

# The effect of wearing earplugs on the level and spectrum of performed music

Emil Kozlowski (1), Jan Zera (1,2) and Rafal Mlynski (1)

(1) Central Institute for Labour Protection - National Research Institute, Warszawa, Poland

(2) The Fryderyk Chopin University of Music, Warszawa, Poland

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## ABSTRACT

Exposure of musicians to sound was measured during rehearsals and at a concert of a wind symphony orchestra. The measurements were made with the use of eight microphones in various locations on stage and averaged over the duration of 10 musical pieces. It was found that the  $L_{Aeq}$  values ranged from 83.0 to 106.5 dB. The daily noise exposure levels  $L_{EX,8h}$ , corresponding to the measured levels exceeded 85 dBA in 8, 5, and 6 microphone positions during a rehearsal, the dress rehearsal and at the concert, respectively. Peak C-weighted SPLs ranged from 119.0 to 132.1 dB. These results suggest that musicians are exposed to sound levels that are hazardous to hearing. To study the effect of sound exposure of musicians on hearing an experiment was conducted in which subjects were exposed in the laboratory to recordings of sound that replicated the conditions of exposure on stage. In five subjects, TTS measured after a 40-minute exposure to recordings of seven pieces reached 15 dB. It also was found that TTS could be prevented by using ER 20 Musicians earplugs. At the next stage of the study the feasibility of using earplugs during musical performances was examined. Seven soloists and three music ensembles performed four pieces of music with custom moulded musician's earplugs, with acoustic filters designed to attenuate sound by 9, 15 or 25 dB. Results showed that the use of earplugs had a pronounced effect on the levels and spectra of played sounds. The effect of wearing earplugs was largest for brass players; the change in 1/3-octave-band levels exceeded 15 dB at high frequencies when musicians donned the earplugs. The levels of sounds played without and with earplugs differed by about 5 dB. It also was found that the changes in level and spectrum of sounds increased with earplug sound attenuation. In the case of woodwind instruments the effect of wearing earplugs was smaller than observed for brass instruments. The changes in 1/3-octave-band levels did not exceed 5 dB and the overall level differed by not more than 2 dB. All performances made with and without earplugs were recorded and judged for quality by six experts. The judgments demonstrated that the use of earplugs deteriorates the quality of performance. The influence of wearing earplugs on performance quality may probably be reduced by training.

## INTRODUCTION

Musicians are often exposed to sound levels [1, 2] comparable with those that are encountered in noisy conditions in the industry. Unlike industrial noise music is not an undesirable effect that should be reduced to the possible extent but is the intended product of the musical sector. Sounds of musical instruments may affect the musicians' hearing and cause tinnitus, hyperacusis or even hearing loss [3, 4, 5]. Avoiding the risk hearing loss is of special importance to musicians as good hearing is essential for them to perform their work. One possible way of reducing harmful effects of high sound levels on hearing is to use earplugs. Earplugs may protect the auditory system against excessive sound levels but may also have a negative effect on the quality of the performance of music. The aim of this work was to examine the effect of using earplugs on the sound produced by members of a concert band during a concert and during rehearsals.

## SOUND EXPOSURE LEVELS AMONG MUSICIANS IN A CONCERT BAND

Measurements were performed during a rehearsal, a dress rehearsal and a concert of a concert band comprising 64 mu-

sicians, playing clarinets (14 persons), trumpets (9), horns (9), percussion (6), saxophones (5) trombones (4), flutes (3), oboes (3), bassoons (2), saxhorns (2), tubas (2), double basses (2), the harp (1), the guitar (1) and the piano (1).

## Measurement setup

Measurements were conducted at 8 microphone positions located close to the musicians, in each instrumental group in the band, as shown in Figure 1. Sound recordings were made using five Brüel&Kjaer type 4190, two Brüel&Kjaer type 4944, and one Brüel&Kjaer type 4189 microphones. The signals from the microphones were delivered to two synchronized four-channel Brüel&Kjaer Pulse measurement systems. Equivalent A-weighted, peak C-weighted sound pressure levels (SPLs) and daily noise exposure level ( $L_{EX,8h}$ ) were determined from these recordings using Pulse measurement software Brüel&Kjaer 7771.



