


Musical Period as a Factor in Exposing Orchestra Musicians to Loud Sounds

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Abstract Numerous studies on noise exposure and hearing loss risk of musicians playing in symphonic or chamber ensembles have been published in the literature. Typically, such studies present data averaged over a specific measurement time during which various repertoire is played, usually not thoroughly analyzed. This often creates concerns that the selection of musical pieces for the measurement may be an important factor determining the sound exposure. Our study was undertaken to examine how the musical repertoire from the classical, neo-romantic and 20th century periods differs in the exposure level (L_{Aeq}) measured near the ears of musicians who play various instruments. The results show that the difference caused by the selection of the repertoire may range from 2 to 6 dB(A), depending on the instrument. In the case of some instruments such a difference may cause a significant change in the physiological load imposed on the musicians' auditory system.

Keywords: music as NIHL factor, musicians' noise exposure.

1. Introduction

Studies on noise exposure and hearing loss risk of musicians began over 50 years ago, and even early studies still bring valuable information (as examples see refs. [1-4]). The body of data collected over the years resulted in the modification of the so called noise directive of the European Union to the form published in 2003 [5]. The EU Directive treats the hearing hazards in the entertainment venues in the same way as hearing hazards caused by industrial noise. Publication of the Directive 2003/10/EC [5] did not terminate the research on musicians' noise exposure which continues up to today (as examples see references [6-15]). Quite extensive reviews of past studies can be found in refs. [6,7]. These studies present data for which played repertoire is known but usually not thoroughly analyzed as to its acoustic content.

The research on sound exposure among musicians often raised questions about the extent to which the measured L_{Aeq} values depended on particular musical pieces being performed, or the historical period from which the music originated. In general, the concerns stating that the selection of musical pieces at the time of measurement is an important factor determining the exposure remain unsolved. The objective of the present study was to determine how the measured L_{Aeq} levels depend on the musical pieces or musical period from which the piece performed during the measurements comes from.

2. Specific selection of material

This research is a subpart of a larger study [14, 15] conducted with the participation of 27 students from the Chopin University of Music in Warsaw. The study was aimed to measure the students' sound exposure under conditions reflecting their typical workday. Students of the Department of Instrumental Studies spend many hours each day either practicing individually or playing as members of chamber and symphony orchestras, jazz bands, and pop music ensembles. Original research was devoted to various daily activities divided into categories ranging from individual practicing to playing in large symphony or wind orchestras. It also dealt with the problem of sound exposure asymmetry between the left and the right ear. In the present study, a part of previous research material is used but the focus is on a factor rarely treated in details, namely the dependence of sound exposure on the music played, either the musical period or particular music pieces.

The music material was subdivided into three periods: classical era of 18th/19th century, neo-romanticism, and the 20th century music. Instrumentalists included players of the flute, clarinet, French horn, trumpet, trombone, violin, viola, cello, double bass, harp and percussion instruments. The corpus of

musical pieces included the works of W. A. Mozart, L. van Beethoven, S. Prokofiev¹, J. Rodrigo¹ as representing the classical music period; S. Moniuszko, A. Dvorak, J. Brahms, A. Glazunov, M. Glinka, F. Poulenc, and J. Strauss for neo-romanticism; I. Stravinsky, D. Shostakovich, L. Bernstein, J. Williams, J. Rutter, R. Bordeau, A. Schoenberg, and K. Penderecki as representatives of the 20th century music.

The measurements were done with the use of two-channel Svantek SV102+ dosimeters, with the microphones mounted on the musicians' arms, symmetrically on both sides of the head, no further away from the ears than 10-15 cm. The sound pressure levels were measured in 1/3-octave bands and averaged for each second of the measurement. Data analysis was conducted using Svantec SvanPC++ software and Matlab environment to obtain the L_{Aeq} values and third-octave sound spectra.

