Parametric Method for the Noise Risk Assessment of Professional Orchestral Musicians

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Abstract

Background: The Occupational Health and Safety (OH&S) literature shows that noise could represent a risk factor for professional orchestral musicians. The continuous exposition to elevated noise levels and the particular nature of the activity make necessary an “atypical” OH&S approach, which was identified to be necessarily organizational. Materials and Methods: In this study, a parametric-based method for orchestral exposure assessment and management was developed. The goal was to achieve a predictive tool to involve safety in the decision making of concert season program. Results: A general validation of the method was obtained by the verification of the main parameters’ (repertoire, headcount, and disposition) significant influence on the sound pressure levels produced by the orchestra. Exposure levels comparable to the trends in literature for symphonic orchestras were observed, with criticalities among brass musicians, which was the only group exceeding the upper exposure action values. Conclusion: This research has emphasized that the exposure condition of musicians can be critical and requires the implementation of improvement plans. The study has shown that the predictive analysis can be performed on parameters describing the concert’s emissive characteristics. The future development of research currently under study will focus on the concert’s pieces and the use of parameters as indicators of the exposure context.

Keywords: Exposure assessment, musicians, noise risk, parametric method, sound measurement, symphonic orchestra

INTRODUCTION

In a field where the quality and beauty of sound is the product of the activity itself, the workers of the music sector suffer from the unwanted part of the sound represented by noise. In particular, the professional orchestral musicians are widely recognized to be exposed, other than occasionally, to noise levels exceeding those recommended by the international prescriptions. Therefore, even if this working environment is clearly not a typical industrial scenario, the noise risk factor represents a concrete Occupational Health and Safety (OH&S) issue.

The particular nature of the examined working activity represents a setback for noise risk’s analysis and management procedures. Sound intensity is an essential component of the orchestral performances. This makes necessary an “atypical” approach compared to occupational sectors wherein the sound occurs exclusively for a general worsening of the working environment quality, as annoyance or damage factor. Moreover, the difficulties to limit the source emission and to respond comprehensively with technical intervention, such as sound insulation and personal protection equipment, make necessary the development of new methodologies and an implementation at European and International policy level. The peculiarity not only in the nature of the noise but also on exposure characteristics suggests an organizational approach.

Despite the relevance of this problematic issue, international research and legislation have not been able so far to respond organically to OH&S requirements in this field. For example, referring to Italian technical normative, for the risk assessment, it is required to consider the exposure to “appreciable different” sound pressure levels (SPL) and to...
measure the equivalent continuous A-weighted level and the maximum C-weighted peak sound level over minimum three musical pieces that are representative of the music typologies performed. Consequently, the analysis has to be performed considering the “recurrent week at maximum risk.” For the music sector, this is defined as the “third worst week” in terms of exposition to noise over the past year, supposing that the activity will not be subject to changes in the immediate future.[2] Because a variability of the exposure conditions for each concert season has been observed, a methodology for identifying the third worst week based exclusively on direct measurements of seasonal concerts would not allow to achieve a preventive tool, but merely to an ex post evaluation of exposure. This does not match with the necessity to find suitable organizational actions and with the principle itself of Prevention Through Design, which is the hinge of the entire international OH&S normative framework.

In this study, therefore, a parametric-based method is proposed to assess aprioristically the exposition of professional orchestral musicians. The aim is to achieve a tool to involve safety as a component of decision making of the concert season program. This work was developed in two paths. In the first, the method parameters were identified and analyzed to define the project’s hypothesis; then they were validated through a yearly-scale monitoring of an important European symphonic orchestra. In parallel with the monitoring, the occupational exposition of musicians of the same orchestra was estimated. The assessment was based on the parametric analysis and was realized with a wide campaign of measurements to estimate the weekly exposition levels of musicians, grouped by instrument typology.

**Literature Review**

In literature, several studies on sound propagation dynamics in auditorium and concert halls exist. Those studies were mainly focused to optimize the ambient acoustic[3] and to improve the working conditions for the professional orchestral musicians.[4,5] Related to the specific OH&S topics, the epidemiological and risk assessment and management studies are less frequent.