**Figure 1.** Wind instrument concert band. Microphone positions 1-8 are shown as closed circles in red



**Figure 2.** Details of microphone 2 position at the French horn musicians

## Results

Results are shown in Table 1. Daily noise exposure levels ( $L_{EX,8h}$ ) were calculated considering 170-, 95- and 80-min duration of, respectively, a rehearsal, a dress rehearsal and a concert. The daily noise exposure levels  $L_{EX,8h}$ , corresponding to the measured  $L_{Aeq}$  shown in the first column of Table 1 exceeded 85 dBA in 8, 5, and 6 microphone positions during the rehearsal, the dress rehearsal and at the concert, respectively. The French horn (microphone 2), flute (microphone 5) and saxophone (microphone 7) players were musicians of the highest exposition to sound. For the French horn players, the source of high sound level was their own instruments and sound of especially loud trumpets (Figure 2). Flutists were exposed mainly to the sound of their own instruments. Saxophonists were exposed at most to the sound of trombones located behind them. The highest  $L_{Aeq}$  level observed during a single musical piece reached 106.5 dB at French horn player microphone position 2 (Figure 2). The limit value of  $L_{Cpeak}=135$  dBC was not exceeded.

## THE EFFECT OF THE USE OF MUSICIANS' EARPLUGS ON THE TTS

Measured levels among band members suggest that musicians are exposed to sound levels hazardous to hearing. To study the effect of music sound exposure on hearing an experiment was conducted in which subjects were exposed in laboratory conditions to sound replicating that produced on the stage. Five subjects took part in this experiment. The TTS

measured after exposition to sound recorded during a concert was used as a measure of fatigue to hearing. In the second part of the experiment, subjects were exposed to sound under the same conditions, except that they were wearing 20-dB musicians earplugs (ER-20).

**Table 1.** Values of  $L_{Aeq}$ ,  $L_{EX,8h}$ , and  $L_{Cpeak}$  measured during the rehearsal, the dress rehearsal and at the concert

Measurement point according to Figure 1	$L_{Aeq}$ , dB	$L_{EX,8h}$ , dB	$L_{Cpeak}$ , dB	
1	rehearsal	93.1	88.6	121.0
	dress rehearsal	91.3	84.3	119.6
	concert	92.5	84.7	119.3
2	rehearsal	97.1	92.6	125.4
	dress rehearsal	99.2	92.2	128.7
	concert	100.1	92.3	131.5
3	rehearsal	92.2	87.7	119.0
	dress rehearsal	92.2	85.2	122.5
	concert	92.9	85.1	119.6
4	rehearsal	92.1	87.6	126.6
	dress rehearsal	91.6	84.6	128.5
	concert	95.4	87.6	129.6
5	rehearsal	93.7	89.2	123.8
	dress rehearsal	95.4	88.4	124.8
	concert	95.6	87.8	123.3
6	rehearsal	91.6	87.1	130.3
	dress rehearsal	91.3	84.3	128.4
	concert	92.7	84.9	127.4
7	rehearsal	95.4	90.9	126.8
	dress rehearsal	96.9	89.9	128.9
	concert	97.5	89.7	132.1
8	rehearsal	94.1	89.6	127.5
	dress rehearsal	92.7	85.7	120.8
	concert	93.4	85.6	120.8