3. Results

The data were analyzed along two major factors. The music period was the major factor considered with arbitrary but rational subdivision into three periods: the classical era, neo-romanticism, and the 20th century music. This subdivision reflects a gradual increase in the number of instruments used in the symphony orchestra. It has to be mentioned that the measurement time devoted to each instrument playing particular repertoire was significantly different from as much as 532 min for the French horn (classical period), 435 min for the violin (neo-romanticism), and 297min for percussion instruments (20th century music) down to 7 min for the trombone in the classical period (see Table 1).

Analyzing particular musical pieces was the second factor considered. The limited amount of data available allowed us for analyzing music material of only three instruments: the trumpet, the trombone and the violin. The results show to what an extent the music of different composers creates a difference in the sound load to performing musicians, expressed by the L_{Aeq} levels.

3.1. Dependence of L_{Aeq} level on the musical period

In the analysis presented in this section all musical pieces of the composers associated with a given musical period were combined together. This approach led to the results presented in Table 1 and Fig. 1. For the trumpet and trombone, the comparison was made across all three periods, for the flute, violin and viola for the classical period and neo-romanticism. The data for other instruments were available only for one particular musical period, depending on the instrument (see Table 1).

Table 1 shows the levels recorded independently for the left and right ears revealing the possible asymmetry in the sound exposure. Figure 1 shows the larger of the levels recorded in the two ears.

Table 1. Left-ear and right-ear L_{Aeq} levels averaged over a given measurement time for music pieces of the three musical periods: classicism, neo-romanticism and the 20th century.

Period	Classicism		Neo-romanticism		20 th century	
	Time [min]	Left/Right ear [dB]	Time [min]	Left/Right ear [dB]	Time [min]	Left/Right ear [dB]
Trumpet	134	93.6/93.4	23	93.9/95.0	86	94.2/95.7
Trombone	7	84.9/82.2	21	95.2/93.8	210	96.3/94.2
Flute	39	95.5/93.1	36	98.3/97.4	-	-
Violin	69	93.7/84.6	435	89.1/85.4	-	-
Viola	75	91.8/85.0	21	92.3/88.2	-	-
Clarinet	-	-	-	-	5	87.5/90.1
French horn	532	84.6/85.9	-	-	-	-
Percussion	-	-	-	-	297	86.1/86.9
Cello	148	84.8/85.0	-	-	-	-
Double bass	-	-	63	79.3/79.8	-	-
Harp	-	-	-	-	65	89.2/87.1

¹ S. Prokofiev's *Classical Symphony* and J. Rodrigo's *Concierto de Aranjuez* were included in the classical music period.

Asymmetry in L_{Aeq} levels among left and right ear is seen for certain instruments, these either held asymmetrically or those with an asymmetric sound radiation pattern. Some effects are related to the influence of the neighboring instruments in the ensemble. A clear asymmetry between left and right ear is seen for the violin and the viola (left ear more exposed) due to close proximity of the instrument resonant body to the player's left ear. A smaller asymmetry is seen for the trombone as the instrument bell is at close distance to the player's left ear. For the same reason a slight asymmetry focusing on the right ear is seen for the trumpet. The right ear asymmetry in the clarinet is likely a result of the placement of the neighboring brass instruments in the orchestra. The asymmetry seen in the present results confirms what was previously seen in the analysis of the whole bulk of data [15], and it is not the major issue in the present study.