The researches showed that musicians were exposed to high noise levels and were at risk for hearing loss.[1] Studies showed higher levels for the whole orchestra in the orchestra pit[6] than on stage disposition.[7] In the pit case studies, the range of the equivalent continuous A-weighted sound pressure levels was never observed under 83 dB(A), with a maximum of 94 dB(A) among brass and woodwinds.[8] Moreover, the pit studies indicated a noise exposure for conductors commonly lower than most of the musicians because of their position above them and at a greater distance from woodwinds and brass.[9]

A research of remarkable interest is the British Broadcasting Corporation (BCC) study “Music, Noise and Hearing” of 2011.[10,11] In this study, measurement campaigns from two-session days at BBC Maida Vale and Manchester Studio 7 of on-stage rehearsals and studio concerts of classical repertoire were made. Daily noise exposure levels were found elevated, especially for brass, woodwinds, and percussion, which presented comparable values with the studies in the orchestra pit. For strings, the values still remained high but with a wider range of variability and a minimum of 79 dB(A). The BBC’s study characteristics of multisession rehearsal on stage presented some analogies with the present research and made it interesting for a preliminary observation of the exposition dynamics expected in our project.

In general, brass and woodwinds players seemed at maximum risk to noise exposure levels,[1-6,9,12] and percussionists were at the greatest risk of excessive peak sound pressure values.[12] The direct disposition of brass in front of percussions determines the measurement of equivalent continuous A-weighted sound pressure levels higher than other instruments like strings, even though they still can present levels over the action values defined by the international legislation. Despite this risk scenario, the effectiveness of the technical interventions commonly adopted, such as personal protection equipment, was limited. The problem was not related to the intrinsic characteristics of hearing protections and screens but rather to its use by musicians,[13] who avoided its usage for cultural motivations and problematic objective; brass players are least likely to use earmuffs because they report usage difficulties related to the instrument characteristics.[14]

Relying on the results of the epidemiological studies, a correspondence between the exposure limit values’ overcoming and the hearing loss of professional orchestral musicians emerged. On a sampled group of workers, it was observed that musicians exposed to noise at equivalent continuous A-weighted sound pressure levels of 81–90 dB for 20–45 h per week for 40 years of employment might be subjected to a hearing loss (exceeding 35 dB) of up to 26%.[15] Moreover, from surveys and audiometric data collected on a sample of different-age students and professionals, a hearing loss over 15 dB was observed in a frequency range between 4000 and 6000 Hz for most of the 60-year-old musicians. The maximum criticality was identified among strings and brass players.[16]

From the international community researches, a diffuse criticality among different instrument typologies played in the orchestras emerged. For this reason, noise-related health impairments in professional musicians should be accepted as occupational diseases also by the international legislator. Currently, the European regulatory framework provides different procedures for the occupational noise risk assessment and management based on international criteria to grant minimum health and safety requirements.[17] For Directive’s purposes, the exposure limit values and exposure action values, in respect of the daily noise exposure levels and peak sound pressure levels, are fixed at the following: exposure limit values \(L_{EX} = 87\) dB(A), \(L_{\text{peak}} = 140\) dB (C), upper exposure action values \(L_{EX} = 85\) dB(A) and
\( L_{c,\text{peak}} = 137 \, \text{dB(C)}, \) and lower exposure action values \( (L_{\text{EX}} = 80 \, \text{dB(A)} \) and \( L_{c,\text{peak}} = 135 \, \text{dB(C)}). \) For activities in which daily noise exposure varies remarkably for each working day, to apply the limit and action values, the member states might use the weekly noise exposure level. Moreover, following the community standards, the Italian Legislation introduced the concept of “recurrent week at maximum risk.” If exposure varied among weeks, the weekly noise exposure level should be referred to the recurring situation of maximum risk.\(^{[18]}\) For the musical and entertainment sectors, the Italian legislator chose to develop specific guidelines.\(^{[2]}\) This document identifies the recurrent week at maximum risk as the third worst week in terms of exposure over the year, supposing the activity does not suffer significant variability. The effectiveness of this definition results is limited because of the variability of the context as discussed on this study. An example of weekly exposure levels for different instrument’s typology was also reported within the guidelines.

**Hypothesis**

From an analysis of the emissive source, intended as the whole orchestra, a daily–weekly–annual variability was evidenced. The activity of professional orchestras, in fact, was influenced both by the rehearsal plan and by the concert’s performance to the public, which varied among the different working weeks and the seasons’ program. This meant that the assessment should be extended to sufficiently long-term periods to be representative of the effective exposure of orchestral musicians over the years or that the health and safety technicians must accept a simplified and cautelative approach by assuming the weekly noise exposure level of the recurrent week at maximum risk.

