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# The exposure of musicians to sound assessed by two-channel noise dosimetry

Agnieszka Paula PIETRZAK[1]; Jan ŻERA[2]

Warsaw University of Technology, Faculty of Electronics and Information Technology, Institute of Radioelectronics and Multimedia Technology, Nowowiejska 15/19, 00-665 Warsaw, Poland

## ABSTRACT

The sound exposure doses of musicians may significantly differ depending on the ensemble, repertoire and the intensity of their daily professional activity. In solo performance the sound levels are often asymmetric between the two ears, which mostly results from the directional characteristics of the instrument's sound radiation, with only a small effect of reverberation, as the player is exposed to the instrument's sound in the near field. In ensemble playing the sound of all the other instruments is usually the main factor influencing the sound exposure dose. In this study a two-channel noise dosimetry was used to assess the sound exposure doses in the left and in the right ear of music students. The measurements were conducted during rehearsals of chamber music ensembles, symphonic and wind instrument orchestras, big-band, and during individual practicing. The results show an interaural asymmetry in sound level, up to about 6 dB, in musicians playing instruments held asymmetrically to the player's head and in cases when the musicians were exposed to intense sound of the neighboring instruments. It also was observed that the spread of sound levels was larger during individual practicing (78–105 dBA) than in large ensembles (79–99 dBA).

Keywords: sound exposure, noise dosimetry, asymmetric sound exposure

## 1. INTRODUCTION

Studies on the exposure to musical sounds have been conducted for more than 40 years (1) and, among others, resulted in implementing into the Directive 2003/10/EC (2) the same requirements for noise limits and good hearing conservation practice in the entertainment sector as those that apply to industrial branches. This was followed by specific regulations, coordinated with the Directive in each EU member state (in Poland by (3) The Regulation of the Minister of Economy and Labor, of August 5, 2005). However, the effect of exposure to musical sounds, as a factor causing hearing loss, is still being researched in musicians who play classical music. The percentage of musicians who suffer from some degree of hearing loss varies, depending on the study. For musicians or music students who play classical music, this percentage ranges from 30 to 60% (4–8). Other studies, e.g. (9), reported that that hearing loss occurs in a much smaller part, 5-25% of classical musicians, with the largest amount of hearing loss caused by brass instruments. Among musicians who play music of other genres 20-50% of the population have various symptoms of hearing loss. Several studies suggest that the most common hearing problems of musicians are tinnitus, hyperacusis, and diplacusis (10–13).

A large body of research has been devoted to the measurement of sound levels encountered during performances, rehearsals and individual music practice, (e.g. 8,14–19). The reports show that the levels are usually highest for brass instruments (85-105 dB), woodwinds (85-95 dB), and percussion (90-95 dB). Flutist can be affected by levels reaching or exceeding 100 dB (14). In some cases (16), high sound levels, amounting to 108 dB, may occur at the place occupied by the conductor on the stage. Lower levels (85-90 dB) were measured in the string section in the symphony orchestra with the second violins affected by the sound of neighboring wind instruments. The differences between the reported sound levels in music (see 5,20 for a comprehensive review of the literature) depend on the acoustical conditions in which musicians work, on the location of instruments in the orchestra on the

[1] A.Pietrzak@ire.pw.edu.pl
[2] J.Zera@ire.pw.edu.pl

stage, and on the performed repertoire.

Recent studies (20–22) have also employed two channel measurement, separately for the left and the right ear, to estimate the asymmetry in sound exposure expected for such instruments as the flute, French horn, strings, or the harp. In individual music practicing (20) largest interaural exposure differences, with higher sound level in the right ear, were found for the flute (4 dB), the piccolo (7 dB) and the bassoon (3 dB). In the case of the tuba the sound level was higher by 4 dB in the left ear. In orchestral playing (5,21), an interaural asymmetry of sound level was found for the bassoon (3 dB), strings (5-6 dB), French horn (2-4 dB) and the flute (4 dB).

The aim of this study was: (a) to estimate the exposure of musicians to sound during various activities during their typical work day, such as individual practicing, playing in ensembles of different sizes, from chamber ensembles to a large orchestra, and (b) to measure the asymmetry of sound exposure between the right and the left ear, at different overall sound levels.