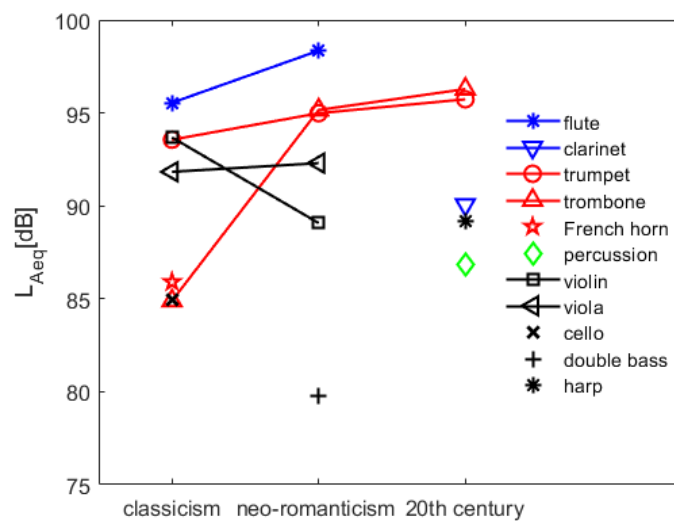


Figure 1. L_{Aeq} levels averaged over music pieces of the three musical periods: classicism, neo-romanticism and the 20th century. Recordings for musicians playing instruments shown in the figure legend.

The data in Fig. 1, depicting the larger L_{Aeq} level out of those recorded in the left or the right ear, show a general change occurring along the three musical periods. As might be expected, a general trend is related to the increase in level as the orchestra size and character of music evolved from the classical period, through neo-romanticism to the 20th century music. This effect is especially pronounced for the trombone, for which the difference between classic and neo-romantic periods is as large as 10 dB, with only slight further increase in the 20th century music. A notable increase by about 3 dB is also seen for the flute between classic and neo-romantic periods, and by about 2 dB for the trumpet. These increase values seem to be small but one has to note that they represent a long term averaging of sound energy produced during the time of playing. Other instruments like the clarinet, harp, or percussion show lower increase levels than those determined for the trumpet and trombone, but the levels are still high. The data in Fig. 1 also show that the French horn in the classical period was used softly not producing high level sound. In the case of strings, the results for viola show an increase in level for the neo-romantic period, as compared to the classical period. This is not the case for violins.

As a brief summary one can see a step increase in levels between classical and neo-romantic periods. The 20th century repertoire does not produce higher levels than that of the neo-romantic period. This is likely related to a large increase in the number of instruments in the orchestra between the classical and neo-romantic periods. Actually, in the 20th century, the musician count in the symphony orchestra did not change much in comparison to earlier neo-romantic music performances.

3.2. The L_{Aeq} levels for selected musical pieces

The data presented in this section attempt to provide information to what an extent various musical pieces differ in the sound levels produced at the musicians' ears. As we entirely relayed on student musician's day-to-day curriculum it was possible to collect a sufficient variety of musical material only for three instruments, the trumpet, trombone, and the violin. Actually, both brass instruments are considered as

producing the loudest sounds among other musical instruments, and the violin displays large sound level asymmetry between the left and right ears.

Table 2. Left-ear and right-ear L_{Aeq} levels averaged over a given measurement time for specific music pieces, for the trumpet, trombone and violin.

Composer/Piece	Time [min]	Left/Right ear [dB]
Trumpet		
L. van Beethoven - <i>Symphonies No. 3 and 7</i>	134	93.1/93.0
A. Dvorak - <i>Slavic Dances</i>	7	95.9/97.8
J. Brahms - <i>Hungarian Dances</i>	7	92.9/93.0
L. Bernstein - <i>Candide</i>	18	93.6/96.4
I. Stravinsky - <i>Firebird</i>	27	94.6/95.4
D. Shostakovich - <i>The Bolt Op. 27</i>	4	93.5/95.1
Trombone		
L. van Beethoven - <i>Symphonies No. 3 and 7</i>	7	84.9/82.2
A. Dvorak - <i>Slavic Dances</i>	21	95.2/93.8
R. Bordeau - <i>Adagio for Wind Orchestra</i>	21	94.1/90.7
A. Schoenberg - <i>Theme and Variations</i>	43	85.3/86.6
D. Shostakovich - <i>The Bolt Op. 27</i>	15	96.8/95.2
I. Stravinsky - <i>Firebird</i>	27	96.0/94.8
J. Williams - <i>Star Wars</i>	110	97.8/95.6
Violin		
S. Prokofiev - <i>Classical Symphony</i>	69	93.7/84.6
A. Dvorak - <i>Symphony No 9</i>	96	84.2/84.6
A. Glazunov - <i>Chopiniana op. 46</i>	47	86.5/84.2
S. Moniuszko - <i>Bajka</i>	29	88.2/86.5
S. Moniuszko - <i>Straszny Dwór</i>	10	90.5/88.6
S. Moniuszko - <i>Jawnuta</i>	60	85.0/85.5
S. Moniuszko - <i>Verbum Nobile</i>	22	87.5/87.9