As an alternative to those different approaches, a parametric study of the exposure conditions was developed. The aim was to assess the effective noise exposure of professional orchestral musicians by identifying the variability criteria for the whole phenomena and then by characterizing the specific condition as a result of the modification of the single parameter or a determined set of parameters. The parameters have been identified from the literature review and the interaction with workers and the people involved at various levels in the management of the orchestra.

The parameter assumed to determine the maximum variability in the sound levels produced by the orchestra is constituted by the type of repertoire performed. For more “recent” repertoires, such as romantic and contemporary, higher SPL compared to classical and baroque repertoires were generally found. Within the same repertoire, some variability could be found because of the single composer’s cultural background and historical period. An example is represented by “late romantic” authors like Shostakovich, who lived in a modern period (1906–1975) but was the author of romantic repertoire’s compositions.\(^{[19]}\) It was also noted that the sound levels could be influenced by the artistic choices of the conductor and eventual specificity of the musicians in relation to the represented repertoire.

Another parameter was constituted by the orchestra headcount on stage. This parameter had an incidence both in terms of total number of musicians in the presented concert and as the number of players for each instrument typology. With an increasing orchestra size, generally increasing emissions were expected. At the same time, some instruments could present sound radiation,\(^{[20]}\) which could determine a local impact for both the player and the colleagues arranged along the propagation direction. This may determine a different incidence on sound pressure levels because of variable number of musicians who play “historically-high” instruments (as previously described).

The repertoire and the orchestra size induced modifications on the third analyzed parameter: the disposition of musicians on stage. Because this parameter did not present a universal definition, a hypothesis was proposed for the purposes of the research. The hypothesis was based on an analysis of strings instruments’ sector for the case study orchestra; under the term “standard” were intended, the orchestra configurations consisting of a string section of 16 first violins, 14 second violins, 12 violas, 10 cellos, and eight double basses. On the occurrence of this standard configuration, the disposition of woodwind, brass, percussions, and other instruments (i.e., piano and harp) was assessed. Any other scenario for strings resulted in the orchestra disposition being defined as “nonstandard.”

An assessment method based on a parametric analysis approach, as developed in the research, permitted to quantify in terms of prevention the exposure of professional orchestral musicians by the acquisition of some key data directly obtainable from the program of concert seasons. To develop such a parametric method and act efficiently on work organization, a statistically valid database from long-term monitoring over seasons of concert activity is necessary. In this study, the results obtained in the first phase of the monitoring are reported. Within this step, parameters’ validation to qualify the context and verification of their congruence to the occupational purposes was done. In fact, for the theoretical development of the parametric analysis, it was associated with an annual in situ measurement campaign. The survey was conducted at a single auditorium, to minimize the variability factor from the different morphoacoustic concert hall characteristics as demonstrated by extensive literature.\(^{[21]}\)

**Input Data**

The input data, monthly extrapolated for the development of the monitoring, is reported in this section. The parametric method should produce data for the concert program of the season.

The concert season program represents an input data source that helps to directly extrapolate some parameters and
The characterization of every working context requires the acquisition of the daily/weekly activity program. From this input data, the expected exposure can be derived. However, depending on the represented repertoire and the artistic choices of the conductor, the weekly orchestra activity can vary significantly. It is therefore necessary, for the application of the parametric analysis, to acquire an appropriate number of historical data to predict the real exposure of workers while the variability of the scenarios is likely to make difficult to achieve a quantification, and merely a qualification can be achieved. In this first phase of the research, the weekly exposure of professional orchestral musicians was taken back to the working hours stipulated in the contract [Table 3].

**MATERIALS AND METHODS**

The monitoring was done in the first semester of 2015 for eleven concert weeks at the examined auditorium. Measurements were executed in accordance with the technical standards and by the adoption of three criteria to compare the following different measures collected: observation of the general rehearsal of each concert, measurement of the rehearsal on its entire duration, and placing of a fixed sound level meter at the conductor.

