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## Various Aspects of Auditory Fatigue Caused by Listening to Loud Music

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Andrzej Dobrucki, Maurycy J. Kin and  
Bartłomiej Kruk

Additional information is available at the end of the chapter

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### Abstract

This chapter presents results of research on influence of auditory fatigue on some aspects of listening condition measured among various groups of listeners. Three experiments have been carried out. The aim of the first one was to find the influence of the kind of headphones used by young people on their hearing loss. The second experiment was concerning the temporary threshold shift (TTS) caused by the listening of loud musical signals after several time of sound exposure. The main interest of the third experiment was the detection ability of changes in spectrum of musical samples obtained after several time of listening to the loud music. It turned out that except for frequency of 4 kHz there is no relation between the types of preferred headphones and the shift of hearing threshold while for the frequency of 4 kHz, a statistically important influence of the headphone types on the threshold values was observed. The second and third experiments were carried out under conditions which normally exist in a studio or on the stage when the sound material is recorded and/or mixed. It turned out that after several loud music listening sessions the average value of temporary threshold shift reached more than 3 dB for 1 kHz and increased up to 6–7 dB with an exposure time of 120 min. On the basis of results obtained from the third experiment, it was found that the decrease in ability to detect the spectrum changes for longer noise exposure exists particularly for lower changes (of  $\pm 1.5$  dB) and at all frequency regions under investigation. It may suggest that the hearing system gets tired for the region of higher frequencies faster than for other bands after listening to loud music. The results may also be influenced by the mental fatigue which occurred after several time duration of permanently played loud sounds, together with demanding tasks. Such conditions involving the mental engagement in a noisy environment, which is referred to the natural scenery of the studio work can significantly reduce the time of exhaustion which causes the decrease of accuracy in solving several tasks. It should be also noted that the tendencies observed within young people culture in listening loud music in order to be isolated from the environment is actually causing not the TTS phenomenon but permanent threshold shift (PTS).

**Keywords:** listening fatigue, perception of spectral changes, temporary threshold shift

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## 1. Introduction

The act of listening to musical sounds is usually considered as a kind of recreation, or an impulse to take a rest. But the music can also be considered as a noise not only from the musical structure and composers' point of view—in some cases, listening to the music may not be only a kind of recreation—for particular professionals it is their work. Reinforcement and recording engineers as well as sound producers are the examples of a trade in which the listening process and its conditions may reflect in the final quality of the work. The people working in these professions are subjected to hearing problem, in the same manner as the noise-exposed workers in an industry. Of course, listening to the musical sounds is different from a simply industrial noise from the psychological point of view: musical sounds are usually nice and desired while the noise means that a particular signal is assessed as awful and unpleasant. Also, the time-frequency structure of musical signals differs from the consistency of noise which makes listening to music a pleasant act. In the modern entertainment industry, there is one fact which may be considered while talking about the reinforcement of sound, it is the sound focusing techniques which enable to focus energy within a selected region using the special transducers, the line arrays in this case [1]. The energy dose of sound is a basic acoustic variable that determines the magnitude of sound, and the other function of sound focusing technique is to increase the clarity of sound by increasing the magnitude of the direct wave and decreasing the reflections from unwanted directions which result finally in higher sound levels. From the measurement point of view, it is not so simple to determine the actual sound level in all areas occupied by the audience. Moreover, it can be found that the sound level measured by the microphone in a sound field may be different than the level in the ear canal, so the maximum impulsive noise levels were high in the ear canal but the implications for the causes of hearing loss are indistinct because of ear amplification of 3–4 dB in the region of 1–3 kHz [2]. It should be also added that the sound sources (as a loudspeaker set, or PA systems) situated very close to the ear might increase the risk of hearing loss.

It may be fairer to say that working with louder music as well as listening to it over a long period of time may systematically lead to a permanent hearing damage or to a listening fatigue, which makes proper attention being impossible. In the past few years, the trend in sound production industry has been to increase loudness of musical recordings, particularly. Many radio stations as well as record companies have applied large amounts of dynamic range compression and other means of recording process in order to be perceived in today's noisy world. The trend called as "loudness wars" has been reflected in the higher subjective impressions in psychological domain, and the slogan "louder sounds are sold better" has come true [3]. Many young people want to single their minds out of different backgrounds by the use of special kinds of headphones and they listen to the sound material louder, beside the fact that the listened material is louder in comparison to the recordings made in the previous century. Also, the contemporary designed and produced equipment allows the listeners to consume the music in accordance with their way of life [4, 5] and with higher concentrated energy of sound in order to make the proper sensations for the audience [1].

The way of stimuli presentation (via headphones or loudspeaker, or naturally listening of the event) seems to be an important thing causing the hearing loss. Young people do not take into

account that the popular or rock music causes the same effects like the higher and longtime exposure to the noise when the earphones are used for listening, due to the average sound level and duration of exposure which simply leads to a listening fatigue. Young people say, we listen to the music that sounds nicely for us and it is not like noise, so why may it be dangerous for our hearing? Sometimes, one can find many pieces of classical music from the twentieth century which are very loud while performed. As an example, the fourth Symphony of Dmitri Shostakovich if given in some fragments, the sound level exceeds 100 dB in the audience area of the concert hall. The main differences between classical and pop-music are in the time duration of continuous exposure to the sound, a character of musical structure and spectral consistence of stimuli. In popular music, the method used for musical production is very often based on the sound compression, and this compression itself may increase the potential risk of hearing damage [6–8] or a listening fatigue which makes proper attention being impossible.