## 2. MEASUREMENT METHOD

The sound level measurements were carried out with the participation of music students, majors in instrument playing at The Fryderyk Chopin University of Music in Warsaw (FCUM). The group included students who played the flute, clarinet, trumpet, trombone, percussion, harp and the double bass. For all of them a full day two-channel noise dosimetry was performed to assess the sound exposure. The students were provided with a personal two-channel noise dosimeter, and the two microphones were mounted on their arms, on both sides of the head. The dosimeter was used to record the equivalent sound level, $L_{eq}$, and the waveform (for later analysis) during all their activities, such as individual playing and playing in various instrumental ensembles. Before setting the day on which the measurements will be conducted the students were asked to specify the days during which represent their typical activity at the university, in terms of the number of hours and type of classes. The students were also asked to fill out a questionnaire in which they specified the instrument they played, the type, and the start and the end time of each activity.

The measurements were carried out with the use of two Svantek SV 102+ personal dual-channel dosimeters, equipped with SV 25D microphones, suitable for mounting on the arms, by attaching them to the clothes. The dosimeters were calibrated with a Brüel & Kjaer 4231 calibrator. The microphones were mounted on the musicians' shoulders, as symmetrically as possible, and as close as possible to the ear. In the case of certain instruments, the microphones were somewhat shifted to the back of the shoulder because the way the musician was holding the instrument prevented the placement of the microphones on the top of the shoulder.

The instruments tested included: the flute, clarinet, trumpet, trombone, tuba, percussion (drums), harp, and the double bass. This work is in progress and other instruments (i.e., French horn, bassoon and instruments of the bow family) will also be tested. The data analysis was done for five types of students' activity: individual (solo) practicing, playing in a chamber ensemble (quartet, quintet, etc.), playing in a large symphony orchestra (usually FCUM student symphony orchestra, 40-80 musicians, depending on the repertoire), in a wind orchestra (FCUM student wind orchestra, 40-80 musicians), and in the FCUM student big-band (40 musicians, use of sound reinforcement).

The analysis of data was carried out using the Svan PC ++ program, which is a standard software for post processing of data obtained from the SV 102+ dosimeter. The material was first checked for the presence of artifacts, such as overloads caused by accidental hitting of the microphone by the musician. For each measurement condition A-weighted equivalent sound pressure level in 1-s time intervals was determined, separately for the right and the left ear. The interaural level difference was determined for each $L_{Aeq,1s}$ value using the calculation scheme in the Matlab program.

## 3. RESULTS

### 3.1 Monitoring time

Table 1 shows the percentage of time the instrument players have devoted to various types of activities, calculated in reference to the total time of monitoring. The overall data (column marked 'Avg.') indicate that the musicians spent 42% of their work time on individual practicing. However, this distribution is uneven across the instruments. In the case of five instruments (flute, clarinet, trumpet, trombone and percussion) for which the data exceed 10 hours of recording, individual practicing accounted for 26-28% (percussion and flute) to 47-50% (tuba and clarinet) of the time of

monitoring. If we assume that in chamber music playing the musician is much less exposed to the sound of other instruments than in large ensembles, such as the symphony orchestra, wind orchestra, and big-band, then it can be estimated that for about 40% of the time musicians play in large orchestras and for 60% of the time they play solo or in small ensembles. An exception from that are the data obtained for the percussionist. The distinction between individual playing and playing in an orchestra or in an ensemble is important; in individual playing the musician is exposed only to the sound of his/her own instrument whereas in the exposure experienced in ensemble playing predominates the sound of neighboring instruments. However, it has to be stressed that in many cases, due to the shortage of practice rooms at the university, the students practice individually in the presence of other students playing in a medium size room at the same time.