The measurement chain was constituted by a class-1 integrating sound level meter equipped by a microphone extension and mounted on a tripod 2 m high on stage and a meter from the position occupied by the conductor. This position was chosen for its intrinsic nature of receiving all the contributes of orchestra instruments. Equivalent continuous A-weighted sound pressure level time history, sound spectrum, statistic levels, and high-definition recordings of the sound were collected for postprocessing and to be available for the future phases of the research. Results of this first part are later reported in this study.

For the workers exposure assessment and management, dedicated measurements were conducted in parallel with

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**Table 1: Monitored concerts’ program**

| Concert no. | Concert details |
|-------------|-----------------|
| 1           | Shostakovich “Sinfonia n.8 op.65 in do minore” |
|             | Takemitsu “Requiem per archi” |
| 2           | Brahms “Tragiache Ouverture in re min op.81” |
|             | Bartok “Conc. N.3 per pf e orch” |
|             | Rachmaninov “Sinfonia n.2 op.27 in mi min” |
| 3           | Kissine “Post–Scriptum” |
|             | Glazunov “Conc. In la minore op.82 per vl e orch” |
|             | Franck “Psyché et Eros” |
|             | Skrjabin “Poema dell’estasi op.54” |
| 4           | Mozart “Maurerische Trauermusik in do min KV 447” |
|             | Mozart “Requiem in re min KV 626” |
| 5           | Ravel “Conc. per la mano sinistra per pf e orch” |
|             | Ligeti “Lontano” |
|             | Bartok “Musica per archi, percussione e celesta” |
| 6           | Cajkovskij “Conc. In re magg op.35 per vl e orch” |
|             | Rimskij–Korsakov “Shèhèrazade op.35” |
| 7           | Prokofev “Sinfonietta in la magg op.5/48” |
|             | Saint–Saens “Conc. n.1 in la min op.33 per vlc e orch” |
|             | Cajkovskij “Sinf. n.3 in re magg op.29 ‘Polacca’” |
| 8           | Pergolesi “Conc. in sol magg per fl, archi e basso continuo” |
|             | Bach “Suite–Ouverture n.2 in si min BWV 1067” |
|             | Pergolesi “Stabat Mater” |
| 9           | Wagner “Siegfrid-Idyll” |
|             | Strauss “Vier Letzte Lieder” |
|             | Webern “Passacaglia op.1” |
|             | Strauss “Tod und Verklaerung op.24” |
| 10          | Spohr “Sinfonia n.6 op.116 Historische symponie” |
|             | Brahms “Conc. n.1 op.15 per pf e orch” |
| 11          | Ravel “Valses nobles et sentimentales” |
|             | Mozart “Conc. n.23 KV488 per pf e orch” |
|             | Mozart “Serenata notturno KV 239” |
|             | Ravel “Rapsodie espagnole” |
the monitoring period. The investigation comprised the whole rehearsals schedule of three concert weeks. For each rehearsal, the measurements were conducted simultaneously with the use of integrated sound level meters at nine different locations and in accordance with the occupational technical standards.[22] Workers were grouped by instrument typology as follows: violin, viola, cello, double bass, flute, oboe, clarinet, bassoon, horn, trumpet, trombone, tuba, percussion, and harp. In the measurement campaigns, continuous surveys by two fixed stations located among violins group and, in analogy with the monitoring, at the conductor were performed. An example of measurement distribution during Shostakovich’s “n.8 op. 65 in do minore” symphony rehearsal is reported [Figure 2].

To estimate the exposure of musicians, it was chosen to divide the rehearsal sessions into two categories and to derive for each one an equivalent continuous SPL from the measurements. The first category, called “Rehearsal,” included all the sessions at the auditorium except the general rehearsals before the concerts. This type of sessions is highly influenced by the artistic choices of the conductor, which can limit the activity to a single composition, with comments and interruptions, or schedule dedicated rehearsal to specific instrument sections (e.g., only strings or only woodwinds). The second category, defined by the term “General Rehearsal,” consisted of the typical, weekly last practice of the orchestra before the concert representation to the public. This session was dedicated to the execution of the entire concert without interruption, and it represented, after a validation of the measurements, an exposure comparable to the one in which workers were exposed during the public performance.