The typical effect of listening to loud sounds is the temporary threshold shift (TTS) or permanent threshold shift (PTS) which play a huge role in the proper assessment of sound while working in a recording studio. The negative effects of TTS may occur when someone is under the noise, or another loud acoustical signal, exposure for a particular time interval, and then having a rest only after the whole work, without breaks for recreation process. The higher sound levels usually influence human concentration in a negative way, like the chaotic visual structures [9] which are based on psychology of perception. The results of a permanent hearing threshold shift of the people working in the entertainment industry as well as the influence of the kinds of equipment used have been presented [10, 11]. The recommendations of a daily dose of noise for sound makers as well as for musicians are not stated because of the nature of work apart from the fact that it may cause permanent or temporary hearing damages.

Physiological and psychological processes connected to a reaction to sound consist of sensational and emotional reactions. The sensational reaction is the effect of a physiological process, which occurs during listening. It arises when stimuli overdraw sensitivity levels, while the emotional reaction is more complex and difficult to analysis because it is not a direct result of received signal features but depends on the habits and conditions of the listener [12]. Noise related to some activities, for example teaching in classrooms, is correlated with performer's fatigue, increases tension and discomfort, and an interference of teaching and speech recognition [13]. Several studies have been conducted to investigate the effects of noise exposure patterns, including noises of different spectra, interrupted noise exposure patterns, and short-duration noise exposures on TTS in order to find and determine the maximum time duration of acting noise at a particular level, and the resting time, after that the ear can recover to the before-noise-state [14–16]. From these studies, a temporary decrease in auditory sensitivity in normal ear was found after exposure to continuous noise levels weighted by A-curve above 80 dB for long periods. The set of audiograms characteristic for particular hearing loss caused by various types of noise are also presented in the literature and those results can give the directions to the protections in order to avoid the permanent hearing damage. Laboratory studies regarding the human response from noise exposure provide a better control over noise exposure variables, because the TTS—which can be studied under controlled conditions in the laboratory—behaves almost consistently. It is a relatively simple matter to determine combinations of levels, duration, and temporal pattern that produce the same TTS as the standard daily noise dose.

It is known from literature [14, 15, 17, 18] that the greatest effect of TTS occurs first for the range of 2–6 kHz, and this upward shift disappears after a time, usually in 24 hours, but may last as long as a week. If exposure to noise occurs repeatedly without sufficient time between exposures to allow recovery of normal hearing, threshold shift may become chronic, and eventually permanent. This is a specific danger when people who work in noisy environments are exposed to further noise afterward while driving, at home or at places of entertainment.

The facts mentioned above may reflect in an increase of hearing thresholds of the young people consuming today's music in the way that "louder means better". Of course, the higher hearing thresholds induce difficulty in collecting, understanding, and interpreting many information from the human environment which influences the sense of safety and causes the changes in the way of thinking and living together in society. It also may be interesting if the European Standard EN ISO 7029 still remains true in the light of youngsters' way of life and this aspect is the aim of presented research. According to this standard, the hearing thresholds increase with the age of a subject, starting from 0 dB, as recommended for 20-year-old people. The authors' research [10] showed that for young people who use to listen to the loud music via headphones the hearing thresholds have been shifted up to 6 dB. Although such hearing is still qualified as "normal" [19] (see also Section 3.1), according to the EN ISO 7029 this value of hearing threshold shift is typical for 40–50 years-old people. The population of young people with shifted threshold of hearing is growing up year-by-year.

## 2. Description of research

### 2.1. Audiometric tests

The research was aimed at young people (16–25 years old) because they are the most vulnerable to hearing loss caused by frequent loud noise exposure in their own choices. Some of the people are working for the entertainment industry in professional way so they were divided into three groups reflecting their activities:

- young classical musicians or music academy students,
- sound engineers of Front of House/Public Address (FOH/PA) systems and
- sound engineers working in recording studios.

The ordinary young users of portable audio equipment were representative as the reference group for this range of age, so the total number of subjects was more than 80 people. After the interviews and giving instructions, the audibility of people was measured by the means of Maico M 53 audiometers. Audiometric tests were conducted in an anechoic chamber and in the recording studio of the Wrocław University of Science and Technology. These places meet the requirements of maximum allowable amount of background-sound pressure level [20]. Therefore, during the test, any masking phenomenon from outer signals does not occur [20, 21]. Before the measurements all audiometers had been basically calibrated and checked aurally, also they had been calibrated subjectively in accordance with the ISO recommendations.

Threshold of hearing levels were determined by the air conduction audiometry. The measurements were carried out according to the applicable standards [20], by ascending methods and with the use of continuous sinusoidal signals. All measurement points were repeated twice in order to eliminate random errors for some of the inexperienced subjects.

## **2.2. Detection of spectral changes of musical signals vs. TTS**

The detection of spectrum changes of musical signals was the subject of investigation in the first part of research. Sixteen subjects in the age ranging from 22 to 25 years, participated in the experiment and all of them are professional recording or reinforcement engineers. Moreover, they have experience in psychoacoustic experiments. They featured the normal hearing, that is, the absolute threshold was not more than 10 dB HL in the entire frequency range (125 Hz–16 kHz) which has been confirmed by the air conduction measurements with the Maico M53 audiometers. The threshold measurements were carried out according to the applicable standards [20, 22] by ascending stimuli methods and with the use of continuous sinusoidal signals with steps of 2 dB. All measurement points were repeated twice in order to eliminate random errors. Because the described experiment was addressed to the people working with or listening to higher sound levels of the music, the loud music as a disturbing noise typical for musical material in the studio or at the concerts, was presented without any break which reflects a typical way of sound exposure at entertainment event or studio works.