Table 1 – Percentage of time devoted to a given activity referred to the total time of monitoring

| | Monitoring time [%][1)] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | flute | clarinet | trumpet | trombone | percussion | harp | double bass | Avg. |
| Individual | 28 | 50 | 42 | 47 | 26 | 60 | 16 | 42 |
| Chamber ensemble | 40 | 32 | 16 | 5 | - | - | 33 | 16 |
| Symphony orchestra | 32 | 4 | 27 | 10 | 64 | 40 | 33 | 22 |
| Wind orchestra | - | 14 | 5 | 19 | - | - | - | 9 |
| Big Band | - | - | 10 | 19 | 10 | - | 18 | 9 |
| Individual and Chamber | 68 | 82 | 58 | 52 | 26 | 60 | 49 | 58 |
| Orchestras and big band | 32 | 18 | 42 | 48 | 74 | 40 | 51 | 42 |
| Number of hours | 10.7 | 21.6 | 19.5 | 33.6 | 13.1 | 4.2 | 5.7 | 108.4 |

[1)] The data obtained for the tuba player were omitted as the recordings were made only during solo playing

### 3.2 Overall levels

The $L_{Aeq}$ levels averaged over dosimeter samples recorded during all measurements are shown in Figure 1. The graph shows the values recorded for all instruments and separately for the left and right ear (these details are not distinctively shown in Figure 1). The highest and lowest values of $L_{Aeq}$ were observed in individual practicing (Figure 1, circles). This confirms that this type of daily activity is not a negligible component of total musicians' daily exposure to sound. It is worth to mention that the two highest values of 104.9 dB and 99.4 dB were obtained, respectively, for the right and left ear of the flutist. The lowest values of 78.4, 79.1, and 80.2 dB are, respectively, for double bass player, left and right ear, and the harpist's left ear. Midrange of considerably high level values of 90.7 to 96.6 dB is occupied by other instruments, mainly woodwinds and brass instruments.

In the case of chamber music (Figure 1, squares) the lowest level of 76.7 dB (left ear) and 77.4 dB (right ear) was also recorded for the double bass player. It is clear that the effect of neighboring instruments in chamber music ensemble was at minimum for this instrument. The highest value of 99.4 dB was obtained for flutist's right ear, and next to it, for the trumpet (98.2 dB, right ear). However, the level measured at the flutist's left ear was 93.8 dB. The difference of about 6 dB between the right and the left ear was same as in the solo playing condition. Thus, the asymmetry of exposure of the left and right ear of flutist was not affected by the presence of chamber ensemble. It is apparent that in chamber ensemble playing exposure of the flutist was by about 5 dB lower than in solo playing what is likely related to the repertoire, less demanding from the flutist in ensemble playing.

For symphony orchestra condition (Figure 1, triangles), the spread of levels is reduced to a range

between 79.2 dB (double bass) and 96.5 dB (flute, right ear). As in previous conditions, the double bass player was less exposed than other musicians for which the level values start from 88.6 dB (harp, right ear). For the wind orchestra (Figure 1, diamonds) the level range is even more compressed to levels from 91.0 to 96.1 dB and, on average, is slightly higher than for the symphony orchestra. These results, however, include data only from three instruments – the clarinet, the trumpet and the trombone. For the big band (Figure 1, crosses), higher level values of 94.5 dB (double bass) to 98.6 dB (percussion) are likely a result of electroacoustic reinforcement of sound on the stage and in the audience area. In contrast to solo and chamber conditions, the musicians are more influenced by the overall sound than by the sound of their own instrument.

In summary, the highest and the lowest levels are at their extremes for the soloistic playing, ranging from less than 80 to over 105 dBA, which is likely due to the repertoire . For large number of musicians in the ensemble, the average level is high but the span of levels is narrow, because of high influence of sound of neighboring musicians.