For the exposure calculation, all the measurements collected for each instrument typology were grouped, and then, for both the types of rehearsal, the equivalent continuous A-weighted sound pressure levels $L_{A_{eq}}$ were derived. Then, $L_{A_{eq}}$ were correlated to their exposure time intervals $T_e$.
the weekly noise exposure levels $L_{EX,w}$ were obtained from the following equation:

$$L_{EX,w} = 10 \log \left( \frac{\sum_{i=1}^{n} 10^{0.1 L_{AeqTi} + T_i}}{T_0} \right)$$

where $T_0$ is the nominal 40-h working week.

In the case study, the exposure time intervals $T_i$ were considered from the orchestral contract. For “Rehearsal,” the exposure time was identified to be 15 h, from the scheduled five sessions of 3 h duration, and for “General rehearsal,” to be 9 h corresponding to the general rehearsal and the two concerts planned each week. The evaluation of the maximum C-weighted peak sound pressure level $L_{c,\text{peak}}$ was referred to the higher value measured during the whole occupational measurement campaign for each instrument typology.

As previously described, the assessment was realized for 3 weeks of working activity. The concerts choice was selected by considering the input data and the exposure scenarios expected from the hypothesis on parameters. Concerts with nonstandard disposition and a limited size of the orchestra were not chosen. The number of brass players and percussionists on stage and in the concerts, which present a major number of different instrument typologies, was also considered. For the exposure assessment, concerts completely made by classical or baroque repertoires were not taken into account, which were characterized by “historically” lower levels, according to the normative definition of recurrent week at maximum risk.

The first analyzed concert was formed by the Symphony “n.8 op. 65 in do minore” of Shostakovich and “Requiem per archi” of Takemitsu. The concert presented contemporary – late romantic repertoire, “standard” disposition on stage, and an orchestra headcount of 91 musicians with six percussionists, including one timpani player, and 11 brass instrument players. The Takemitsu’s composition was limited to the strings section. The second was entirely constituted by a romantic repertoire: Cajkovskij’s Symphony “n.3 in re magg op.29–Polacca,” Sinfonietta “in la magg op.5/48” of Prokof’ev, and Concert “n.1 in la min op.33 per violoncello e orchestra” of Saint-Saëns. The size was 80, with 10 brass and the timpani in a “standard” disposition. The last considered concert week was found for concert 8.

**RESULTS AND DISCUSSION**

From the output of the monitoring, a variability range of the equivalent level at the fixed station between 78.5 and 83.6 dB (A) and peak values between 109.0 and 118.6 dB were observed for each instrument typology.

The minimum equivalent continuous A-weighted level among the monitored concerts was found for concert 8.

**Table 4: Monitoring outputs**

| Concert   | Ti    | $L_{Aeq}$ | $L_{c,\text{peak}}$ |
|-----------|-------|-----------|---------------------|
| Concert n.1 | 02:34:59 | 82.1      | 118.6               |
| Concert n.2 | 03:11:51 | 83.5      | 115.5               |
| Concert n.3 | 02:12:15 | 82.0      | 115.9               |
| Concert n.4 | 01:56:06 | 80.5      | 109.0               |
| Concert n.5 | 02:31:37 | 81.0      | 114.3               |
| Concert n.6 | 01:17:33 | 79.6      | 113.9               |
| Concert n.7 | 02:23:57 | 81.1      | 113.2               |
| Concert n.8 | 02:07:25 | 78.5      | 109.3               |
| Concert n.9 | 02:26:24 | 80.9      | 113.8               |
| Concert n.10 | 02:09:14 | 83.6      | 113.6               |
| Concert n.11 | 02:34:51 | 79.6      | 115.8               |

**Figure 3: Variability range of the equivalent continuous A-weighted sound pressure level for each instrument typology**
Table 5: $L_{\text{Aeq}}$ and $L_{\text{c,peak}}$ values obtained from the exposure assessment measurement campaign at the analyzed symphonic orchestra