The results are grouped in Fig. 2 and the details related to particular musical pieces are shown in Table 2. For the trumpet, the range of levels span over about 4÷5 dB from 93 dB for L. van Beethoven's *Symphonies No 3 and 7* and J. Brahms's *Hungarian Dances* to 98 dB of A. Dvorak's *Slavic Dances*. For the trombone, the span of levels is the largest, and of about 13 dB from L. van Beethoven symphonies (85 dB) to J. Williams *Star Wars* (98 dB). This clearly is an effect of the more frequent use of trombones in symphonic music across the 19th and 20th centuries. Finally, for the violin, the differences are of about 10 dB, from 85 dB for Dvorak's *Symphony No 9* to 94 dB for S. Prokofiev's *Classical Symphony*. The *Classical Symphony*, composed in the 20th century, was included in the classical period because of its classical orchestration.

As a general conclusion of the survey of levels produced by various musical pieces it may be noted that, after disregarding certain specific pieces such as A. Schoenberg's *Theme with variations* or early use of trombones by Beethoven, for the majority of cases the span of the L_{Aeq} levels is within 5÷6 dB. This is at least true for the three instruments considered here: the trumpet, the trombone and the violin.

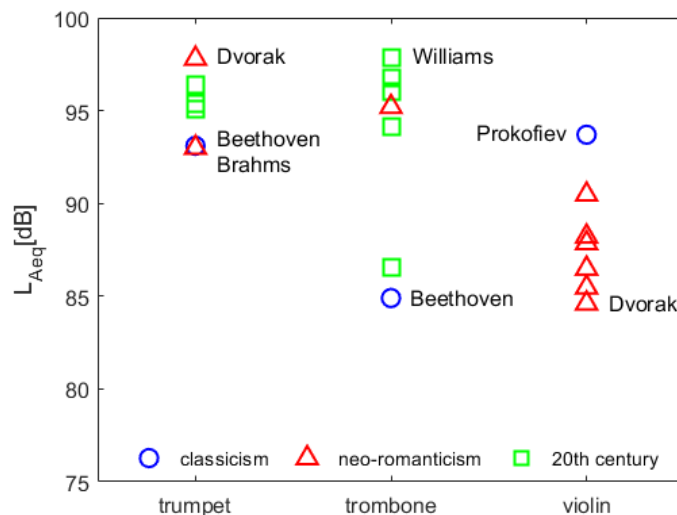
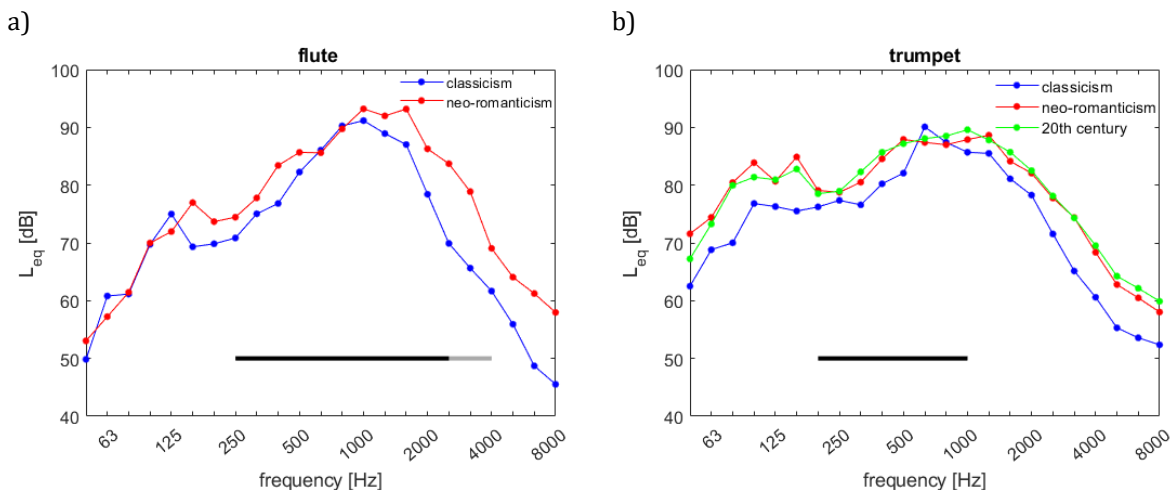