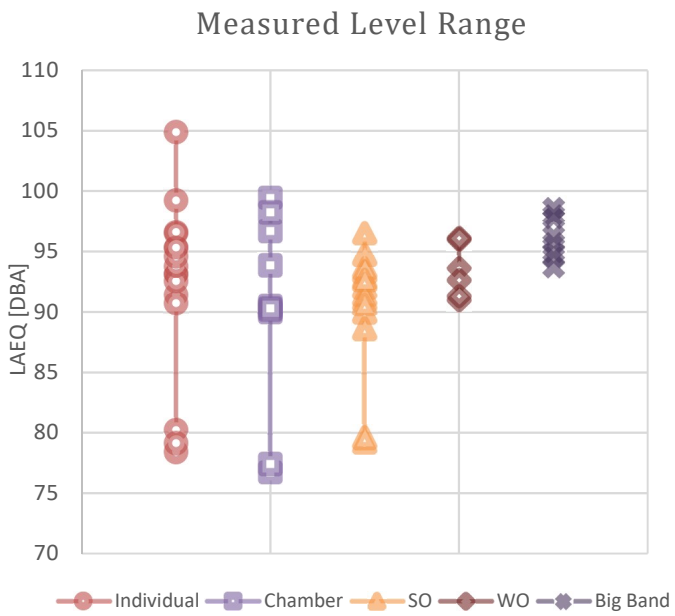


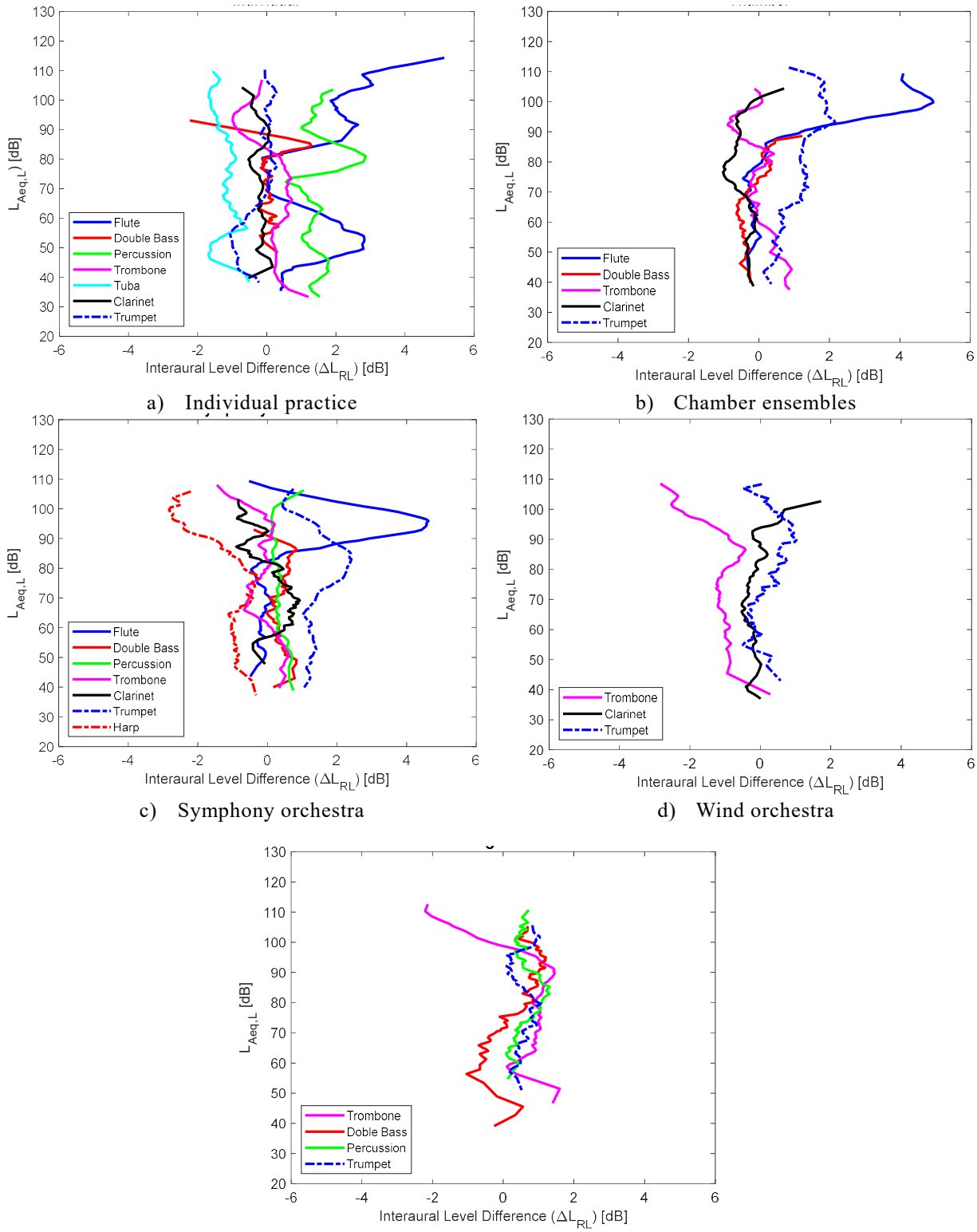

Figure 1 – Ranges of $L_{\mathrm{Aeq}}$ measured for every type of activity

### 3.3 Right-left ear level difference

Panels a-e in Figure 2 show the asymmetry in sound exposure between the right and the left ear. Each panel represents one measurement condition: (a) individual practicing, (b) chamber ensemble, (c) symphony orchestra, (d) wind orchestra, and (e) the big band. Different lines represent the data obtained for different instruments. The asymmetry in sound exposure was assessed by calculating the level difference between right and left ear, $\Delta L_{\mathrm{RL}} = L_{\mathrm{AeqR}} - L_{\mathrm{AeqL}}$. Positive values of $\Delta L_{\mathrm{RL}}$ represent conditions in which right ear was more exposed, and negative $\Delta L_{\mathrm{RL}}$ those in which the left ear was more exposed. The graphs plotted in Figure 2 show how the $\Delta L_{\mathrm{RL}}$ changes with the overall $L_{\mathrm{AeqL}}$ level of samples recorded in the left ear, averaged over 1-s intervals. Thus, the level in the right ear can be obtained by adding the values on the abscissa to the values on the ordinate.

In the solo playing condition (Figure 2a) a different degree of asymmetry in noise exposure (larger than 1 dB) is apparent for the flute, percussion, tuba, trumpet and the double bass. The largest asymmetry, with the right ear more exposed, is seen for the flute at high levels of 90-115 dB. This asymmetry reaches 5 dB for the loudest sounds what may be an indicator of high risk of hearing loss as it occurs for the left ear $L_{\mathrm{AeqL}}$ of about 112 dB, which means that right ear exposure reaches almost 120 dBA.

Percussion is the second instrument in row in terms of the size of asymmetry with the level in the right ear by 3 dB higher (at $L_{\mathrm{AeqL}}$ = 80 dB) exposure. The data for percussion show an asymmetry of 1-2 dB with the right ear more exposed, for the entire range of levels during playing.