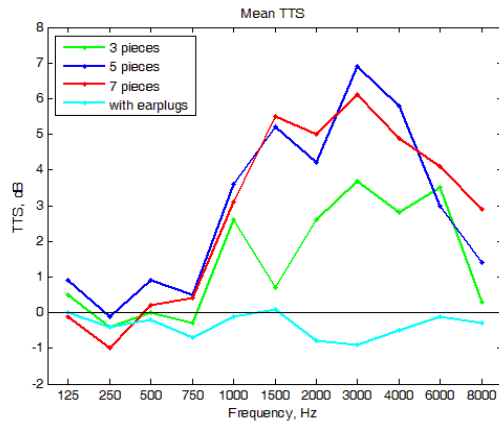
## Measurement setup

A test signal used was that recorded at the concert of a concert band at French horn position (Figure 1, microphone 2, a view in Figure 2). Test signal was reproduced by a system consisting of Dell D630 laptop, the RME Fireface 800 audio interface, the Yamaha YDG 2030 graphic equalizer, the two Crown MacroTech 2400 amplifiers, the JBL DSC 260 limiter, and four JBL SR4722A loudspeakers. Sound level in 1/3-octave frequency bands was kept within 1 dB of the original recording up to a frequency of 12.5 kHz. TTS among subjects was measured in an audiometric booth using an Interacoustics type AC40 audiometer.

TTS was determined after three durations of exposure: 19 min. (three musical pieces,  $L_{Aeq} = 103.4$  dB), 31 min. (five pieces,  $L_{Aeq} = 102.6$  dB), and 40 min. (seven pieces,  $L_{Aeq} = 101.8$  dB). When the ER 20 Musicians earplugs were used TTS was measured after exposure to 40 min. of playing (seven pieces).

## Results

Mean TTS over five subjects is shown in Figure 3. Average TTS exceeded 3 and 6 dB after 19-min. exposition (three) and 31-min. exposition (five musical pieces played), respectively. The mean TTS did not further increase after 7 pieces played because in the last musical piece moderate sound levels were produced. Variability in TTS was much larger for individual subjects and reached 15 dB at 3000 Hz. TTS after exposition to sound when subjects wore earplugs was not larger than 1 dB (Figure 3, line in cyan). Thus the TTS was eliminated by using ER 20 Musicians earplugs.



**Figure 3.** Hearing threshold elevation (TTS) after exposition to three (19 min.), five (31 min.) and seven musical pieces (40 min.) played at a concert of wind instrument concert band at a measurement microphone position 2. Line in cyan shows the TTS when subjects wore ER20 earplugs

## CHANGES IN SOUND LEVEL AND SPECTRUM OF MUSICAL PERFORMANCES WITH EARPLUGS

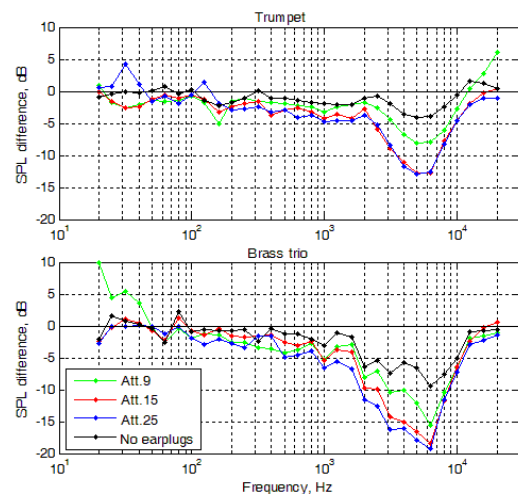
### Measurement setup

Measurements were conducted for seven performances of soloists: a flutist, a clarinetist, a trumpeter, a saxophonist, a violinist, a drummer, and a vocalist, and for the three music ensembles: a brass trio (trumpet, trombone, and French horn), a saxophone quartet (soprano, alto, tenor, and baritone saxophones), and a woodwind quintet (flute, oboe, clarinet, bassoon, and French horn). Four musical pieces were performed in all conditions. Musicians played with no hearing protectors (reference condition) and used silicon custom-moulded musician's earplugs with acoustic filters providing flat attenuation of 9, 15 or 25 dB (ER-9, ER-15, and ER-25 musicians earplugs). Music was first recorded in a recording studio (Brüel&Kjaer 4190 microphone) and then analyzed with the use of a Brüel&Kjaer PULSE measurement system.

