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Sound exposure among the Finnish National Opera personnel

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Abstract

The purpose of the study was to determine how and when the personnel of the Finnish National Opera are exposed to noise and whether exposure depends on musical selection of repertoire. Additionally, an evaluation of sound exposure level due to individual rehearsals was included.

The measurements were done using individual noise dosimeters and fixed-point measurements. From the measurements, annual noise exposure in the Opera was evaluated. The conductors, dancers, and double bass players were exposed to levels below 85 decibels, A-weighted (dB(A)), which is the national action level. The choir members were exposed to sound levels of 92 and 94 dB(A). Within the orchestra, the highest sound exposure levels were found among percussionists (95dB(A)), flute/piccolo players (95 dB(A)) and brass players (92-94 dB(A)). Other sound exposure levels among orchestra members varied from 83 to 89 dB(A). Soloists and rehearsal pianists are likely to be exposed to sound levels exceeding the national action level.

From an exposure perspective, the individual rehearsals (79-100 dB(A)) proved to be as important as performances and group rehearsals (82-99 dB(A)) among orchestra musicians and choir singers. The ambient sound level for the lighting crew was 76 ± 4dB(A). However, the measured sound levels at the ear varied from 77 to 92 dB(A) due to the communication via headphones that had individual volume control.

For the majority of personnel of the Finnish National Opera, sound exposure level exceeded the national action level value of 85 dB(A). Artists exceeded the action level during both individual and group rehearsals, as well as during performances. Hearing

protection has been designed for musicians. Education/reinforcement is required to ensure it is worn.

Keywords: classical music, musician, hearing loss risk, choir

Introduction

Classical music is known to expose performing artists to elevated sound levels. In one of the earliest studies conducted in the sixties, Lebo and Oliphant[1] measured sound levels of two rock n' roll-bands and one symphony orchestra. The sound levels of the symphony orchestra were around 90 dB(A) during loud passages, whereas the sound levels of the rock n' roll-band exceeded 110 dB(A). The measurements were done at a fixed point in the centre of the orchestra. The study did not consider the exposure time, and thus annual sound exposure could not be evaluated.

Westmore and Eversden measured sound levels of a symphony orchestra[2]. The measurement time totalled 14.4 hours, and from that 3.51 hours exceeded 90 dB(A), and 0.02 hours exceeded 110 dB(A). The microphone was mounted in a stand at the height of 1 meter in different locations near the musicians. The highest peak sound levels were out of range for the sound meter, and no annual sound exposure was evaluated.

Jansson and Karlsson measured sound levels for three orchestras during performances[3]. They divided classical music into "heavy" and "light" music, and presented according to these two categories the safe playing time for musicians. No individual rehearsals were measured. Even though the results showed that the sound

exposure levels exceeded the national action level, Jansson and Karlsson did not consider classical music harmful. This was due to a second study, in which the hearing of 392 musicians was measured and compared to the reference material. The study led to the conclusion that there are no significant hearing differences between the two groups[4].

Royster et al. measured hearing thresholds of 59 musicians and examined equivalent continuous sound pressure levels of the Chicago Symphony Orchestra[5]. Noise-induced hearing loss was detected in 52.5 percent of the participants. The equivalent sound level ranged from 75 to 95 dB(A). This study did not evaluate individual rehearsals in detail, but four measurements with a violin and a viola were obtained. Findings from this limited sample suggest that individual rehearsals should be further studied and included in the overall sound exposure construct.

Utilizing noise dosimeters, Sabesky and Korczynski measured the individual noise dose of the Winnipeg symphony orchestra members[6]. Equivalent continuous sound levels varied at group rehearsals from 88 to 90 dB(A), in the orchestra pit from 85 to 86 dB(A), and on the main stage from 82 to 88 dB(A). Peak levels exceeded 140 dB(A). No individual rehearsals were included, and therefore the evaluated sound exposure level is likely an underestimate.

The sound exposure of a professional opera singer has not been widely studied. Measurements reported in some studies, have shown elevated sound levels: the most

common readings ranged from 80 and 85 dB, with a peak level of 115 dB, occuring when two choirs were measured. However, the nature of the choirs were not specified (e.g. professional, amateur)[7]. A- weighing was not used in measurement. If the choirs consisted of amateurs, results were likely to be higher for professionals. A professional classically trained tenor can generally sing 10-12 dB louder than an amateur[8]. No sound exposure measurements were conducted.

