing levels for four instrument groups were not ranked by predicted noise exposures. However, thirteen musicians (25%) had a high-frequency notch suggestive of noise damage. Less than half of the musicians reported regular use of hearing protection. Whereas conventional hearing protectors are unsuitable for musicians, specialized hearing protectors with uniform attenuation may be appropriate for certain situations. An educational program to inform musicians about the effects of sound exposure, risk of hearing loss, and exposure control options is warranted.

SOMMAIRE

Cet article examine la documentation concernant l'exposition des musiciens d'orchestre symphonique à la pollution sonore et à la perte de l'ouïe. L'article examine aussi des données récentes sur 53 membres du Vancouver Symphony Orchestra (VSO).

Trois études d'exposition à la pollution sonore fût examinées. L'équivalent moyen du niveau de son, L_{eq} , de 146 musiciens symphonique était de 90 dBA. Les joueurs d'instruments de bois et de cuivre ont une valeur plus élevée de L_{eq} que les instrumentistes à cordes. Huit études qui examine la sensibilité de l'ouïe des musiciens d'orchestre ont été révisées. La plupart des études semblent indiquer qu'il n'y a pas de différence considérable entre le niveau de l'ouïe des musiciens d'orchestre et d'une population non exposée. Par contre, plusieurs études ont identifiées des pointes de haute fréquence qui suggèrent un changement de niveau provoqué par le bruit. En plus, un niveau de l'ouïe élevée fût observé parmi certains groupes d'instruments (bois, cordes et cuivre). La revue ne démontre aucune évidence décisive sur l'efficacité des contremarches et des écrans (les deux seuls moyens physique proposé comme contrôle aux expositions à la pollution sonore). Étant donné l'acoustique physique de la situation, des gains significatifs par ces moyens sont peu probable.

L'évaluation des résultats d'examen de l'ouïe de 53 membres du VSO indique un niveau médian de l'ouïe semblable, anticipé par âge, d'une population qui n'as pas été exposée à la pollution sonore. Le classement du niveau médian, justifié par âge, pour quatre groupes d'instrument n'a pas tenu compte d'un résultat prédit en ce qui concerne les expositions à la pollution sonore. Cependant treize musiciens (25%) avaient une pointe de haute fréquence qui suggère l'endommagement de l'ouïe par le bruit. Moins de la moitié des musiciens auraient utilisé, régulièrement, des dispositifs de protection contre le bruit. Quoique les dispositifs conventionnels de protection de l'ouïe ne conviennent pas aux musiciens, des dispositifs de protection spécialisé avec atténuation uniforme peut cependant être approprié dans certaines situations. Un

programme éducatif conçu pour informer les musiciens des effets nuisifs de la pollution sonore, de la perte de l'ouïe, et des méthodes optionnelles de contrôle contre l'exposition au bruit est justifié.

1. OBJECTIVES

In 1996 the Workers' Compensation Board of British Columbia (WCB of BC) lowered its regulatory noise criterion level from 90 to 85 dBA. The change created a noise-exposure knowledge gap for workers in sectors with noise exposures in the range 85 to 90 dBA. To improve the WCB noise database, projects were undertaken to obtain noise exposures for workers in laundries and kitchens, tire shops, fast food restaurants, etc. In 1999, WCB jurisdiction was extended to performers in the entertainment sector for the first time. However, rather than initially launch an extensive noise survey to determine the noise exposure for symphony musicians in BC, it was decided that an international literature review would be valuable as a foundation and context for understanding the situation of local professional musicians.

Initially, the literature was reviewed to:

- a) Determine the sound exposure for symphony musicians;
- b) Evaluate the risk the sound exposures pose to the hearing of the musicians;
- c) Evaluate musicians' hearing loss by comparison with that of groups who were not exposed to noise;
- d) Examine the effectiveness and practicability of techniques for controlling noise exposure.

Following a presentation of the WCB of BC review, the Vancouver Symphony Orchestra (VSO) instituted a hearing conservation program, beginning with hearing tests of their musicians. Upon receipt of copies of the musicians' audiograms WCB also decided to:

Compare the VSO orchestra musicians' hearing thresholds with expected values.

2. 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 which 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-hour day, 5-day week. For workers exposed to noise in some other pattern, a related descriptor, $L_{EP,d}$, has been recommended (EEC, 1986) and is employed in this review. $L_{EP,d}$ 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:

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

ISO 1999 (1990) excludes hearing loss due to high-energy impact noise. Peak sound pressure levels are not considered here as they do not relate to gradual noise-induced hearing loss; very high peaks can often be shown to be artifacts in dosimetry. Kwiatkowski, Schäcke, Fuchs, and Silber (1986) suspected peak artifacts were caused by accidental contacts with the microphone. Peak values are liable to be compared wrongly with permissible $L_{EP,d}$ values.

High sound levels have been measured with conventional sound level meters within the body of orchestras by Axelsson, Lindgren and Sanden (1981) and Westmore and Eversden (1981). This is to be expected since the orchestra must generate sufficient sound power to "fill" an auditorium. Orchestras can generate high continuous equivalent sound levels with high crest factor (about 30 dB, Sabesky, 1995). Maximum "Fast" levels of 120 dBA and still higher "Peak" sound pressure levels have been detected.