Figure 2. L_{Aeq} levels averaged over music pieces shown in Table 2 for the three musical periods: classicism, neo-romanticism and the 20th century. Recordings for musicians playing the trumpet, the trombone, and the violin.

3.3. Sound spectrum of pieces from different musical periods

There are certain systematic differences in instruments’ long-term averaged spectra obtained for different musical periods. The third-octave spectra for wind instruments are shown in Fig. 3. Different colors in Fig. 3 refer to different musical periods. The horizontal line at the bottom of each panel shows the musical scale of a given instrument. In the case of the flute (Fig. 3a), in frequency bands above 1 kHz, levels larger by about 5÷10 dB are seen in neo-romantic period, comparing to the classical period. This is due to a larger number of instruments used and the inclusion of an octave-higher scaled piccolo flute (see line in grey added to the black line representing the flute scale). For the trumpet and the trombone (Fig. 3b and 3c), there are spectra representing the all three musical periods considered in this study. What is clearly seen is an increase in level in bands above 1 kHz (trumpet) or in the entire frequency range (trombone) for neo-classicism and the 20th century music, as compared to classical period. There is no pronounced difference between neo-classicism and the 20th century music. Again, the changes are clearly related to the quick development of the size of the symphony orchestra in the neo-romantic period as compared to classicism (even for Beethoven’s pieces), with no further change in the 20th century.



c)

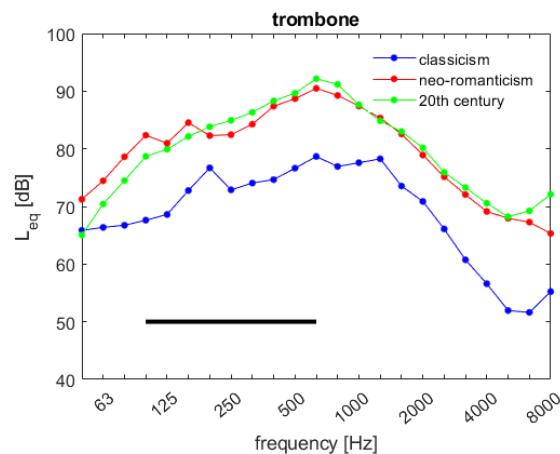
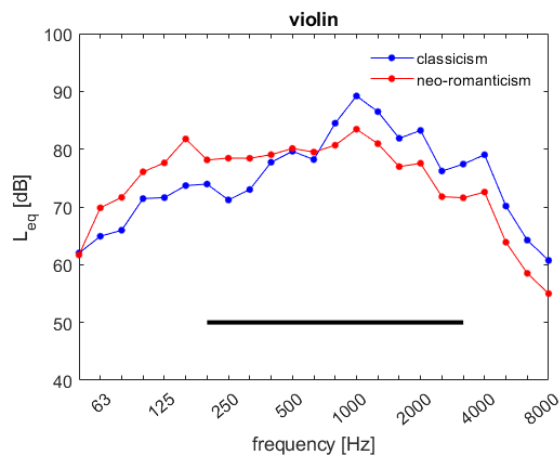


Figure 3. Third-octave levels averaged over music pieces of the three musical periods: classicism, neo-romanticism and the 20th century. Recordings for instrumentalists playing instruments as shown by the figure titles.