This project started after the Finnish National Opera musicians complained of temporary ear ringing after performances of a modern atonal opera, 'Insect life' (Hyönteiselämää), by Kalevi Aho. After a preliminary survey, the administration of the National Opera decided that a full survey of the personnel's noise exposure should be conducted.

Materials and methods

The personnel's sound exposure was initially evaluated by measuring A-weighted equivalent continuous sound pressure level (L_{AEq}) (either an equivalent sound level of measurement, or for the group, the arithmetic mean of the equivalent sound levels were calculated). If based on measurements, harmful sound levels could be expected, the average sound exposure level for a year ($L_{AEq,a}$) was evaluated as follows:

$$L_{AEq,a} = 10\lg(\frac{1}{T}\sum_{i=1}^{2}10^{L_{Ai}/10}t_i) \qquad (1)$$

where T is 1500 hours, i=1 group rehearsals and performances, and i=2 individual rehearsals, and t_i exposure time respectively. Selected individuals were provided with

dosimeters. They were asked to turn on the dosimeter each time they played. Each individual was instructed how to mount the microphone properly. Thus the error of an individual measurement is approximately 5 dB and the error of the group mean is smaller. In order to differentiate the location and/or type of exposure, each subject kept a record, which identified whether they engaged in individual rehearsals, group rehearsals or a performance.

The orchestra (65-88 members) was divided into ten groups based on their instrument (table I, figure 1). The number of subjects in each group is shown in table I. The sound level for each group was measured during individual rehearsals, group rehearsals, and performances. A total of 87 measurements were taken. The exposure time was evaluated based on the opera's work schedules, which provided the time spent on each of the above mentioned activities. The orchestra had no specified rooms for individual rehearsals. Nonetheless, individual rehearsals were mostly done at the opera house in small rooms with no sound absorbing material. Group rehearsals were done in a large room dedicated for these purposes, or in the orchestra pit.

The choir (45-60 members) was divided into bass, tenor, alto, and soprano singers (table II, figure 1). The sound level was measured for nine tenors, seven basses, six sopranos, and seven altos during individual rehearsals, group rehearsals, and performances, for a total of 66 measurements taken. The exposure times were evaluated based on the choir members' personal record keeping. As the records serve as a work list to the employee they are accurate to 10 % level. The measurements were

conducted during six group rehearsals or performances, in which the choir’s role was significant. During the Opera 'Insect life' (Hyönteiselämää), fixed measurement points were placed on the main and side stages in locations that correspond to typical working zones during the performance. The choir had a single room for individual rehearsals with absorbing material on two of the walls and the ceiling. Group rehearsals were conducted in any room large enough to accommodate the group.

Single measurements were done among technical personnel, soloists, rehearsal pianist, conductors, and ballet dancers (figure 1).

Sound levels of one rehearsal pianist were measured during two rehearsals in different rooms while training the soloists. In the first measurement, there were 2 and 3 singers present (soprano, tenor, and bass; bass part time, and no dosimeter) and during the second measurement one singer (soprano). Sound levels of the rehearsal pianist and the soloists were measured by a noise dosimeter (Larson & Davis 705, 706) in two rehearsal rooms. Both rooms had absorbing material on two of the walls and the ceiling.

Equivalent sound levels were recorded using a dosimeter (Larson & Davis 705). The microphone was located on middle of the left or right shoulder of the test subject. In the case of string instruments and harps, the microphone was positioned on the opposite shoulder.

The fixed point measurements were conducted using the dosimeter (Larson & Davis 705). Dosimeters were mounted on a stand at the height of 1 meter (m). The location of each dosimeter was selected to give a representative sample of the area.

Technical personnel are exposed to the noise from instructions coming through the headphones. To assess this exposure, one miniature microphone (Sennheiser KE 4-

211-2) was mounted under the headphone at the ear canal entrance (8 measurements). A second was mounted on the

shoulder of the technician. The sound was recorded on a DAT-recorder (Sony TDC-D8) via 2-channel pre-amplifier and analysed using a digital signal analyser (B&K 2133). L_{Aeq} was calculated for one-minute sequences. In addition, dosimeters were used to measure the ambient levels (11 measurements on a person, 11 fixed points). All these results were combined to give the sound exposure.