More recently, integrating meters have been used to measure L_{eq} values within orchestras. McBride, Gill, Proops, Harrington, Gardiner and Attwell (1992) measured "general" L_{eq} sound levels, but reported only nine personal dosimeter L_{eq} values in five rehearsals and two concerts. Personal L_{eq} values for second violins were 0.8 dB higher and bassoonists were 10 dB higher than "general" levels. Performance L_{eq} values were 2.5 to 3.5 dB higher than rehearsal values. Williams (1994) reports 212 L_{eq} samples, giving a spatial average sound level of 87 dBA. The L_{eq} data were obtained over about 250 hours in front of, behind, to the side and within certain orchestra sections for a range of concerts, composers and auditoria but only eight personal noise exposures on two types of instruments were reported.

Kwiatkowski et al (1986) acquired personal dosimetry on 29 musicians playing in the pit of the Deutsche Oper Berlin

(DOB). They concluded exposure levels primarily depended upon the instrument and to a lesser extent on the composer. They subdivided the musicians' exposures into four instrumental groups and presented mean group L_{eq} values as shown in Table 1. Members of the brass group have the highest levels, followed by clarinet, flute, bassoon, percussion group (most of whose members are traditionally located in front of the brass), violin and viola, and finally cello, bass, harp and piano.

Royster, Royster and Killion (1991) obtained 68 dosimeter L_{eq} samples from the 100-member Chicago Symphony Orchestra (CSO) under rehearsal and performance conditions for a variety of orchestral works. Royster et al displayed L_{eq} distributions with class width 2 dB for Kwiatkowski's instrumental groups. The data are summarized in Table 1. In an exploratory study of the sound field around the heads of a violinist and a violist, Royster et al showed the left ear was exposed to sound levels 6 and 8 dB higher than the right ear, respectively. Greater differences occurred as players inclined the head towards their instruments.

An extensive study of the Winnipeg Symphony Orchestra (WSO) was carried out by Sabesky and Korczynski (1995). Personal dosimeter samples were obtained from the 67-member orchestra in seven surveys covering three different venues and a variety of musical works under both rehearsal and performance conditions. The samples were obtained in accordance with CSA Z107.56-1994 for a total sampling time of over 180 hours. The present article takes 49 of the WSO dosimeter samples after eliminating records (obtained by private communication from Sabesky, 2000) which contained overloads and partial rehearsal exposures. These data are summarized in Table 1 for the four instrumental groups.

The agreement between the three studies for the mean L_{eq} values is excellent for like groups and orchestras.

The mean L_{eq} for all musicians in the three orchestras is 89.7 dBA ($n = 146$). As Kwiatkowski et al (1986) did not

report individual L_{eq} values, the overall standard deviation cannot be calculated. The samples of Royster et al (1991) and Sabesky et al (1995) together give a mean $L_{eq} = 89.6$ dBA, standard deviation = 4.6 dB ($n = 117$) and corresponding 95 % Confidence Interval = 0.9 dB.

The WSO and CSO employ their musicians for 15 hours per week over an 8-month annual season. Thus, for these orchestras a total correction of -5.9 dB ($= 10\log_{10}(520 \text{ h/y}/2000 \text{ h/y})$) can be applied to the measured L_{eq} to obtain:

$$\text{Annual Mean } L_{EP,d} = 84 \pm 1 \text{ dBA (95\% CI).}$$

3. HEARING LOSS RISK

Table 2 details the expected NIPTS for male musicians, based on three different $L_{EP,d}$ exposure ranges: 85-89.9, 90-94.9 and 95-99.9 dBA over a 30-year exposure. Values for males were used as hearing levels are poorer for males than females in the general population and thus a "worst case scenario" is presented. 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. Annex B of ISO 1999 (1990) provides median expected hearing threshold levels associated with age (HTLA) for non-noise-exposed populations at various age groups for males and females. The expected HTLA shown in Table 2 is for 50 year-old males at the 50th fractile. The expected NIPTS shown is at the 10th fractile, that is 90% of the exposed group will have hearing no worse than the predicted levels.

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 for this population of young adults have a range of ± 20 dB, normally distributed around 0 dB. Hearing loss is not

Group No.	Instruments in Group	CSO			WSO			DOB		
		L_{eq} , dBA	s, dB	n	L_{eq} , dBA	s, dB	n	L_{eq} , dBA	s, dB	n
1	Violin and viola	88.4	5.3	23	88.5	2.7	18	89.1	-	14
2	horn, trumpet & trombone	93.5	3.2	13	94.5	3.5	10	93.4	-	6
3	Clarinet, flute, bassoon & percussion	91.2	3.2	17	92.2	3.1	10	91.9	-	4
4	bass, cello, harp and piano	84.9	2.6	15	86.2	2.4	11	87.0	-	5
Mean L_{eq} , dBA, all groups of musicians		89.3	4.9	68	90.0	4.1	49	90.0	-	29

Table 1. Comparison of Musicians' L_{eq} derived from Personal Dosimetry
(s = standard deviation, n = number of samples)

$L_{EP,d}$ Range dBA	Noise-induced Permanent Threshold Shift, dB					Predicted % Musicians	
	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	In $L_{EP,d}$ 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
HTLA	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 (based on 15 h/week “service”)

considered present until HTLs of 20 dB or greater are reached (Davis and Silverman, 1970, p. 193).