Ten musical pieces had been equalized at octave bands of 125 Hz, 1 kHz, and 8 kHz as center frequencies, with  $\pm 1.5$  dB,  $\pm 3$  dB and finally  $\pm 6$  dB boosts of a sound material. It should be added that these frequencies as well as introduced spectral changes were chosen as typical values of correction parameters in low, medium, and high regions of frequency in mixing consoles often used in live-reinforcement applications. The 10-second samples have been prepared with a digital audio workstation and then recorded digitally by a TASCAM DA-30 DAT recorder. As a trial, test stimuli samples have been presented in pairs, where the first one contained the original (nonequalized signal) and the second one, the processed signal. The time interval between samples was set at 1 s, and between pairs as 2 s. The test samples have been presented via active TLC loudspeakers and played back from DAT recorder. The subjects' task was to answer if these samples sounded the same, or not. Every combination of signal-equalization occurred at least three times because of the statistical significance. The length of the test sequences did not exceed 5 min. The test signals contained pieces of various musical styles (pop rock, jazz, symphony, chamber music, heavy metal, etc.). The musical material used as a disturbing noise contained mostly pop and rock pieces frequently broadcasted in radio stations. The sound pressure levels in octave bands in the range of 63 Hz–4 kHz were practically constant at 87–93 dB and decreased to about 80 dB at 31 Hz and 8 kHz octave bands. These conditions of levels were maintained for both test and disturbing signals. Similar stimuli have been used in other experiments [11] as a reflection of typical distributions of sound pressure levels in musical selections performed by American rock and roll groups. This method of an experimental performance was chosen in order to limit the effect of fatigue of the subjects during the test sequence as well as the fact that listeners' attention should not be devoted on the new audio material. Also, the fixed sample sequence was used with an intention to minimize some artifacts which can appear in subjective assessment and

simply refers to an accuracy increase because the attention of listeners was focused only on the noticeable changes between presented samples, without additional tasks about scaling and identifying the reason of the differences [23, 24].

In this experiment, the TTS phenomenon for the listeners was also the subject of research. The hearing thresholds were measured after every session of music exposure which enabled observation of the TTS caused by listening of loud musical signals in several periods of exposure. In this case, the thresholds of hearing were measured in the same way that at the beginning of experiment, i.e., by ascending stimuli methods and with the use of continuous sinusoidal signals with steps of 2 dB. These measurements were repeated twice.

### 3. Analysis of the results

#### 3.1. Average hearing threshold

Figure 1 shows the values for threshold of hearing for the left and right ear of the population tested before the experiment. These values have been averaged over results obtained for 276 listeners. It can be easily seen that the threshold of hearing is uniformly shifted by about 7–8 dB. In order to confirm the results, various types of statistical testing have been applied. When a calculated value of particular statistics for a tested factor is less than the critical value, depending mainly on the number of repetitions and the level of significance  $\alpha$  (usually stated as 0.05), the influence of this factor is not important from statistical point of view, so it can be fairer to say that this factor does not influence the obtained results. In this case, the Bartlett test has been used. This test features the distribution asymptotic to  $\chi^2$  thus it can be applied even to a small population. This kind of test enables to confirm homogene-

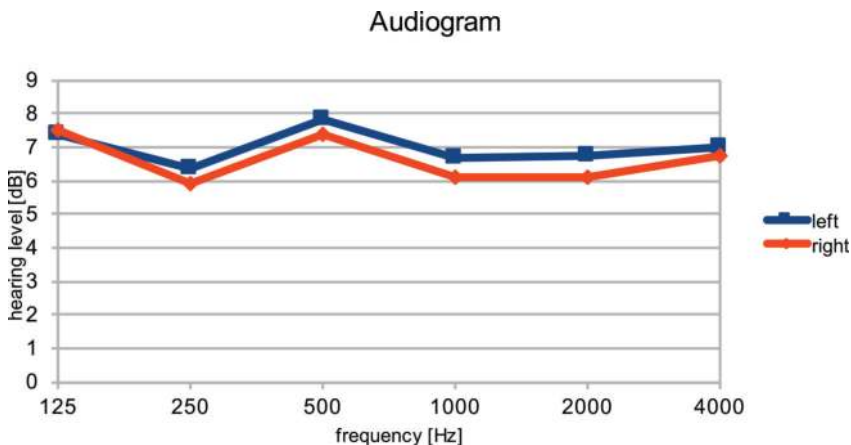


Figure 1. The average values of the threshold of hearing shift for the tested population.

| <i>F</i> (Hz) | 250  | 500  | 1000 | 2000 | 4000 | 8000  |
|---------------|------|------|------|------|------|-------|
| $\bar{x}_L$   | 7.40 | 6.34 | 7.83 | 6.65 | 6.73 | 7.01  |
| $\sigma_L$    | 6.07 | 6.06 | 6.19 | 6.21 | 8.65 | 10.36 |
| $\bar{x}_R$   | 7.52 | 5.93 | 7.36 | 6.12 | 6.09 | 6.74  |
| $\sigma_R$    | 5.70 | 5.44 | 6.00 | 6.82 | 9.86 | 9.81  |

**Table 1.** The average values and standard deviations for hearing thresholds for left and right ears measured for all the 276 subjects.

ity of variances of obtained results, with the assumption that they featured a normal distribution. The results of statistical treatment showed that the variances of obtained results were homogenous ( $\chi^2 = 24.893 < \chi_{\alpha}^2 = 39.977$ , at  $\alpha = 0.05$ ) for all frequencies. According to the classification of the Bureau International Audiophonology [19], five types of hearing loss can be distinguished:

- hearing loss up to 20 dB: normal hearing
- hearing loss in the range 21–40 dB: a mild degree of hearing loss
- hearing loss in the range 41–70 dB: a moderate degree of hearing loss
- hearing loss in the range 71–90 dB: a severe degree of hearing loss
- hearing loss greater than 91–120 dB: very severe hearing loss.