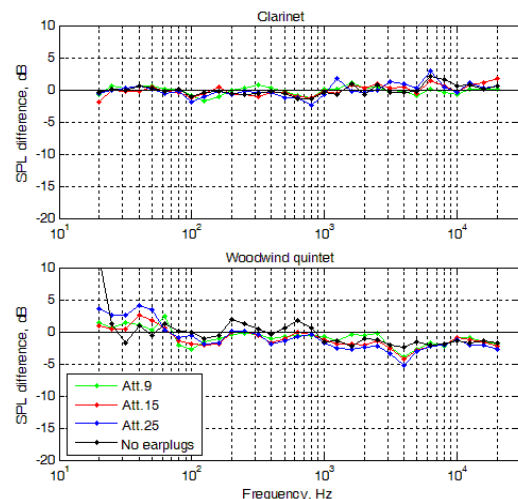
### Results

Effect of wearing earplugs on music performances was examined by comparing sound spectra in 1/3-octave bands and A-weighted sound pressure levels of played music. Musicians first performed music in reference condition without earplugs. Then they repeated the repertoire using 9-, 15-, and 25-dB earplugs. The initial reference condition without no earplugs was repeated at the end of the recording session. This allowed for a control of changes in the performance during the recording session which lasted for about 40 minutes. It also made it possible to monitor changes in playing which might result from previous playing with earplugs attenuating the played music.

Analysis of level differences in 1/3-octave bands between performances with the use of 9-, 15- and 25-dB earplugs and the initial performance without earplugs was done for different instruments and instrumental groups. Examples of such changes for trumpet and brass trio, and clarinet and woodwind quintet is shown in Figure 4 and 5.



**Figure 4.** Change in 1/3-octave frequency band levels for music performed with 9- (green), 15- (red), and 25-dB (blue) earplugs. Difference between final and initial reference conditions (no earplugs) is shown by a black line. Data for trumpet and brass trio



**Figure 5.** Data for clarinet and woodwind quintet. Details as in Figure 4

Large change in 1/3-octave sound pressure levels was observed for the trumpet and the brass trio (Figure 4). There was a systematic fall in level by 5 to 15 dB (trumpet solo) or 20 dB (brass trio) in high frequency range, above 2 kHz. These changes depended on earplugs' attenuation. In contrast, there is quite small influence of wearing earplugs on clarinet and woodwind quintet performances shown in Figure 5. For woodwind instruments, the change in 1/3-octave band levels is less than 4 dB. Results do not show any significant difference in level for performances with the use of 9-, 15- and 25-dB earplugs, and are not frequency dependent as it was for brass instruments in Figure 4. In addition, the observed differences were not larger than the differences between initial and final reference conditions (line in black).

The changes in sound spectra shown in Figures 4 and 5 are only representative examples of either a large or a small effect of wearing earplugs on performed music. Similar large

changes to that of the brass quintet, amounting to 8 dB above 1 kHz, were observed for the saxophone quartet. The reason for that is that saxophones, unlike other woodwind instruments, are controlled by players in a manner similar to that used by brass instrument players. In the control of sound of these instruments by players, feedback obtained by listening to the sound is very important. Other woodwind instruments take advantage from strong acoustic coupling of the reed vibration to the air column in the instrument.

Earplugs also significantly influenced performances of solo saxophonist (change in level of 5 to 10 dB in frequency bands above 1 kHz). Little influence of earplugs occurred for woodwind instruments (flute - 3 dB, piccolo - 4 dB), and a vocalist (less than 5 dB). Playing instruments such as violin, xylophone, and snare drum also revealed small influence of using earplugs on spectrum of produced sound. For all these instruments, musicians likely use some non-auditory motoric-mechanical feedback both feedback in addition to listening to sound to control their performance. All non-auditory control of playing helps in reducing influence of earplugs on playing. A vocalist, for example, usually hears his or her voice through bone conduction what also diminishes the effect of using earplugs.