In Table 2, a slight noise-induced hearing loss is predicted at 3 kHz and above for $L_{EP,d}$ 90 to 94.9 dBA for the most susceptible 10% of musicians; 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.

HTLA combines with NIPTS, though not in strictly arithmetical fashion (ISO 1999:1990). 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 $L_{EP,d} = 90$ dBA. Also shown is the combined NIPTS and HTLA, which is much greater than NIPTS, reducing the significance of the latter.

4. HEARING LOSS IN ORCHESTRA MUSICIANS

Studies that examined hearing sensitivities of orchestra musicians were reviewed. The review revealed that 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 (1981) evaluated hearing levels of 139 musicians in Gothenburg, Sweden. The musicians worked an average of 29 hours per week in the orchestra. Thirty-five percent of the musicians worked in an orchestra pit, rather than on an open stage. The authors found poorer hearing in bassoon, French horn, trumpet and trombone players compared to a non-exposed reference group. History of firearm use and serving as a military musician were also associated with poorer hearing levels.

A follow up study of the Gothenburg Symphony (Kähäri,

Axelsson, Hellström and Zachau, 2001) examined hearing levels of 140 musicians and found no severe hearing losses. Male musicians’ median hearing levels indicated a high-frequency “notch”, suggesting noise damage. Percussion and woodwind players had slightly poorer hearing levels than other musicians.

Johnson, Sherman, Aldridge and Lorraine (1985) found that instrument type and position on the orchestral stage were not significantly correlated with hearing loss for 62 members of the Minnesota Orchestra. Musicians’ hearing levels were not significantly different from an unscreened control group of non-exposed individuals.

In a later study, Johnson, Sherman, Aldridge and Lorraine (1986) compared hearing sensitivities of 60 orchestra musicians with 30 non-musicians for the conventional audiometric frequencies (0.5-8 kHz) and for extended high-frequencies (9-20 kHz). The musicians’ mean practice/performance time was 33 hours per week and a mean of 31 years at their occupation. The authors found no significant difference in hearing sensitivity between 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, Eller, Dahlin and Skylv (1989) compared median hearing levels of 95 orchestra musicians with the ISO 1999 (1990) screened non-noise exposed population. These musi-

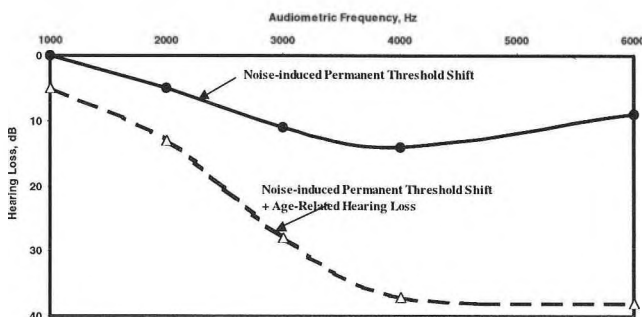


Figure 1. Predicted Hearing Levels ($L_{EP,d} = 90$ dBA, 10th fractile, 50 year-old Males)

cians 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 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 (1992) 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 (1991) compared mean hearing levels of 59 Chicago Symphony Orchestra musicians to age and sex-matched ISO 7029 screened and unscreened non-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, Lundquist and Olaussen (1983) examined the hearing of 417 musicians from five Swedish orchestras. Hearing levels were tested twice for 123 musicians, 6 years apart. Median hearing levels 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 hearing levels. 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, that is hearing loss accelerating in later years. Karlsson concluded the risk of noise-induced hearing loss in symphonic musicians is nil or negligible.

It should be noted that only exposure resulting from the orchestra rehearsals and performances is reported in the studies reviewed here. 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.

5. NOISE EXPOSURE CONTROL

5.1 "Engineering" Controls

References to "engineering" or "physical" 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 of plexiglass and polycarbonate have been suggested as means to reduce sound levels for musicians playing near loud instruments. Chasin and Chong (1994, p. 194) point out that shields "only give significant protection if used within 18 cm of the musician's head", a severe restriction on the musician. Presbury and Williams, of Australia's National Acoustic Laboratory (NAL), after contacting 16 orchestras around the world commented (p. 339):

"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, at NAL, of acoustic shields shaped to reduce unwanted reflections. A shield in anechoic conditions gave insertion losses of 8-10 dB; insertion losses in the more diffuse sound field of the orchestra environment realized 3-5 dB. They noted the musicians' "cultural resistance" to the shields.

Williams (1994) reports that 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".