a) Individual practice

b) Chamber ensembles

c) Symphony orchestra

d) Wind orchestra

e) Big band

Figure 2 – Interaural sound level difference for various typical daily music activities

The data for the trumpet, tuba, and the double bass show higher levels in the left ear but the difference in level does not exceed 2 dB. For the tuba, exposure of the left ear if consistently larger by about 1 dB at all playing levels, from 40 to 110 dB. In the case of the double bass, largest asymmetry associated with higher level in the left ear occurs for the highest playing levels, 90-93 dB. This asymmetry is likely related to a change in the player's body position during articulation of the loudest instrument sounds. Average difference over all $L_{AeqL}$ levels was 5.7 and 1.5 dB respectively for the

flute and percussion (right ear more exposed), and -1.5 dB for tuba (left ear more exposed). In the case of the remaining instrument the exposure difference was not larger than 0.7 dB.

In chamber ensemble condition (Figure 2b), asymmetry seen for flute player is similar to that observed for the individual condition, with an increase in $\Delta L_{RL}$ to about 5 dB for levels $L_{AeqL}$ between 85 and 110 dB. For other instruments, the pattern of results differs from that obtained in the individual playing condition. Stronger asymmetry with larger right ear exposure is seen for the trumpet, with $\Delta L_{RL}$ reaching about 2 dB for $L_{AeqL}$ exceeding 90 dB, and somewhat larger exposure ($\Delta L_{RL}$ = -1 dB) of the left ear is apparent for the clarinet player for $L_{AeqL}$ exceeding 75 dB, and the trombone at 90-95 dB. The average asymmetry over all levels is 5.6 dB for the flute and 1.5 dB for the trumpet. Differences for other instruments are less than 1 dB.