Results

Insert Figure 1 about here

Single measurements

The sound levels at the conductor's location (figure 1) varied between 80 and 88 dB(A) based on the work. The highest levels were observed during 'Swan Lake' (86 dB(A)) and 'Die Walküre' (88 dB(A)). Levels for the modern opera, 'Insect Life' (Hyönteiselämää), were at 83 dB(A). The mean sound level for the rehearsal pianist was 95 dB (A) and for the soloists, the tenor, 97dB(A), and the soprano 105 dB(A) .

The sound levels to which dancers were exposed were measured for two works: 'Swan Lake' represented a classical ballet, in which the orchestra played in the orchestra pit, and 'UR', a modern ballet in which music was played from a tape. Both works are considered to be very loud. In 'Swan Lake', two dancers wore the meters during so-called walking roles (figure 1). The average sound levels were 73 and 77 dB(A). For

‘UR’, the sound level varied in different locations (8 fixed points) of the stage ranging from 80 to 83 dB(A).

The exposure of the members of the lighting crew were measured in their typical workstations (the mixing table, beside the stage, and at the lantern control (figure 1)). The sound level measurement of the lighting crew using the headphones varied significantly. During the measurement the ambient noise level due to music exposure were 76 ± 4 dB (A); however, the noise level under the headphones varied between 77 and 92 dB(A). This difference was attributed to varying the volume control settings by the technician during the measurement.

Measurements of the choir and orchestra

The sound levels and sound exposure level of the choir are provided in table II. The sound levels during the individual rehearsals were considerably higher than during group rehearsals and performances (figure 1). According to record keeping, an annual average of 1300 hours (h) was used for group rehearsals and performances, and 200 hours for individual rehearsals. Individual rehearsals comprised approximately 13 % of the total singing time. However, they were the major source of exposure for all groups except for sopranos where both rehearsals and performances were equally important.

Table I around here

Sound levels, and sound exposure levels for different instrument groups of the orchestra are shown in table I. During performances and group rehearsals, sound levels varied between groups from 82 dB(A) for the double bass players to 98 dB(A) for flute/piccolo players (figure 1). For individual rehearsals, the highest levels were found among percussionists and flute/piccolo players. During individual rehearsals, the lowest sound level was found among double bass players (79 dB(A)). Apart

from the double bass players, both the individual rehearsals and group rehearsals exceeded the national action level of 85 dB(A). There is a large variation on weekly activity due to the seasonal character of the work. To overcome this problem annual sound exposure levels were calculated. They were lower than sound levels during various activities. This is due to the fact that the musician's average daily working time was around 5.5 h/day instead of 8 h/day used in occupational noise exposure evaluation (table III).

Table II around here

Table III around here

Possibilities to reduce the sound exposure by technical means were evaluated by an experienced industrial hygienist [(9)]. The evaluation revealed that the rooms for personal rehearsals were not appropriate for this purpose. They were too small and the reverberation time was too long. The orchestra pit was very small. Orchestra rehearsal hall was large and the distances between players were considerably longer than in the pit, up to 2.5 m.

Discussion

In the Finnish National Opera the dancers, conductors and double bass players were not exposed to sound levels exceeding 85 dB(A). For other groups, such as choir,

soloists, orchestra and technical personnel members, higher sound exposure levels occurred during individual and group rehearsals, as well as during performances. In addition, results of this study show that individual rehearsals are a significant source of exposure. In fact, it was the main noise exposure source for the choir members, percussionists, woodwind instrument players except for the flute/piccolo players, brass players, and harp players.

The largest differences between sound levels at individual rehearsals and performances and group rehearsals were found with the choir. Although only 13 % of the singing time was utilized at the individual rehearsal, it was the major source of exposure. This was mainly due to the fact that at choir rehearsals the sound power was 6 to 20 times higher than at group rehearsals and performances.