Chasin and Chong (1994, 1995) conjectured that situating trumpets on risers should reduce noise for "downwind" players by taking advantage of the instruments' directional radiation properties at high frequency. Spectral envelopes of brass instruments playing *mezzoforte* are rich in overtones as

shown by Fletcher and Rossing (1998, p. 231, p. 454). The time-averaged spectrum of the trumpet attains a broad maximum at mid frequencies (about 1.6 kHz). Spectra of other brass instrument peak at lower frequencies. Above the maximum in the spectra, sound pressure levels fall at the rate of about 12 dB/octave.

Directivity functions given by Davis and Davis (1975, p. 250) for the trumpet at different frequencies instruments have been replotted in Figure 2 to show Directivity Indices (at angle = 0°).

Below 2 kHz, sound intensity levels at 30° are lower than on-axis levels by less than 2.7 dB. Even at 4 kHz, the 0° sound intensity level is reduced by directivity by only 3.3 dB at 30°.

Thus, high frequency spectral components in the trumpet spectrum are not significant contributors to the A-weighted sound level nor do they have strong directivities. The suggested control technique of using directivity of brass instruments with risers will therefore be ineffective; the dominant mid-frequency components of the brass have weak directivities, whereas the more directional components at higher frequencies are insignificant contributors to the overall sound level. Kwiatkowski et al (1986) concluded that there was no realistic means to control the noise exposure of musicians.

5.2 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 low frequencies, resulting in distortion of the music. The occlusion effect (an enhancement of low frequency bone-conducted sound

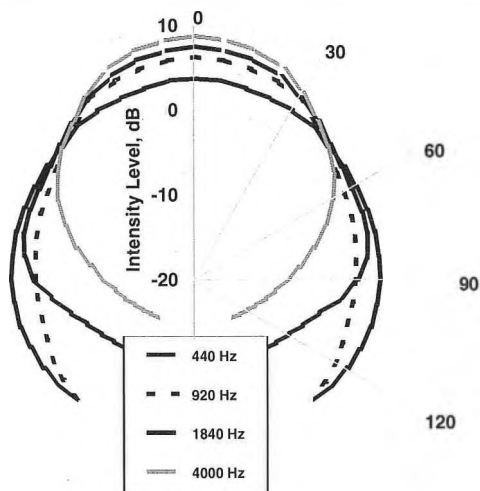


Figure 2. Polar Radiation Pattern for the Trumpet
(after Davis & Davis, 1975, p. 250)

due to plugging the ear canal) causes an “echoey” perception of sound unacceptable to musicians. For musicians, the most appropriate hearing protection would be earplugs such as:

- i) 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 earplug. The occlusion effect can be reduced if the custom-molded earplug is fabricated with deep insertion (a long ear canal).
- ii) 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.

6. POSTSCRIPT: ANALYSIS OF VSO HEARING TEST DATA

The authors met with the Health & Safety Committee of the Vancouver Symphony Orchestra (VSO) to present the foregoing review. Subsequently, VSO implemented a hearing conservation program which included education sessions for musicians regarding effects of sound on hearing, hearing protection and hearing tests. Hearing test data for noise-exposed workers in British Columbia are submitted to a central data registry at the Workers’ Compensation Board. The authors analyzed the VSO hearing test results in order to evaluate the extent of hearing loss in these musicians.

The hearing tests were conducted by trained/certified Industrial Audiometric Technicians using a standard test protocol (modified ascending/descending technique for threshold determination) and audiometers calibrated annually to ANSI Standard S3.6-1996 specifications. Tests were conducted in audiometric booths meeting ANSI Standard S3.1-1999 criteria for permissible ambient noise levels. In addition to hearing thresholds at 500 through 8000 Hz, information on hearing protection use, years at occupation, age and gender was recorded at the time of the test.

Fifty-three VSO members (31 males and 22 females) were tested. Median hearing levels for male and female musicians

were similar to the hearing threshold levels associated with age (HTLA) per ISO 1999 Annex B, unscreened 50th fractile) as shown in Figures 3.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 3.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 HTLA 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 HTL except for the brass group, which showed slightly poorer hearing (see Figure 3.D).

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 the instrument groups, in contrast to

the finding of Royster et al (1991) that violinists and violists had significant left ear asymmetries at 4000 Hz.

Forty-seven percent of VSO musicians reported regular use of hearing protection, with most using CSA Class A earplugs. Class A protectors according to Canadian Standards CSA Z94.2-94 provide approximately 30 dB of attenuation at 1000 Hz and above. One would expect a greater use of the "musicians" earplugs (with uniform attenuation, Class B or C). Interestingly, musicians in the instrument group with the highest estimated noise exposure (horn, trumpet and trombone) reported the least frequent regular use of hearing protection (10%).