Somewhat different results were obtained for strings. Figures 4a and 4b show a comparison of spectra obtained for the classical and neo-romantic periods for the violin and the viola. For the violin (Fig. 4a), there is a decrease in level in high frequency bands and an increase in low frequency bands for the neo-romantic period, as compared to classicism. For the viola (Fig. 4b), there is only an increase in level in low frequency range for neo-romantic period as compared to classicism. The reasons for this particular small change is unknown.

a)



b)

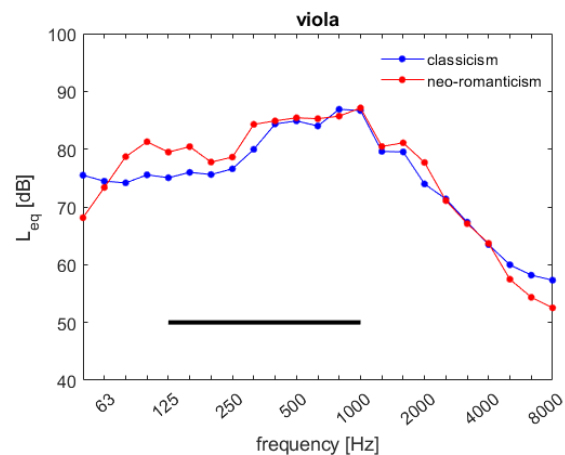


Figure 4. Third-octave levels averaged over music pieces of the two musical periods: classicism and neo-romanticism. Recordings for instrumentalists playing violin and viola.

4. Discussion

The results of this study clearly show the increase in level to which the musicians are exposed when playing music of the 19th-century neo-classical period and analogously playing the music of the 20th century as compared to the classical 18th/19th musical period. The two more recent periods do not much differ in the size of the orchestras in terms of the number and the use of instruments, and both much differ in the number of instruments in each section from the classical period and orchestras used by Haydn, Mozart and Beethoven. Whereas the number of musicians in the classical period, including Beethoven's symphonies (except the 9th symphony) equaled 40 persons (20÷30 strings), in the nineteenth century the number of musicians increased to 60 or over 100 musicians (60÷80 strings). The increase in the number of brass and woodwind instruments was specifically important for the observed sound levels. In the classical period, there are usually two wind instruments of each kind with no trombones and no tubas in the symphonic orchestra. In the neo-romantic period, the number of brass instruments increased to 2÷3 trumpets, 3 trombones, 4÷6 French horns, and 1÷2 tubas. Woodwinds increased to 3 flutes (one piccolo) sometimes 4

clarinets and bassoons with a double bassoon. In some pieces of the 20th-century period the number of wind instruments is even larger. This increase in ensemble size throughout the 19th century is the major reason for the increase in measured L_{Aeq} levels. The sound level increase is also due to the change in the articulation of instrumental sounds and much higher complexity of harmonic relations in the chords.

It has to be noted that the measurements considered in this study take into account the sound radiation from the own musician's instrument as well as the sounds arriving from the neighboring instruments. Especially, the brass instruments usually create high levels to musicians playing other instruments, located at close distance to the brass instrument section.

5. Conclusions

The study is a part of a larger study conducted earlier and devoted to measuring sound exposure of musicians in their everyday curriculum activities [15]. The current approach was focused on the problem of how the sound level to which the musicians are exposed depends on the musical period in which the pieces were composed. This is closely related to the size of the musical ensembles the musicians work with. It was found that:

- With arbitrary classification of repertoire into classical, neo-romantic, and 20th century periods, the levels occurring in brass section increase by about 5 dB for post classical periods. There is no large difference between neo-romantic and the 20th century music. There is no significant change for strings.
- Generally, the L_{Aeq} levels are the highest for brass instruments and woodwinds and often exceed 95÷97 dB. However, similar levels can occur for violins and violas for the ear directly exposed to the sound radiated from the resonance body of the instrument
- A quick check of how the L_{Aeq} level depends on the particular musical pieces revealed that for the pieces considered the span of levels is as large as 5÷6 dB, slightly larger for 19th and 20th music than in the classical period. This information, although derived from a limited set of analyzed pieces, provides important input to an often addressed criticism that the measured levels depend on repertoire played during the measurements.
- The third-octave spectral analysis has shown that for music periods later than the classical period there is significant, 5÷10 dB level increase in frequency bands above 1 kHz for brass and woodwind instruments. Such a change was not seen for strings.

Acknowledgments

The study was supported by the statutory grant from the Institute of Radioelectronics and Multimedia Technology.

Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

References

1. E. Jansson, K. Karlsson; Sound levels recorded within the symphony orchestra and risk criteria for hearing loss; *Scandinavian Audiology* 1983, 12, 215–221.
2. J.D. Royster, L.H. Royster, M.C. Killion; Sound exposures and hearing thresholds of symphony orchestra musicians; *The Journal of the Acoustical Society of America* 1991, 89, 2793–2803.
3. H.M. Laitinen, E.M. Toppila, P.S. Olkinuora, K. Kuisma; sound exposure among the Finnish National Opera personnel; *Applied Occupational and Environmental Hygiene* 2003, 18, 177–182.
4. J. Lee, A. Behar, H. Kunov, W. Wong; Musicians' noise exposure in orchestra pit; *Applied Acoustics* 2005, 66, 919–931.
5. Directive 2003/10/EC of European Parliament and of the Council of 6 February 2003: On the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). 17th individual Directive within meaning of Article 16(1) of Directive 89/391/EEC, No L42/40, 2003.
6. I. O'Brien, W. Wilson, A. Bradley; Nature of orchestral noise; *The Journal of the Acoustical Society of America* 2008, 124, 926–939.
7. I. O'Brien, T. Driscoll, B. Ackermann; Sound exposure of professional orchestral musicians during solitary practice; *The Journal of the Acoustical Society of America* 2013, 134, 2748–2754.

8. J.H. Schmidt, E.R. Pedersen, P.M. Juhl, J. Christensen-Dalsgaard, T.D. Andersen, T. Poulsen, J. Bælum; Sound exposure of symphony orchestra musicians; *Annals of Occupational Hygiene* 2011, 55, 893–905.
9. M. Pawlaczyk-Łuszczynska, A. Dudarewicz, M. Zamojska, M. Śliwinska-Kowalska; Evaluation of sound exposure and risk of hearing impairment in orchestral musicians; *International Journal of Occupational Safety and Ergonomics* 2011, 17, 255–269.
10. E. Kozłowski, J. Żera, R. Młyński; Sound levels on stage during performances of music school symphony and wind symphony orchestras; *The 20th International Congress on Sound and Vibration*, Bangkok, Thailand, 2013.
11. M. Jasiński, A. Pietrzak, J.H. Shin, J. Żera; Exposure of music students to sound in large music ensembles; *Audio Engineering Society Convention 138*. Audio Engineering Society, 2015.
12. M. Pawlaczyk-Łuszczynska, M. Zamojska-Daniszewska, A. Dudarewicz, K. Zaborowski; Exposure to excessive sounds and hearing status in academic classical music students; *International Journal of Occupational Medicine and Environmental Health* 2017, 30, 55–75.
13. A.P. Pietrzak; Musicians' daily sound exposure assessed by full-day dosimetry; *Vibrations in Physical Systems* 2019, 30.
14. K.H. Smith, T.B. Neilsen, J. Grimshaw; University student musician noise-dosage study measuring both ensemble and full-day noise exposure; *The Journal of the Acoustical Society of America* 2019, 145, 494–500.
15. A.P. Pietrzak; Musicians sound exposure assessed by the two-channel noise dosimetry; *Doctoral dissertation*, Warsaw University of Technology, 2021 (in Polish).

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