According to the Finnish legislation, if the noise level exceeds 85 dB(A), the employer must develop a Hearing Conservation Programme (HCP). In HCP the first task is to evaluate the sources of noise and the possibilities to reduce the levels by technical means. If reduction of the noise source is not possible, the workers should be provided with Hearing Protective Devices (HPDs), and the workers should be informed about the risks and the correct use of the selected HPDs in an appropriate way. The use was charted with a questionnaire that was made among the personnel [(9)]. The opera allowed everyone to buy hearing protectors of their choice at Opera's expense. Still, most of the artists did not use HPDs. About 77 % of the artists never used HPDs when playing alone. The use was more frequent at group rehearsals where

most of the artists used HPDs at least sometimes. Only less then three percent used HPDs always. The use of HPDs is not related to exposure. 50 % of the musicians exposed to over 90 dB(A) never used HPDs while over 90 % of musicians with exposure less than 90 dB(A) used at least sometimes HPDs in performances/rehearsals. These rates are very low compared to the self-reported symptoms: 19 % of the orchestra and 41 % of the choir informed that their hearing had worsened in the latest audiometry performed. These results indicate a serious lack of education and training causing poor motivation in the use of HPDs.

In the Opera five types of HPDs were used: Danalink ER-15, Elacin ER-15/25, E.A.R Ultratech, E.A.R. Classic. The four first types have uniform attenuation, are designed for musicians. Applying the HML check - method of EN 458-1993[(10)], the level inside HPD (table IV) can be evaluated using the M-index, and results in tables I and II. According to EN 458, the attenuation is good if the level inside the hearing protector is 75-80 dB(A), and acceptable if the level inside the hearing protector is 70-75 dB(A), or 80-85 dB(A). Table IV shows that best overall products are the E.A.R. Ultratech, and the Elacin ER-15. The Elacin ER –25, and the E.A.R Classic is best suited for trumpet, brass, and percussion instrument players, as well as for singers in individual rehearsals. The Danalink ER-15 is best suited for string instrument players.

Conclusions

In the Finnish National Opera most of the personnel involved with performances is exposed to noise levels hazardous to hearing. This includes the technical personnel

who is mainly exposed via the headphones. Only dancers, conductors and double bass players were not exposed to sound levels exceeding 85 dB(A). Individual rehearsals proved to be as important source of exposure as group rehearsals and performances. The best way to reduce exposure is HPDs that attenuate approximately 15 dB. However, most of the artists did not use HPDs. This indicates that special attention should be paid to the motivation of the artists and technical personnel. For technical personnel HPDs with limited audio input where purchased. This reduced their risk of noise exposure to minimum.

This study increased the interest of Opera personnel considerably. A hearing protection group was established. The purpose of the group is to evaluate the possibilities to reduce exposure by technical means. The group has been existed approximately one year; no concrete results can yet be shown. However, the group has still regular meetings, and produce suggestions on this topic.

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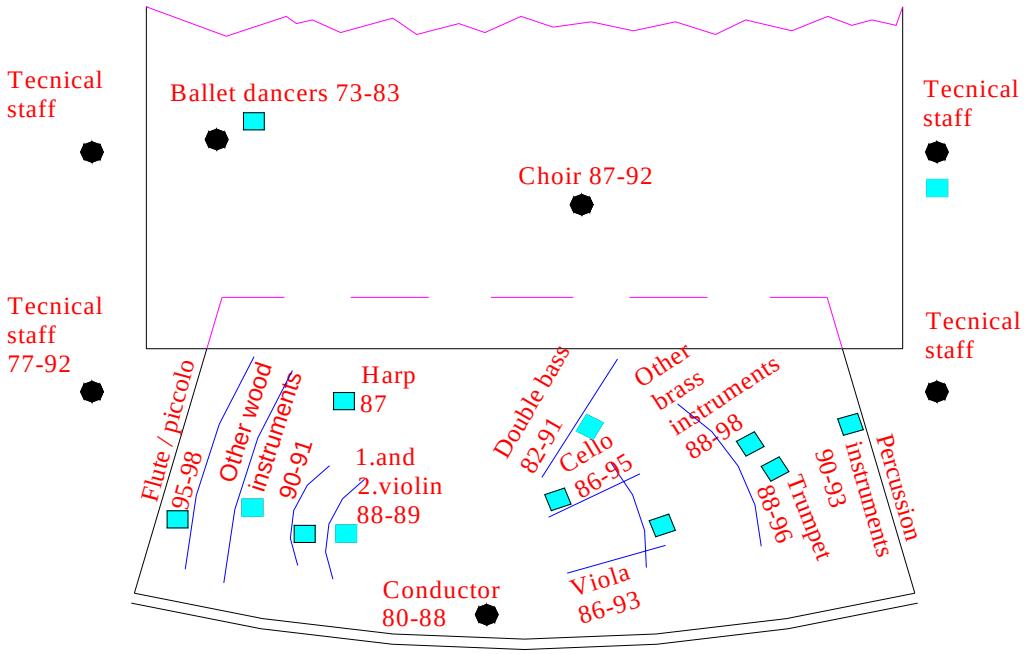