7. SUMMARY

The noise exposure data of Royster et al (1991) and Sabesky and Korczyński (1995) combine to give a mean $L_{EP,d} = 84 \pm 1$ dBA (95% C.I.) normalized from a 15 h/week and 8 month year to a 40 h/week. About 42% of musicians will have L_{EX} greater than 85 dBA; 10% will have $L_{EP,d}$ greater than 90 dBA and 1% will have L_{EX} greater than 95 dBA. VSO musicians are contracted to provide 20 hours per week of "service" for a 39 week season. This exposure duration for the VSO gives:

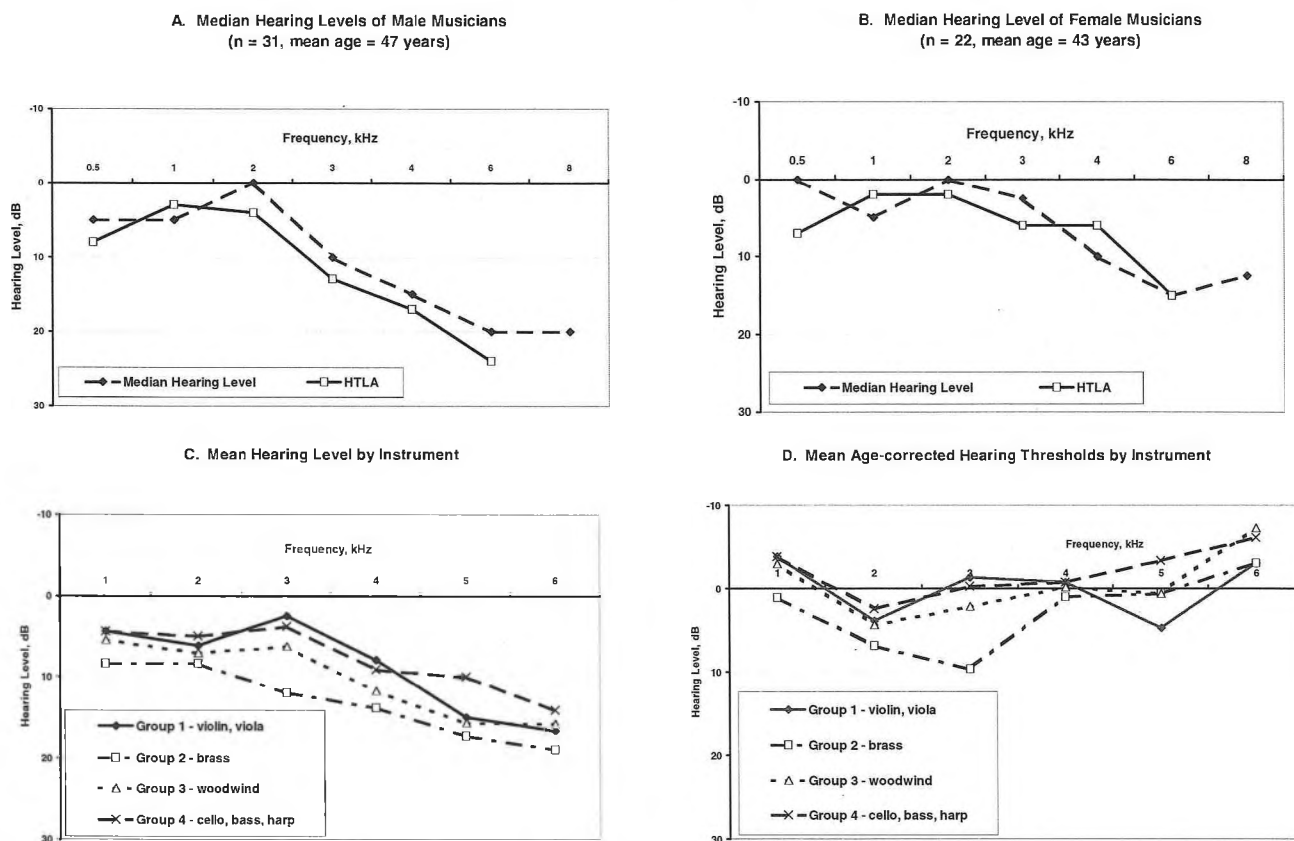


Figure 3. Hearing Levels for Vancouver Symphony Orchestra Musicians.

Annual Mean $L_{EP,d} = 86 \pm 1$ dBA.

Based on the exposures established, some noise-induced hearing loss is predicted for some orchestra musicians. However, most studies of musicians' hearing, including the present analysis of VSO hearing test data, found threshold levels not significantly different than non-exposed populations. This finding is interesting, since 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 including the VSO data indicated 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. However, the majority of VSO musicians reported using CSA Class A earplugs, which are conventional, highly attenuating protectors. This points to the need for an educational program to inform musicians about the effects of sound exposure, risk of hearing loss, exposure control options and appropriate hearing protection selection.