| Instrument     | $L_{\text{Aeq}} \text{ Min dB (A)}$ | $L_{\text{Aeq}} \text{ Max dB (A)}$ | $L_{\text{Aeq}} \text{ Mean dB (A)}$ | $L_{\text{c,peak}} \text{ Min dB (C)}$ | $L_{\text{c,peak}} \text{ Max dB (C)}$ | $L_{\text{c,peak}} \text{ Mean dB (C)}$ | $\Sigma$, min |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|------------|
| Conductor      | 74.8                                | 87.4                                | 80.6                                | 104.1                                | 118.6                                | 110.0                                | 2150       |
| Violin         | 75.6                                | 85.1                                | 83.0                                | 105.1                                | 120.6                                | 110.3                                | 2065       |
| Viola          | 72.6                                | 83.0                                | 79.1                                | 105.0                                | 120.0                                | 109.5                                | 715        |
| Cello          | 78.9                                | 90.1                                | 84.7                                | 108.5                                | 119.6                                | 109.0                                | 895        |
| Double-bass    | 74.3                                | 88.0                                | 80.8                                | 107.1                                | 126.5                                | 112.3                                | 790        |
| Flute          | 81.1                                | 91.2                                | 86.5                                | 106.1                                | 125.5                                | 115.2                                | 1535       |
| Oboe           | 82.5                                | 89.3                                | 85.5                                | 107.2                                | 123.6                                | 113.7                                | 1130       |
| Bassoon        | 77.4                                | 91.2                                | 84.1                                | 104.8                                | 128.7                                | 117.0                                | 855        |
| Clarinet       | 79.5                                | 91.4                                | 84.5                                | 106.1                                | 125.6                                | 114.3                                | 1180       |
| Horn           | 81.0                                | 91.9                                | 86.5                                | 113.9                                | 125.5                                | 117.8                                | 995        |
| Trumpet        | 82.2                                | 91.1                                | 85.7                                | 112.5                                | 131.2                                | 119.5                                | 925        |
| Trombone       | 85.2                                | 91.1                                | 88.1                                | 110.7                                | 135.8                                | 124.7                                | 875        |
| Tuba           | 83.2                                | 89.0                                | 85.4                                | 110.7                                | 134.8                                | 121.7                                | 513        |
| Percussion     | 79.8                                | 85.6                                | 82.2                                | 109.8                                | 116.5                                | 112.2                                | 600        |
| Harp           | 83.5                                | 84.4                                | 84.0                                | 111.5                                | 115.5                                | 115.5                                | 165        |

Figure 4: Monitoring trend of the analyzed indicators among different concerts

Figure 5: Correlation among total headcount and equivalent continuous SPL (concerts 1 and 2)

The data confirmed the parametric hypothesis about repertoire (baroque), orchestra headcount (smallest size of 30 musicians), and disposition (“nonstandard” because of strings 8:8:6:4:2). A general verification of the hypothesis on repertoire parameter was also found among the concerts presenting the higher values of the monitoring, such as concerts 1, 2, 3, and 10. In fact, this group of concerts was characterized by contemporary and romantic (n. 1, 2, and 3) or entirely romantic (n. 10) repertoires, which confirmed the expected trend for this parameter.

Even a linear trend was partially respected; a weaker correlation was observed in relation to the total headcount parameter by the results of the monitoring. The comparison among concerts with the same repertoire and disposition and different headcount (i.e., concerts 1 and 2) may demonstrate lower measured equivalent continuous A-weighted sound pressure level for concerts with smaller total headcount [Figure 5].

To investigate the reasons of this result, the number of musicians for each instrument typology and in particular for players of “historically-high” instruments was noted. In addition, this verification did not explain the event. In fact, between the two observed concerts, limited differences on percussions and woodwinds were found (with one more flute, clarinet, bassoon, and percussion for concert 1, which present lower $L_{\text{Aeq}}$) and no variations among strings and brass [Table 6].

Therefore, the typology of pieces represented in the concerts by the observation of the time history measured during the concerts’ general rehearsal was analyzed deeper. In concert 1, the orchestra played two compositions, which were Shostakovich’s Symphony “n.8 op. 65 in do minore” and Takemitsu’s “Requiem per archi.” For concert 2, the program was made by the following three pieces: “Tragische Ouverture in re min op.81” of Brahms, “Concert N.3 per pianoforte e orchestra” of Bartok, and “Sinfonia n.2 op.27 in mi minore” of Rachmaninov. From the concert 1 time history [Figure 6], it was observed that Shostakovich’s Symphony “n.8 op. 65 in do minore” had an equivalent continuous sound pressure level more than 9 dB(A) higher than Takemitsu’s “Requiem per archi.” Assuming the intrinsic difference in sound intensity of the two pieces because of their characteristics (i.e., typology and size), the whole concert’s
Figure 6: Time history correlation between different musical pieces of concert n.1