Figure 1. Measurements during performances/group rehearsals. On the figure is shown the measurement technique (circle = fixed point measurements, box = dosimeter measurements), location of groups, and typical measurement result. The drawing is not in scale.

Table II. The sound levels during rehearsals and performances and the sound exposure level for the choir

Group	Sound pressure level (SPL): group rehearsals and performances [dB(A)]	Sound pressure level (SPL): individual rehearsals [dB(A)]	Sound exposure level [dB(A)] $L_{AEq,a}$
Tenors	87	100	92
Basses	87	100	92
Sopranos	92	100	94
Altos	88	100	92

Table I. A summary of musician's sound levels, and exposure levels. L_{AEqP} is the average sound level for performances and orchestra rehearsals, L_{AEqH} is the average sound level for individual rehearsals, and $L_{AEq,a}$ is the annual sound exposure level. If no range is provided, only one subject was measured. The total number of test subjects is indicated in parenthesis following the group name.

Instrument group	L_{AEqP} [dB(A)] Die Walküre	L_{AEqP} [dB(A)] Insect Life	L_{AEqP} [dB(A)] Don Giovanni	L_{AEqP} [dB(A)] Swan Lake	L_{AEqH} [dB(A)] (range)	$L_{AEq,a}$ [dB(A)]
1. and 2. Violin (4)	89	88	88		86	86
Viola (3)	92	90	86	93	86 (84-88)	87
Cello (4)	90	95	86	88	88	86
Double Bass (4)	88	91	82		79	83
Flute/Piccolo (4)	95	98	97		96	95
Other wood instruments (6)	90	91	91		91 (91-92)	89
Trumpet(2)	96	93	88		97 (93-99)	94
Other brass instruments (9)	93	93	88	98	95 (92-99)	92
Harp(1)				87	89 (89-90)	87
Percussion instruments (3)	93	91		90	99	95

Table III. Working hours for the orchestra (h/year)

Instrument group	Performances and group rehearsals [h/year]	Individual rehearsals [h/year]
1. and 2. Violin	850	520
Viola	770	520
Cello	765	520
Double Bass	795	520
Flute/Piccolo	730	520
Other wood instruments	770	520
Trumpet	770	520
Other brass instruments	750	520
Harp	750	520
Percussion instruments	750	520

Table IV. Calculated sound pressure levels (dB(A)) inside the hearing protectors among various groups in the Opera

Performer	Danalink ER-15, M=10	Elacin ER-15, M=14	Elacin ER-25, * M=24	E.A.R. Ultratech, M=18
1. and 2. Violin	76-79	72-75	62-65	68-71
Viola	76-83	72-79	62-69	68-75
Cello	76-85	72-81	62-71	68-77
Double Bass	69-81	65-77	55-67	61-73
Flute/Piccolo	85-88	81-84	71-74	77-80
Other wood instruments	80-81	76-77	66-67	72-73
Trumpet	78-87	74-83	64-73	70-79
Other brass instruments	78-88	74-84	64-74	70-80
Harp	77-79	73-75	63-65	69-71
Percussion instruments	80-89	76-85	66-75	72-81
Choir: individual rehearsals	90	86	76	82
Choir: performances	77-82	73-78	63-68	69-74

*These values apply to E.A.R. Classic which has the same M-index.