8. REFERENCES

- American National Standard S3.1-1999, "Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms".
- American National Standard S3.6-1996, "Specification for Audiometers".
- Axelsson, A., Lindgren F., Sanden, A., "Hearing in Classical Musicians", *Acta Otolaryngologica Suppl.* 377, 1981, p. 3-74.
- Canadian Standards CSA Z94.2-94, "Hearing Protectors".
- Canadian Standards CSA Z107.56-94, "Procedures for the Measurement of Occupational Noise Exposure".
- 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).
- Davis, D. and Davis, C., "Sound System Engineering", First Edition, Appendix VI "Directivity of Instruments and Devices", Howard W. Sams Co. Inc., 1975.
- Davis, H. and Silverman, S.R., "Hearing and Deafness", Third Edition, Holt, Rinehart and Winston Inc., New York, 1970.
- EEC Directive EEC/86/188 "The protection of workers from the risks related to the exposure to noise at work", May, 1986
- Fletcher, N.H. & Rossing, T.D., "The Physics of Musical Instruments", Second Edition, Addison-Wesley Publishing Co. Inc., 1990.
- ISO (1990), International Standard ISO 1999 Second edition, "Acoustics - determination of noise exposure and estimation of noise-induced hearing impairment".
- 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.E., Aldridge, J., Lorraine, A., "Extended high frequency hearing sensitivity - a normative threshold study in musicians", *Ann. Otol. Rhinol. Laryngol.* 1986, 95, p. 196-202.
- Kähäri, K., Axelsson, A., Hellström, P., Zachau, G., "Hearing assessment of classical orchestral musicians", *Scand. Audiol.* 30:13-23, 2001.
- Karlsson, K., Lundquist, P. and Olaussen, T., "The hearing of symphony orchestra musicians", *Scand. Audiol.* 12:257-264, 1983.
- Kwiatkowski, A., Schäcke, G., Fuchs, A. and Silber, P., "Schalldruckpegel im Orchestergraben eines Opernhauses", *Zentralblatt für Arbeitsmedizin, Arbeitsschutz, Prophylaxe und Ergonomie*, 36(1986) 58-64.
- McBride, D., Gill, F., Proops, D., Harrington, M., Gardiner, K. and Attwell, C. "Noise and the Classical Musician", *BMJ* Vol. 305, p. 1561-1563, 1992.
- Ostri, B., Eller, N., Dahlin, E. and Skylv, G., "Hearing impairment in orchestral symphony orchestra musicians", *Scand. Audiol.* 18:243-249, 1989.
- Presbury, J. & Williams, W., "Occupational Noise Exposure Management in an Orchestral Setting", *J. Occup. Health Safety*, Aust. NZ 2000, 16(4): 337-342.
- 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.
- Sabesky, I.J. and Korczynski, R.E. (1995), "Noise Exposure of Symphony Orchestra Musicians", *J. of Applied Occupational & Environmental Hygiene* (10)2.
- Westmore, G.A. and Eversden, I.D. "Noise-Induced Hearing Loss and Orchestral Musicians", *Arch. Otolaryngol.*, Vol. 107, Dec 1981.
- Williams W. (1994), "ABC Symphony Orchestras - Noise Exposure of Orchestra Members", National Acoustic Laboratories Commissioned Report No. 109, January 1995.
- Williams W. (1995), "Orchestral Noise?", Australian Acoustical Society Conference.

A SINGLE SOURCE LABORATORY

for Calibration and Repair of

Sound, Vibration, and Electronic Test Instrumentation

SPECIALIZING IN:

- ACCELEROMETERS
- MICROPHONES
- SOUND LEVEL METERS
- VIBRATION METERS

- FIELD CALIBRATORS
- AUDIOMETRIC EQUIPMENT
- VIBRATION TEST EQUIPMENT
- FREQUENCY ANALYZERS

OUR AUTOMATED FACILITY ASSURES YOU OF:

CALIBRATIONS TRACEABLE TO N.I.S.T.

CERTIFICATION: ISO 9002

ACCREDITATION: ANSI/NCCL Z540-1-1994
ISO/IEC GUIDE 25 (1990)

COMPLIANCE MIL-STD-45662A
ISO 10012-0 1992 (E)
ISO 17025 (1999)

SUPERIOR WORKMANSHIP

COMPLETE TEST DOCUMENTATION

QUICK TURNAROUND TIME:

- TWO WEEK TURNAROUND
- 48 HOUR CALIBRATION SERVICE AVAILABLE FOR AN ADDITIONAL FEE.

OTHER SERVICES INCLUDE:

- CUSTOM SYSTEM INTEGRATION
- ON-SITE CALIBRATIONS

Authorized Calibration and Repair Center for:

- Rion
- Ono-Sokki
- Scantek Inc.

We service equipment Manufactured by:

- ACO Pacific
 - Brüel & Kjær
 - CEL
 - Dytran
 - Endevco
 - Fluke
 - G.R.A.S.
 - Hewlett-Packard
 - Larson Davis
 - Metrosonics
 - Norsonic
 - Norwegian Electric
 - PCB
 - Rion
 - Simpson
 - Syminex
 - Quest
 - and others
- (Contact for Details)

FREE INITIAL OR NEXT CALIBRATION, COMPLIMENTS FROM WCCL.

YOUR COST OF THE INSTRUMENT WILL BE MANUFACTURERS LIST PRICE.