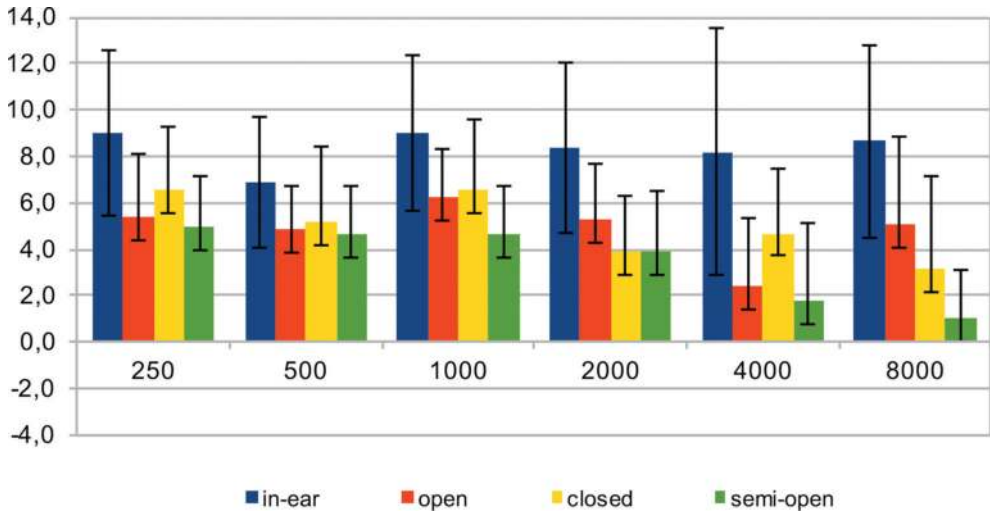
According to this classification, the tested young people belong to the group of normal hearing, but the shift in the threshold of hearing points with the slow tendency to begin a permanent damage of hearing which is caused by a long-term work with loud music (see Section 3.3). These values, however, are the average ones and the greatest hearing losses can be balanced by the results for the people with otological normal values that is shown in the **Table 1** as the values of standard deviations, especially for higher frequencies. Thus, it was decided to divide the whole group into the categories which could influence the obtained results and reflect the hearing loss for some specific conditions of working activity as well as kinds of equipment used by the people.

### 3.2. The influence of different kind of headphones on the threshold of hearing

In this section, results of pure tone audiometry for users of different types of headphones are presented. These results present “the worse” ear (left or right) for each subject, and these values have been averaged over the people who declare to use particular types of headphones. They are shown in **Figure 2**.

It can be seen that the type of headphones used has a major impact on the threshold of hearing values. On the basis of analysis of variance, it was found that for all tested groups of people using different types of headphones and particular frequencies there was a good convergence between all the subjects’ notes and thresholds did not depend on the listener in all cases at





**Figure 2.** The influence of different kind of headphones on the threshold of hearing. Standard deviation values are presented as vertical lines on the tops of the bars.

the 95% of confidence ( $p < 0.02$ ). It was decided to use the  $F$ -Snedecor statistics because of nonequal numbers of particular groups of users declaring the specific kinds of earphones. It turned out that except for frequency of 4 kHz there is no relation between the types of preferred headphones and the shift of hearing threshold ( $F < F_{\alpha} = 2.75$ , where,  $F$  and  $F_{\alpha}$  are calculated and critical values of  $F$ -Snedecor test, respectively, at  $\alpha = 0.05$ ). For the frequency equal to 4 kHz, the influence of the headphone types on the threshold values was observed ( $F = 3.35 > F_{\alpha}$ ). It means that the most unfavorable for the hearing are the in-earphones, especially at high frequencies to which our hearing system is the most sensitive. The air in the ear canal is a natural protection from high-sound pressure. Using inside earphones the length of the channel is reduced, through which natural protection becomes less effective. A good alternative are semi-open headphones that in a small way can isolate us from the outside noise. They additionally ensure good hygiene of the ear and by their design, they protect from very high-sound pressure acting directly on the ear membrane. The results of upward threshold shifts obtained for the 4 kHz frequency are presented in **Table 2**.

In order to determine how the particular kinds of headphones are injurious for hearing conditions, the structure index test as a statistical treatment was applied. This test allows to classify the groups of results as influenced by a particular factor, the kind of headphones and its influence on the hearing threshold values in this case. The results of such testing for these series reflect the degree of hearing damage caused by the type of used headphones, with  $u_{\alpha} = 1.96$  at  $\alpha = 0.05$ . It turned out that for the frequency of 4 kHz the most dangerous type of headphone for the hearing threshold is the in-ear one ( $|u| = 4.73$ ), while an influence of the semi-open is inessential statistically ( $|u| = 1.05 < u_{\alpha}$ ). The degree of injury for hearing damage obtained for the open and the closed headphones are lower than for the in-ear headphones ( $|u| = 2.52$  and  $|u| = 2.12$ , respectively).



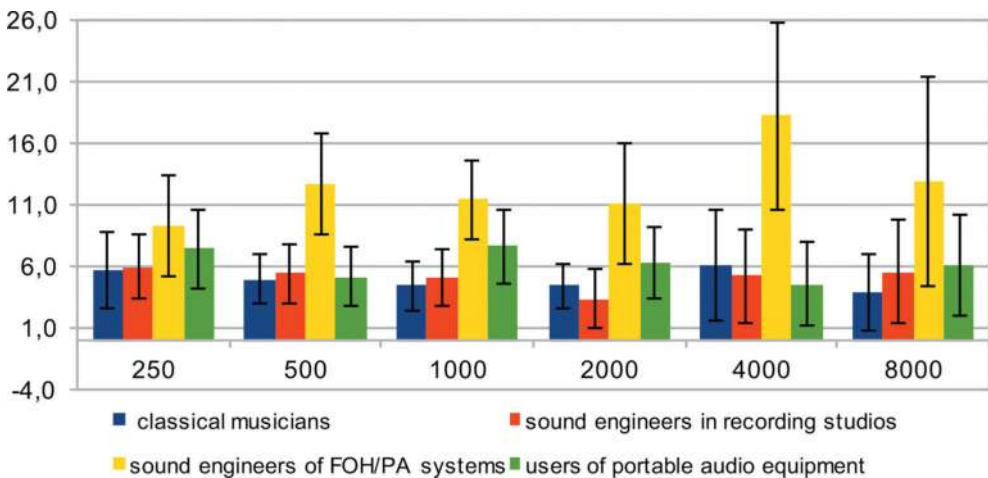
| In-ear | Open | Closed | Semiopen |
|--------|------|--------|----------|
| 8.2    | 2.4  | 4.7    | 1.8      |

**Table 2.** The average values for upward shift of hearing thresholds at 4 kHz for various types of headphones used by investigated subjects (in dB).