For symphony orchestra (Figure 2c) significant asymmetry with right ear more exposed remains for the flute player at $L_{AeqL}$ of 90-100 dB. There is also a right ear exposure consistently stronger across levels for the trumpet, with maximum $\Delta L_{RL}$ exceeding 2 dB for $L_{AeqL}$ at about 80 dB. Stronger left-ear exposure with $\Delta L_{RL}$ exceeding -2 dB for $L_{AeqL}$ larger than 90 dB is observed for the harpist. Average differences are smaller than for the previously discussed conditions: 1.8 dB for the flute and -2.4 dB for the harp, with less than 1 dB for the remaining instruments.

As mentioned earlier for the symphony orchestra, there is larger influence of sound of neighboring instruments on an exposure than in the two previously discussed conditions of solo and chamber playing. Whereas for the flutist there is still a dominating right-ear exposure at high levels which must be related to the dominating sound of his/her own instrument, the symmetric exposure at lower levels is due to the influence of other instruments. For the trumpet, consistently larger exposure of the right ear is likely due to the sound of other instruments of the brass section (such as the French horns or trombones). Domination of left ear exposure for the harpist at high levels is likely related with the sound of neighboring instruments (such as percussion or woodwinds) because in solo playing the harpist exposure is more intense in the right ear which is positioned closer to the body of the instrument.

For wind orchestra (Figure 2d) the three considered instruments (clarinet, trumpet and trombone) do not show large left-right ear asymmetry in the exposure, which is due to the overall high level produced by large number of wind instruments. In this kind of orchestra there are no violins, violas and cellos. In transcriptions of symphonic pieces, which are often played, the role of bow instruments is taken over by woodwinds and brass instruments. For instance, as many as 16 clarinets may play the parts of the first and second violins. General high levels occurring during performances produce fused sound and strong domination of sounds of other instruments over the own instrument sound. In the data shown in Figure 2d, strong asymmetry up to $\Delta L_{RL}$ = - 3 dB (left ear more exposed) is seen only for the trombones. The likely reason is that trombone players sit in the last row of brass instruments with percussion instruments on the left side behind them. Overall asymmetry in wind orchestra condition, $\Delta L_{RL,}$ is 1.6 dB for the clarinet player (right ear more exposed) and -2 dB for the trombonist (left ear more exposed).

In the data obtained for the big band (Figure 2e), there is an asymmetry with higher by about 2 dB exposure in the left ear dB at high $L_{AeqL}$ (>100 dB) seen for trombonist, similar to that observed for this instrument in wind orchestra (Figure 2d). It is likely that the reason for this is the exposure to the sound of percussion placed just behind the trombonists. For other data in Figure 2e, there is a slight shift towards right ear being more exposed. This is most likely a result of centrally positioned loudspeaker in the back of the stage used by the sound reinforcement system during the big band performances. For this reason the overall asymmetry in the big band is +0.7 dB (right ear more exposed) except for the trombone in high level condition ($\Delta L_{RL}$ = -1.4 dB, left ear more exposed) due to its position close to percussion instruments.

## 4. CONCLUSIONS

Musicians performing classical music are exposed to high-level sounds, often exceeding 90 dBA, during their typical working day. Such exposure may exceed acceptable daily exposure level of 85 dB.

In solo practice, due to the directional pattern of the instrument and depending on the repertoire, the largest spread of levels occurs, from 78 to over 105 dBA. For large ensembles, the variability in level decreases with increase lowest levels and decrease of the high levels. For chamber ensembles the level range is 77-99 dBA, for symphony orchestra 79-97 dB. In wind orchestra and big band the variability in level is limited to 5 - 6 dB, from 91 to 96 dBA, and from 94 to 99 dBA, for wind orchestra and big band, respectively.

For some instruments, exposure to sound is strongly asymmetric. The right ear is more exposed in musicians playing the flute, the left ear in musicians playing the trombone and the tuba. In the case of other instruments the degree of asymmetry is smaller and depends on the conditions in which musicians play.

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