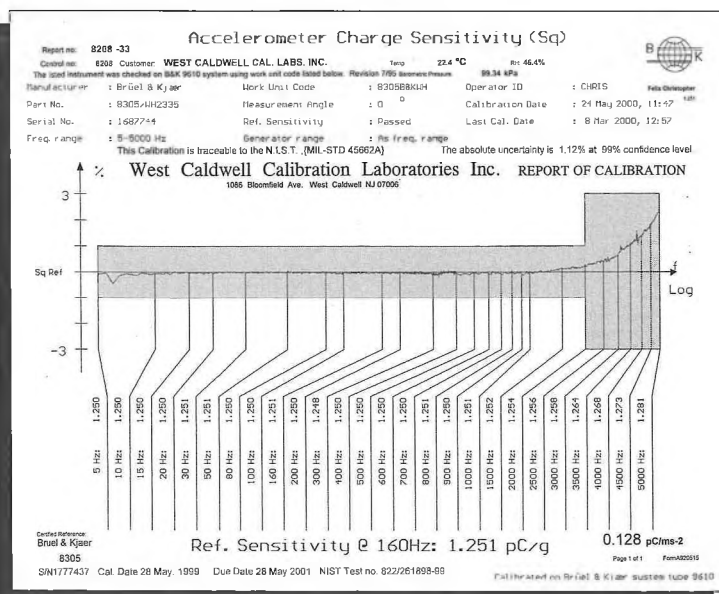
We will be pleased to order for you, any instrument from the following manufacturers:

ACO PACIFIC
BRUEL&KJAEER
CEL
DYTRAN
ENDEVCO

G.R.A.S.
LARSON-DAVIS
METROSONICS
NORSONIC
NORWEGIAN ELECTRIC

PCB
RION
SYMINEX

SAMPLE REPORT & CERTIFICATE:



West Caldwell Calibration Laboratories Inc.

Certificate of Calibration

for

ACCELEROMETER

Manufactured by: BRUEL & KJAEER

Model No: 8305/WH2335

Serial No: 1687744

Calibration Recall No: 8208

Submitted by: FELIX CHRISTOPHER

Customer: WEST CALDWELL CAL LABS INC.(USA)

Company:

The subject instrument was calibrated to the indicated specification using standards traceable to the National Institute of Standards and Technology or to accepted values of natural physical constants. This document certifies that the instrument met the following specification upon its return to the submitter.

West Caldwell Calibration Laboratories Specification No. 8305/WH2335

Upon receipt for Calibration, the instrument was found to be:

Within (X) see attached report.

the tolerance of the indicated specification.

West Caldwell Calibration Laboratories' calibration control system meets the requirements, MIL-STD-45662A, ANSI/NCCL Z540-1, IEC Guide 25 and ISO 9002

Calibration Date: 24-May-00

Calibration Due: 24-May-01

Certificate No: 8208-33

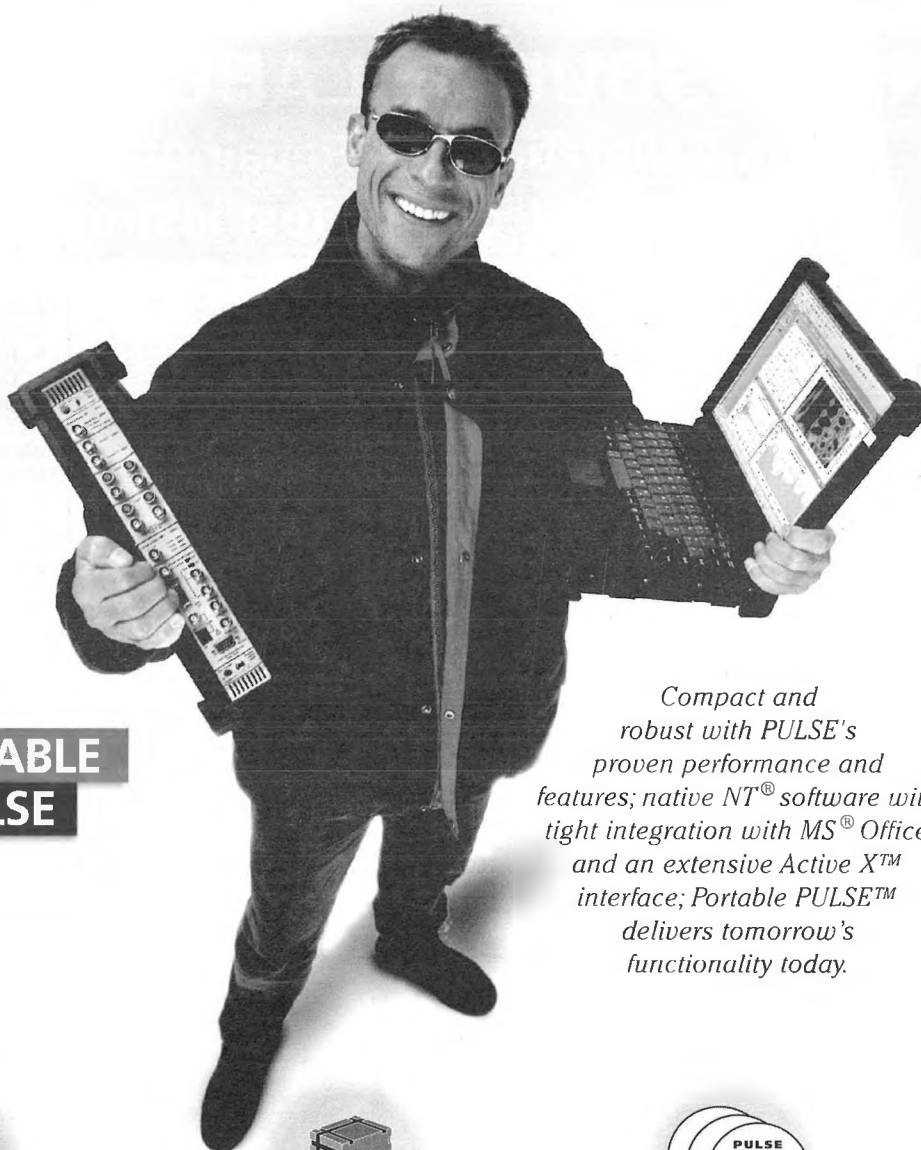
Approved by: Felix Christopher
Quality Manager