### 3.3. Threshold of hearing in terms of professional work

Some of tested people have been working in the profession for 7 years. By analyzing these data, it can be concluded that even 3–4 years of working in the entertainment industry, especially as the front-of-house engineers may cause a slight loss in hearing ability. By comparing other professional groups, it can be assumed that the results coincide in a large extent and the type of work (noise level) has no longer such effect on the threshold of hearing. In **Figure 3**, hearing thresholds are presented depending on the profession. In **Figure 3**, there are also results for the ordinary user of portable equipment – there are the subjects nonpracticing in any kind of sound-engineering profession as well as musicians. These results present “the worse” ear (left or right) for each subject, and these values have been averaged over the people within the particular group of profession as well as “amateur” listeners.

On the basis of analysis of variance, it turned out that for frequency values of 500 Hz, 1 kHz as well as 4 kHz the influence of working activity on the threshold of hearing has been observed ( $F > F_{\alpha} = 3.29$ , where  $F$  and  $F_{\alpha}$  are calculated and critical values of  $F$ -Snedecor test, respectively, at  $\alpha = 0.05$ ). For the other frequencies, there is no relation between the profession of work and the shift of hearing threshold values. As it was mentioned in previous chapter, the hearing loss at 4 kHz can be interpreted as the beginning of permanent hearing damage resulting from the exposure to the sound at high levels while the upward threshold shifts that appeared



**Figure 3.** Thresholds of hearing depending on the profession. Standard deviation values are presented as vertical lines on the tops of the bars.

for lower frequencies (500 and 1000 Hz) are the results of the exposure to hyper-compressed musical sounds in these frequency bands, especially occurring on stage in order to increase the total loudness impression.

### 3.4. Detection of spectral changes vs. auditory fatigue

In **Figure 4**, results of this part of the research are presented. They are expressed as the percentage of correct answer number obtained before and after the loud music exposure. Subjects listened to the test trials containing the introduced several spectral modifications and have to denote if they perceived them. Thus, results may be expressed as a percentage of correct answers in a dependence of degree of introduced corrections for several noise-like exposures. For statistical treatment, the Bartlett's test was applied allowing the confirmation of homogeneity of variances of obtained results. On the basis of this test, for every exposure, the results were homogeneous ( $\chi^2 = 4.922 < \chi_{\alpha}^2 = 28.869$ , at  $\alpha = 0.05$ ). Thus, the obtained results may be averaged over the total number of subjects and over the all styles of musical material. It is clearly noticeable that the differences before and after exposure for particular frequency are significant ( $\chi^2 = 9.103 > \chi_{\alpha}^2 = 5.986$ , at  $\alpha = 0.05$ ).

It can be noted that the decrease in ability to detect the spectral changes for longer noise exposure has been observed particularly for lower changes and all frequency regions. Moreover, the number of false alarms (i.e., the case when the subjects signalized that some correction had been introduced, but no spectral changes have been really done) is less than 5% of the number of total answers at a specific condition which means that listeners mostly have not perceived the small changes in spectra. The changes of  $\pm 1.5$  dB are perceived with detection ability higher than 70% only at the beginning of the test for middle and higher frequency regions. When subjects are exposed to noise for a longer period, their ability to detect changes in the spectrum of musical signals is less effective. For the noise exposure longer than 1 h the ability gets worse, especially for 8 kHz octave band where the only larger ( $\pm 6$  dB) equalization of the musical sounds may be perceived properly. This fact can be explained by the nature of frequency analysis made by the hearing system: this range of frequency is responsible for the proper reproduction of temporal structure of transient sounds [25], and the influence of rise time, especially, for the loudness impression has been reported [26]. The loudness changes may be perceived effectively when the "carrier" sound levels are higher than the hearing threshold of 10–20 dB [27]. When the changes of spectra in this frequency region do not exceed  $\pm 3$  dB the difference of spectrum could be detected less effectively than in other investigated frequency bands because of the lower loudness impression in this region after several times of sound exposure. For octave bands of 125 Hz as well as for 1 kHz, the perceived spectral changes at the level of 70% have been noted for  $\pm 3$  dB, or greater. It may suggest that the hearing system gets tired for the region of higher frequencies faster than for other bands after listening to a loud music. It can be shown that the trend is almost the same for every frequency of notched/boosted bands: when the attenuation, or amplification in a particular octave band increases, the percentage of correct answer reflecting the ability of detection of changes in the spectrum of musical signals also increases. It can also be observed that the differences between obtained values for increasing time of loud music exposure gets lower when the changes in spectra increase: the difference of ability of perception of spectrum