The A-weighted sound levels were determined, as they correlate with change in loudness among various performances when earplugs were donned or doffed by musicians. Examples of A-weighted sound levels measured for the trumpet, the clarinet, the brass trio, and the woodwind quintet are shown in Table 2.

The highest differences in A-weighted sound levels between performances with earplugs donned and doffed were observed for the trumpet. The level of music played on the trumpet with 25-dB earplugs was lowered by 5 dB. A regular decrease in level for earplugs with increasing attenuation is also observed in these data. Quite similar results were obtained for the brass trio. In addition, all these data showed that A-weighted levels of second performance without earplugs (condition 'e') were lower than those in initial reference condition (a) without earplugs. This shows the importance of the context. After listening to sound attenuated by earplugs musicians performed differently, in comparison with usual conditions without earplugs. In the case of woodwind instruments, with the exception of saxophones, the influence of wearing earplugs was smaller than that for brass instruments.

**Table 2.** Effect of using 9-, 15- and 25-dB earplugs on A-weighted sound level. Column "Final" shows difference in level between final and initial performance without earplugs

	Change in A-weighted sound level averaged over four performances, dB			
	9	15	25	Final
<i>Trumpet</i>	-3.1	-4.2	-4.5	-1.5
<i>Clarinet</i>	-0.1	-0.3	-0.3	-0.7
<i>Brass trio</i>	-2.9	-2.9	-3.9	-1.1
<i>Woodwind quintet</i>	-0.9	-0.9	-1.2	0.4

Change in A-weighted sound level when earplugs were used is shown for brass and woodwind instruments in Table 2. For trumpet and brass trio change in level is about 5 dB. For the clarinet and the woodwind quintet the change in level only occasionally exceeds 1 dB.

## ASSESSMENT BY EXPERTS

All performances were recorded by a stereophonic microphone system and recordings were judged for quality of performance by six experts. Experts had a musical background

or they were practising musicians. Experts did not use any preset parameters and scales. They were free to choose any description of the quality of music performances. Experts knew the conditions under which each sample was recorded, and in particular the earplug used.

Judgments demonstrated that the use of earplugs deteriorates the quality of performance. Use of earplugs by musicians causes changes in musical timbre, intonation, dynamic range, and synchrony within the ensemble. These observed changes were the highest for brass instruments which confirms previous objective assessment of played music.

## CONCLUSIONS

Results obtained in the present study show that most musicians during performance of a concert band (wind instruments) were exposed to sound that exceeded daily noise exposure level limit. The highest sound pressure levels were measured close to French horn players with the dominant noise arriving from neighbouring trumpets.

The results of this study indicate that musicians who often play concerts and practice many hours during the day work in hazardous conditions. In such conditions musicians can feel fatigue of their hearing. TTS, which is a symptom of hearing fatigue, was observed after exposition to sound recordings that replicated the conditions of exposure on stage in the French horn player's position. The results showed that TTS could be prevented by using ER 20 Musicians earplugs.

Results of this study also show that the use of earplugs had an effect on sound of played music. This effect was largest for brass instruments. Changes exceeding 15 dB in 1/3-octave-band levels in high frequency range were observed, and change in A-weighted level close to 5 dB. The likely reason for that is that brass players have a large flexibility in the control of loudness and timbre by listening. Woodwind instruments, due to strong coupling of the reed with the instrument air column do not require such a control by listening to maintain stable playing conditions. In general, using earplugs has only a moderate effect on the sound played on performed instruments that offer means to control sound other than just listening to sound (i.e. mechano-motorical control of sound). This does not mean, however, that artistic quality of performance remains unchanged, and this was reflected in the experts' opinions. It is possible that the influence of wearing earplugs on performance quality may be reduced by training.

## ACKNOWLEDGEMENTS

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