West Caldwell Calibration Laboratories, Inc.
1085 Bloomfield Avenue
West Caldwell
New Jersey
07060

Telephone
(973) 860-4900
Fax
(973) 860-0207

Free yourself!

Brüel & Kjær PULSE - the Multi-analyzer goes portable



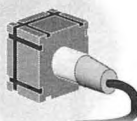
**PORTABLE
PULSE**

*Compact and
robust with PULSE's
proven performance and
features; native NT[®] software with
tight integration with MS[®] Office,
and an extensive Active X[™]
interface; Portable PULSE[™]
delivers tomorrow's
functionality today.*



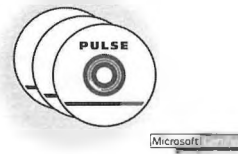
Your PC is your Analyzer

FFT, 1/n-octave and overall level analyzers can run on your PC simultaneously (**multi-analysis**). How? The unique **Analysis Engine** software delivers scalable real-time signal processing performance from your PC processor without additional DSP hardware (Minimum PC requirements: 300 MHz Pentium II, 128MB RAM, 4GB Hard disk).



Intelligent Front-end

Portable PULSE's front-end supports **transducer ID** (TEDS) according to IEEE P1451.4, with which the system automatically detects and identifies connected transducers. No more setting up channel sensitivities or entering transducer type into the measurement set-up - it's all done automatically! You just **Plug'n'Play!**



Part of the PULSE family

Open, modular and scalable, the Brüel & Kjær PULSE family is your sound and vibration measurement platform of the future. Start anywhere and add applications, channels and processing resources as your needs grow. And all this comes at a price that will pleasantly surprise you.

Capabilities

- 4 input and 2 generator output channels (2-6 channel configurations to follow)
- DC to 25.6 kHz on input channels
- Gap free recording of time data to PC disk (TTD)

Analysis types supplied as standard

- Octave analysis (CPB): 1/1, 1/3, 1/12, 1/24-octaves along with overall levels
- FFT: Up to 6400 lines of both baseband and zoom analysis
- Overall levels: 7 different broadband quantities

Battery operation

Typical 3 hours battery life with continuous operation on 4 channels, replaceable without interrupting the measurement.

PULSE features

- Drag and drop reporting in Word
- Tight integration with Excel
- Data export in all common formats

PULSE applications

- Sound Intensity
- Noise Source Identification
- Sound Quality
- PULSE Bridge to MATLAB[™]
- PULSE Bridge to ME'scope[™]
- Vold-Kalman Order Tracking Filter
- Modal Test Consultant[™]
- Time Capture

HEADQUARTERS: DK-2850 Nærum · Denmark · Telephone: +4545800500 · Fax: +4545801405 · <http://www.bk.dk> · e-mail: info@bk.dk
USA: 2815 Colonnades Court · Norcross, GA 30071 · Toll free: (888) 788-1138 · <http://www.BKhome.com> · e-mail: BKinfo@SpectrisTech.com
CANADA: 90 ch. Leacock Drive · Pointe-Claire, Québec H9R 1H1 · Telephone: (514) 694-8522

Australia (02)9450-2066 · Austria 0043-1-8657400 · Brazil (011)5182-8166 · Canada (514)695-8225 · China (86)1068029906 · Czech Republic 02-67021100
Finland (09)755 950 · France (01)69906900 · Germany 06103/908-5 6 · Hong Kong 25487486 · Hungary (1)2158305 · Ireland (01)4504922
Italy (02)57604141 · Japan 03-3779-8671 · Republic of Korea (02)3473-0605 · Netherlands (0)318 559290 · Norway 66771155 · Poland (22)8409392
Portugal (1)4711453 · Singapore (65) 377-4512 · Slovak Republic 421754430701 · Spain (91)3681000 · Sweden (08)4498600 · Switzerland 01/9436070
Taiwan (02)7139303 · United Kingdom (0181)954-2366
Local representatives and service organizations worldwide

Brüel & Kjær