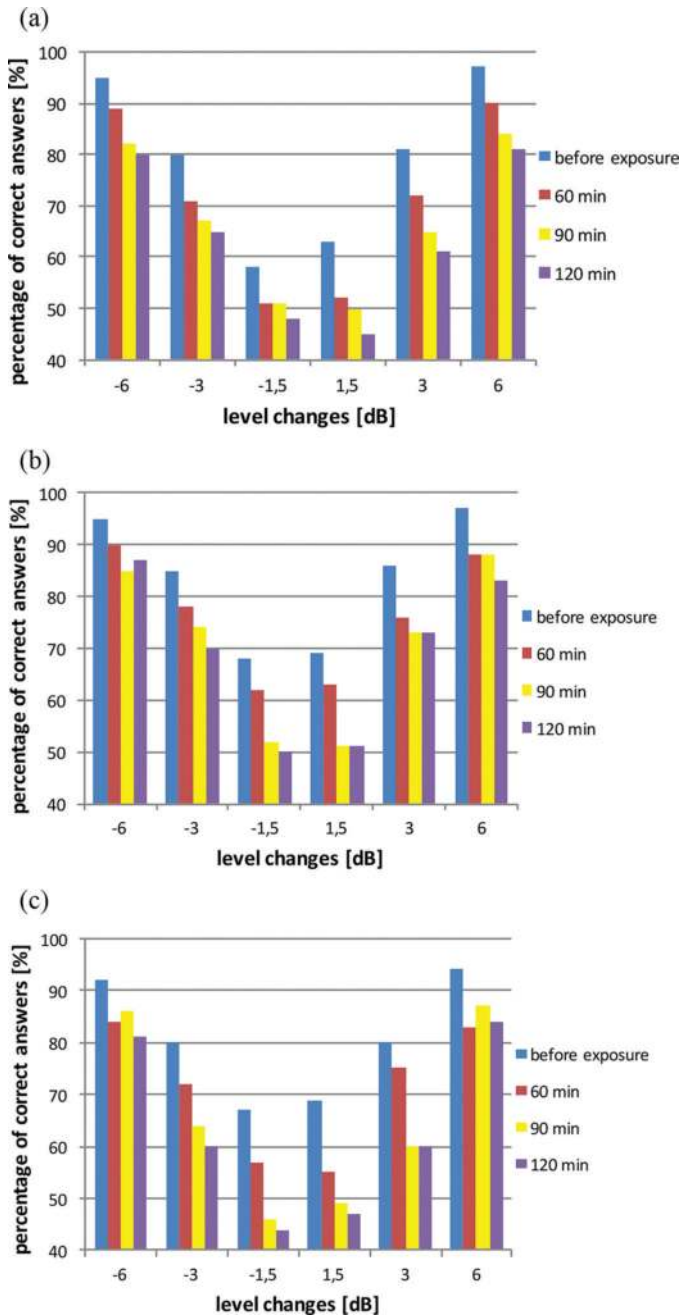


Figure 4. Detection of spectrum changes for frequencies of 125 Hz (a), 1 kHz (b) and 8 kHz (c) for different values of level changes in particular octave band.

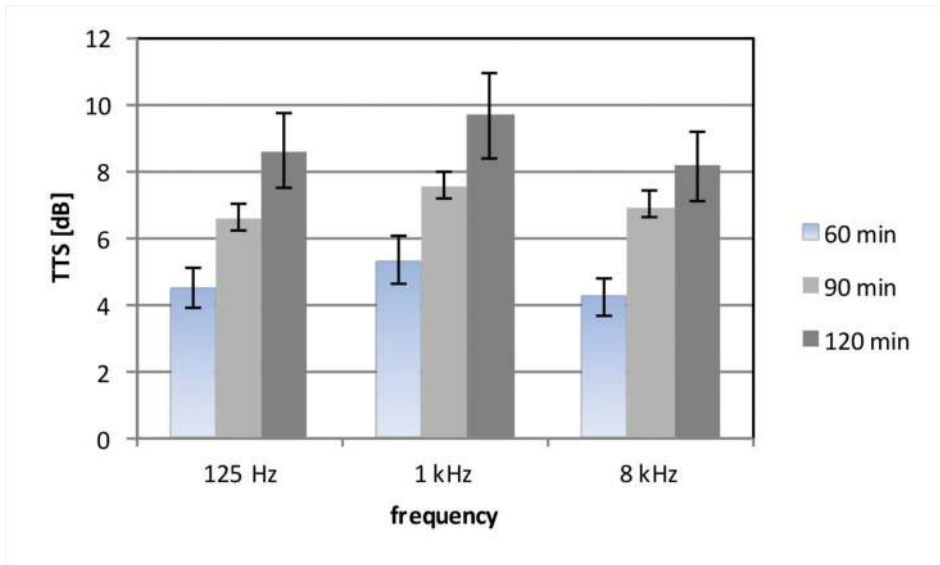


Figure 5. Average values of TTS after noise exposure of 1 h, 1.5 h and 2 h.

changes between fresh-ear listening and perception after 2 h-exposure takes 20% for ±1.5 dB spectrum modification, and then decreases to about 10% for ±6 dB attenuation/amplification. These results are convergent to the ones obtained in experiments on the profile analysis [28–30]: the values reported in a literature are equal to 2–3 dB for similar frequency regions, which can be compared to the values obtained for detection ability at 70% of correct answer number measured before the exposure to the music treated as a disturbing noise.

The obtained results can also be discussed in the light of TTS values presented in Figure 5. They have been averaged over all listeners. As it can be seen, the greatest values of TTS have been obtained for 1 kHz (about 9.5 dB, after 120 min of exposure) but the way of change is monotonic for all investigated frequencies. Moreover, the differences between the TTSs after the loud music exposure of 1 and 2 h are about 4 dB, for all frequencies. These values are

| Spectral change/<br>standard<br>deviation | -1.5 dB | +1.5 dB | -3 dB | +3 dB | -6 dB | +6 dB |
|---|---------|---------|-------|-------|-------|-------|
| $\sigma_0$                                | 18.2    | 14.0    | 8.4   | 6.6   | 4.8   | 3.9   |
| $\sigma_{60}$                             | 27.3    | 22.8    | 20.3  | 18.6  | 15.0  | 11.5  |
| $\sigma_{90}$                             | 31.1    | 33.2    | 24.7  | 24.3  | 13.2  | 12.7  |
| $\sigma_{120}$                            | 36.0    | 34.3    | 25.3  | 24.2  | 16.5  | 15.8  |

Table 3. Standard deviation values of percentage of correct answer for spectra changes of musical samples equalized at 125 Hz, measured at different times of loud music exposure (in %).