Figure 7: Sound spectra of concert n.1

| Table 6: Headcount details of concerts 1 and 2 |
|-----------------------------------------------|
|                  | Concert 1 | Concert 2 |
| Violin I         | 16        | 16        |
| Violin II        | 14        | 14        |
| Viola            | 12        | 12        |
| Cello            | 10        | 10        |
| Double-bass      | 8         | 8         |
| Flute            | 4         | 3         |
| Oboe             | 3         | 3         |
| Clarinet         | 4         | 3         |
| Basson           | 3         | 2         |
| Horn             | 4         | 4         |
| Trumpet          | 3         | 3         |
| Trombone         | 3         | 3         |
| Tuba             | 1         | 1         |
| Percussion       | 6         | 5         |
| Harp             | 0         | 0         |
| Total headcount  | 91        | 87        |

| Table 7: Noise exposure for the professional musicians of the analyzed orchestra |
|-------------------------------------------------------------------------------|
| $L_{EX,w}$  | $L_{c, peak}$ |
|---------|---------------|
| Conductor | 80.2  | 118.6 |
| Violin   | 79.4  | 120.6 |
| Viola    | 79.1  | 120.0 |
| Cello    | 83.6  | 119.6 |
| Double-bass | 80.7  | 126.5 |
| Flute    | 84.8  | 125.5 |
| Oboe     | 83.5  | 123.6 |
| Basson   | 84.0  | 128.7 |
| Clarinet | 84.8  | 125.6 |
| Horn     | 85.8  | 125.5 |
| Trumpet  | 85.5  | 131.2 |
| Trombone | 84.5  | 135.8 |
| Tuba     | 84.0  | 134.8 |
| Percussion | 80.7  | 116.5 |
| Harp     | 81.6  | 115.5 |

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equivalent continuous SPL was influenced by the duration of each piece. This was once more highlighted for concerts with more than two compositions.

Relating to the analyses of measurements’ sound spectra, a comparison between concert 1 and concert 2 was done [Figures 7 and 8]. A similar one-third octave bands distribution between the two concerts was observed, in particular for medium–high frequencies and with a general scaling in intensity. From these data, as a first approximation, the choice of the fixed monitoring position could also be validated. In fact, the contribution of all the instruments, and in particular the strings distribution, determined the spectra shape, with no prevalence of specific bands.

In relation to the weekly exposure for musicians of the analyzed orchestra [Table 7], it has been obtained that most of the musicians, divided by instrument typologies, do not exceed the upper exposure action value of 85 dB (A), except for horn and trumpet. However, for none of them has the overrun of the exposure limit value of 87 dB(A) been found. Viola and violin musicians present weekly levels under the lower exposure action value of 80 dB(A). In only one measure of the entire measurement campaign, a peak exceeding the lower exposure limit of 135 dB(C) has been found. This level was obtained for a trombone musician and represents the maximum peak determined for all the instruments typologies. The value is related to a timpani percussion impulsive event during the performance of the general rehearsal of concert 1.

**CONCLUSION**

The study shows a general verification of the hypothesis on parameters. The repertoire considerably influences the sound levels produced by the orchestra. The “headcount” and “disposition” parameters have also been verified, and even some deviations were observed on their linear correlation with equivalent continuous pressure levels obtained. This last assertion could be motivated because of the following evidences that emerged during the development of the research: the variability induced by the choices of the director, the number of musicians for each instrument typology, and the different pieces composing the weekly concert program. An example is concert 11 program, in which Mozart and Ravel compositions are performed for significant variability of all the three main parameters of the research. To ensure a reduction of this variability, further developments will consider in detail the single pieces performed by the orchestra.

The parametric analysis and the validating monitoring have made possible the assessment of the exposure for workers, in accordance with the normative requirements. The results of the study confirm the trends observed in literature for other symphonic orchestras. The exposure conditions of professional orchestral musicians can be critical as among brass instruments, wherein an exceed of the upper exposure action values have been verified. The implementation of improvement plans is once more highlighted and has to take into account the particular nature of the working activity with an organizational approach. An effective intervention, in accordance with the principles of Prevention Through Design, at the programming phase of concert seasons shall not interfere with the relevance of artistic choices. To achieve this goal and based on the previous considerations, further development of the research is currently under study to improve the use of parameters as indicators of the exposure context presented in this study.

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**Conflicts of interest**

There are no conflicts of interest.
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