| Spectral change/<br>standard<br>deviation | -1.5 dB | +1.5 dB | -3 dB | +3 dB | -6 dB | +6 dB |
|---|---------|---------|-------|-------|-------|-------|
| $\sigma_0$                                | 10.8    | 9.9     | 6.5   | 6.1   | 4.3   | 3.9   |
| $\sigma_{60}$                             | 22.1    | 20.3    | 16.3  | 15.2  | 10.8  | 10.2  |
| $\sigma_{90}$                             | 23.6    | 22.8    | 16.8  | 16.2  | 11.3  | 10.9  |
| $\sigma_{120}$                            | 28.2    | 30.8    | 16.5  | 16.6  | 11.0  | 11.2  |

**Table 4.** Standard deviation values of percentage of correct answer for spectra changes of musical samples equalized at 1000 Hz, measured at different time of loud music exposure (in %).

greater than those resulting from the detection ability presented in **Figure 4** because of the different stimuli used in both tests, although the character of changes is similar.

For a quality of the work activity in this particular profession it is important to detect these changes as accurate as possible, especially at a work as a studio recording engineer. However, the long exposure to the noise causes the worsening of attention, or listening fatigue. This phenomenon may be expressed as the standard deviations values of obtained results which is presented in **Tables 3–5**. These values may show that after every sound exposure, the attention of listeners gets lower causing an increase of uncertainty during evaluation of musical samples.

It can be seen that precision in spectral changes detection increases when these changes are greater ( $\pm 6$  dB, in this case). Another interesting fact is that after every acting noise (ranging from 60 to 120 min) the standard deviation values increase, but this change is not monotonic: sometimes exposure time does not influence the value of standard deviation of the obtained results which was confirmed by Bartlett test ( $\chi^2 = 3.427 < \chi_{\alpha}^2 = 5.986$ , at  $\alpha = 0.05$ ), and sometimes this influence is significant (as for 125 Hz band, where  $\chi^2 = 11.886 > \chi_{\alpha}^2 = 7.802$ , at  $\alpha = 0.05$ ). This means that the uncertainty for sound color evaluation for small differences of spectra is relatively high when some masking sounds appear simultaneously which increases the hearing system fatigue. For the lowest investigated equalization ( $\pm 1.5$  dB) the standard deviation for results after listening to loud music takes values greater than those presented for  $\pm 3$  dB correction. Without the noise-like signal exposure, the standard deviation is almost the same as for  $\pm 3$  dB (before listening to loud music) and this is in good agreement with previously reported

| Spectral change/<br>standard<br>deviation | -1.5 dB | +1.5 dB | -3 dB | +3 dB | -6 dB | +6 dB |
|---|---------|---------|-------|-------|-------|-------|
| $\sigma_0$                                | 9.8     | 9.5     | 7.5   | 6.8   | 4.2   | 3.9   |
| $\sigma_{60}$                             | 20.7    | 21.2    | 12.3  | 13.5  | 11.0  | 10.7  |
| $\sigma_{90}$                             | 25.7    | 25.8    | 17.9  | 15.9  | 13.3  | 14.9  |
| $\sigma_{120}$                            | 26.3    | 24.5    | 17.8  | 16.3  | 16.8  | 15.5  |

**Table 5.** Standard deviation values of percentage of correct answer for spectra changes of musical samples equalized at 8 kHz, measured at different time of loud music exposure (in %).

research [31, 32] for amateurs as well as for professional sound engineers. Taking into account the obtained values for all kinds of spectral modification at given octave bands it can be clearly seen that longer exposure to loud signals causes greater uncertainty of sound color assessment but the relation is not proportional: the great increase has been noted when time exposure is 90 min and further prolongation of noise exposition up to 2 h does not influence the standard deviation values for lower and higher frequency regions, so it might be said that the concentration is kept at the same level. It should be also noted that the values of standard deviation are higher for 125 Hz for a modified frequency band than for higher frequencies which clearly means that uncertainty of spectrum change detection is worse for lower frequencies.

#### 4. Conclusions

The audibility of timbral modifications depends on the frequency of modified region, the amplitude of peak (or notch) as well as the bandwidth. As it is reported in the literature, changes in sound quality, for example, made by introducing resonances or notches depend on musical material used in audition, the listening environment and reverberation used at a recording process [30]. The most important result of present experiment is that the audibility of spectral changes depends on the level of this modification as well as on the time of disturbing loud music exposure. Moreover, with discontinuous, irregular impulsive, or transient sounds characteristic for speech and musical signals, the test material is less resistible in comparison to the steady sounds. Obtained results are in good agreement with the ones reported in the literature as results of profile analysis [29] as well as the "classical" view on the timbre change perception [28]. It should be noted here that so called traditional view on the timbre perception is based on the intensity discriminations in particular frequency bands while the basic assumption of the profile analysis is that discrimination of the spectral changes is based on the evaluation of the overall spectrum shape involving the memory and interstimuli intervals. The results of experiments provided by both methods are similar in a case of such signals as used in our research. According to this, the ability of the distinguished changes in spectrum are 2–3 dB for listeners with normal hearing. It may be assumed that this fact takes place at the beginning of experiment (before exposure to the loud musical material). For the people with relatively small hearing loss (up to 20 dB) the predicted results of the peak or notch of spectrum modification may be shifted up to 5–6 dB which coincides with our results: the attenuation/amplification must be at 6 dB to be perceived with the greatest accuracy after longer (more than 1 h) presentation of loud music.

On the basis of the obtained results, it may be stated that the temporary threshold shift phenomenon is the important factor that determines perceptibility of changes in spectral and amplitude domains of musical signals. This conclusion results from the way of changes in obtained values for different time of loud music exposure. This is a usual phenomenon especially for 1 kHz because this range of frequency is the most sensitive for human hearing [33] and this fact can help the listeners to take a good decision during sound evaluation. Results of spectral changes detection are convergent with results reported in the literature. According to these results, the TTS measured immediately after loud music exposure ranges from 10 to 30 dB, depends on the

level, time, and the temporal and spectral structure of noise or loud music [15, 18]. Moreover, if one can assume that TTS phenomenon causes similar effects that may be characteristic for the hearing loss, the decrease of sensitivity of the hearing system affects the perception of auditory signals in all their dimensions, that is, temporal and frequency resolution as well as loudness perception may be distorted or deteriorated. This effect may be observed in the discotheque attendants or in the people who are exposed to the noise level greater than 90 dB [17].

The results may also be influenced by the mental fatigue which occurred after permanently playing loud sounds for several time durations, together with demanding tasks. Such conditions involving the mental engagement in a noisy environment which is natural in the studio can significantly reduce the time of exhaustion which causes the decrease of accuracy in solving several tasks [9].

Nowadays portable players are getting cheaper, smaller, and offer more and better sound quality. Everything would be fine, if not the fact that listening to the loud music does not hurt. These devices induce young people to listen louder and louder, applying that noise directly on themselves. It is very easy to meet someone on the tram, the bus, or on the street with headphones in their ears and the music is reproduced so loud that it is possible to recognize songs that are played being in a distance from the listening person. The body does not give us a sign that the process of destroying the hearing has just began, and once damaged, hair cells would never regenerate. The results of the research conclude that if a person listens to loud music on MP3 player for 5 years for an hour a day it is enough to ruin a hearing system permanently. Thus, it should be noted that the tendency observed in young people to listen loud music in order to be isolated from the environment is still actual which will cause not the TTS but PTS. The most dangerous factor influencing the human hearing system reported in the literature [8, 10, 18] is the type of headphones used for every day listening. Most of young people listen to the music through inside earphones which causes that the reduction in the length of outer ear channel, and as a consequence, a natural protection becomes less effective. From sociological point of view, the young people like this kind of earphones because they take up little space and can be always carried in a pocket, but on the other hand, they are the worst for our hearing. Research has shown that 2–3 years of using this type of headphones leads to a slight hearing damage resulting with incomprehensibility of a whisper or a quiet voice. Listening to music is becoming an addiction primarily among young people, but unfortunately this fact is ignored in the mainstream media.

## Glossary of used terms

**A-weighting** is the correction of the sound pressure level (SPL) as a function of frequency in such a manner that it reflects human feeling of loudness level of different frequencies. The A-weighting curve is defined in the International Standard IEC 61672:2003

**Clarity of sound** is the property of reproduced sound that allows the listener to distinguish the basic components of information. It depends on the degree to which the sound is free from any kind of distortion.



**Closed headphones** are the headphones which have the back of the earcups closed. Closed headphones isolate the ear from external ambient noise and minimize the music leakage out of the earpieces.

**Dynamic compression** is a signal processing operation that reduces the volume of loud sounds or amplifies quiet sounds by narrowing an audio signal's dynamic range. The device which realizes dynamic compression is called a compressor.

**Earphones** are electroacoustic transducers which converts an electrical signal into acoustical one and deliver it directly to the ear.

**Energy dose** is the integral of the square of acoustic pressure over time. The units of energy dose are Pa<sup>2</sup>s and Pa<sup>2</sup>h. It is also known as sound exposure.

**Front of House (FOH)** is the part of a performance venue which is open to the public, for example, an auditorium and foyer. Front of house sound engineer is normally positioned in a small sectioned-off area front of house, surrounded by the audience or at the edge of the audience area. From this position, he has unobstructed hearing and a clear view of the performance, enabling the operation of the speaker system, show control consoles and other equipment. In this case, Front of House can refer to both the general audience/public area or to the specific small section from where the show is operated.

**Headphones** are a pair of earphones connected with a bail which is put on the head. The bail provides the necessary downforce of earpieces to the ears.

**Hearing level (HL)** is defined in a similar way as the SPL (see below), except the reference level which is equal to normal threshold of hearing for a given frequency. Hearing level is applied in audiometry for determination of hearing loss.

**Inside or inner earphones** are very small earphones which are inserted directly into ear canal.

**Loudspeakers** are electroacoustic transducers, which convert an electrical signal into acoustical one and radiate it into space. The loudspeakers occur most often as loudspeaker sets, which consist of a few single loudspeakers, enclosure, filters, amplifiers etc.

**Open headphones** have the back of the earcups open. The sound in the ear canal does not depend on the downforce of the earphones to the ears. Open headphones do not block out ambient noise and allow audio leakage out of the earpieces.

**Permanent threshold shift (PTS)** is a permanent shift in the auditory threshold. It may occur suddenly or develop gradually over time. A permanent threshold shift results in permanent hearing loss.

**Public address (PA)** is an electronic sound amplification and distribution system, used to delivery sound with sufficiently high SPL to the public in large spaces: railway stations, airports, stadiums, department stores etc.

**Semi-open headphones** are a compromise between open and closed headphones. They combine all the positive properties of both designs.

**Sound pressure level (SPL)** is defined as twenty logarithms of the ratio the RMS (root mean square) value of an actual acoustic pressure and the reference level equal to 20  $\mu\text{Pa}$ . Unit of the SPL is decibel (dB).

**Temporary threshold shift (TTS)** is a temporary shift in the auditory hearing threshold. It may occur suddenly after exposure to a high level of noise, a situation in which most people experience reduced hearing. A temporary threshold shift results in temporary hearing loss.

## Author details

Andrzej Dobrucki\*, Maurycy J. Kin and Bartłomiej Kruk

\*Address all correspondence to: [andrzej.dobrucki@pwr.edu.pl](mailto:andrzej.dobrucki@pwr.edu.pl)

Department of Acoustics and Multimedia, Faculty of Electronics, Wrocław University of Science and Technology, Wrocław, Poland

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