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9. LOUD MUSIC LISTENING VS. THE PERCEPTION OF CHANGES IN PARAMETERS OF MUSICAL SIGNALS

9.1. Introduction

Listening to music may be considered not only as a kind of recreation but also as a hazard of a noise exposure. Some working activity as reinforcement and recording processes are the examples of a trade in which the listening process and its condition may reflect in the final quality of the work. The working people in these professions are the subjects to hearing protection, in the same manner as the noise-exposed workers in an industry. 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 during their preparation while the noise means that particular signal is assessed as unwanted and unpleasant stimulus. Also, the time-frequency structure of musical signals differs from the noise's consistence what makes the listening to music as a pleasant act. In the past few years, the tendencies of sound production caused the increase of a loudness of musical recordings, particularly. Many radio stations and record companies have applied increasing amounts of dynamic range compression and other means of recording process in order to be perceived clearly in today noisy world. The trend has been reflected in the higher subjective impressions in psychological domain, according to the slogan "louder sounds are sold better" [34]. Many young people want to separate their minds out of different backgrounds by the use of special kinds of headphones and they listen to the sound material louder, beside of the fact that the listened material is louder in comparison to the recordings made in previous century. Also the contemporary designed and produced equipment allows the listeners to consume the music in accordance with their way of life [15, 28] and with higher concentrated energy of sound in order to make the proper sensations for the audience.

The energy dose of sound is an acoustic variable that determines the magnitude of sound, and the other function of sound focusing technique is to increase the clarity of sound by the

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increasing the magnitude of the direct wave and decreasing the reflections from unwanted directions what results finally in higher sound levels. It is not so simple to determine the actual sound level in all areas occupied by the audience from measurement point of view. It can also be found that the sound level measured by the microphone in a sound field may be different than the level in ear canal, so the maximum impulsive noise levels were high at the ear canal but the implications for the causes of hearing loss are indistinct due to an amplification of outer ear canal of 3 - 4 dB in the region of 1 - 3 kHz [14]. It should be also added that such sound sources as headphones, loudspeaker sets, or PA systems are situated very close to the ear that may provide the risk of hearing loss. Thus, it can be said that working with louder music as well as listening to it over a long period of time systematically may lead to a permanent hearing damage or a listening fatigue what makes the proper attention being impossible.

The way of stimuli presentation seems to be an important thing causing the hearing loss so it is important to determine if the music is exposed via headphones or loudspeaker, or naturally listening of the event. 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 what simply leads to a listening fatigue. Young people's way of thinking is as follows: we listen to the music that sounds nicely for us and it is not alike as noise, so why may it be dangerous for our hearing organs? They often also say that the sound level during some symphonic concerts exceed 100 dB what is not so dangerous. However, the main differences between classical and pop-music are in a time of continuous exposition to the sound, a character of musical structure and spectral consistence of stimuli. In popular music the way used very often during musical production process is based on the sound compression, and this compression itself may increase the potential risk of hearing damage [21, 23, 26, 27] or a listening fatigue what makes the proper attention being impossible.

The typical effect of the listening to loud sounds are the Temporary Threshold Shift (TTS), or Permanent Threshold Shift (PTS) which play an important role in the ability of the proper assessment of sound while listening, or 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 [20] what is based on psychology of perception. 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 beside the fact that it may cause permanent or temporary hearing damages.

Noise related to some activities is correlated with performer's fatigue, increases tension and discomfort, and an interference of teaching and speech recognition, as it has been reported for teaching in classrooms [17, 31]. 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 particular level, and the resting time, after that the ear can recover to the before-noise-state [3, 12, 18]. According to these studies, a temporary decrease in auditory sensitivity in a normal ear was found after exposure to continuous noise levels weighted by A-curve above 80 dB for long periods of time. 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 fairly 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 that the greatest effect of TTS occurs firstly for the range of 2 - 6 kHz, and this upward shift disappears after the time, usually in 24 hours, but may last as long as a week [3, 10-12]. 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 particular danger when people who work in noisy environments are exposed to further noise afterwards in driving, at home and at places of entertainment.

These facts may be reflected in an increase of hearing thresholds of the young people consuming today-music in accordance with the way that says “louder means better”. Of course, the higher hearing thresholds induce difficulties in collecting, understanding and interpreting many information from human environment what 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 actual in the light of youngsters’ way of life and this aspect was 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 years-old people. The authors’ research [4] 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. According to the European Standard EN ISO 7029 these values are typical for 40 – 50 years-old people and this population is still growing up year-by-year [8].

9.2. Description of research

9.2.1. Audiometric tests of hearing threshold

The research was aimed at young people (16-25 years old) because they are the most vulnerable to hearing loss caused by frequent loud music exposure in their own choices. Some of them are working professionally for an entertainment industry. The whole tested population was divided into four groups:

- young classical musicians or music academy students,
- sound engineers of Front of House/Public Address (FOH/PA) systems,
- sound engineers working in recording studios,
- users of portable audio equipment (non-professional).

The ordinary young users of portable audio equipment were representative as the reference group for this range of age, so the total number or the subjects was more than 80 people. After the interviews and the spoken instructions the people were 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 [7]. Therefore during the test, any masking phenomenon from outer signals does not occur [7, 9]. Before the measurements all audiometers had been basically calibrated and checked aurally, also they had been calibrated subjectively in an accordance with the ISO recommendations.

Thresholds of hearing levels were determined by the air conduction audiometry. The measurements were carried out according to the applicable standards [9, 25] 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.

9.2.2. Measurements of Temporary Threshold Shift (TTS)

The TTS phenomenon for the listeners was the subject of the part of research. The hearing thresholds were measured before, and after every session of music exposure what enabled to observe the TTS caused by the listening of loud musical signals during three periods of loud music exposure. These periods were of 60, 90 and 120 minutes. The musical material used as a disturbing noise contained mostly pop&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.

In this part of research the thresholds of hearing were measured in the same way as in previous part of experiment, i.e. by ascending stimuli method and with the use of continuous sinusoidal signals with steps of 2 dB. These measurements were repeated twice. Sixteen subjects at ages ranging from 22 to 25 years participated in the experiment and all of them were students of acoustics experienced in psychoacoustical experiments. They featured the normal hearing, i.e. the absolute threshold was no more than 10 dB HL in the entire frequency range (125 Hz to 16 kHz) what has been confirmed by the air conduction measurements [25], with the Maico M53 audiometers. Moreover, they have already started to practice mostly as engineers' assistants working for sound reinforcement as well as recording industry.

9.2.3. Detection of spectral changes of musical signals vs. TTS

The detection of spectrum changes of musical signals was the subject to investigate. Sixteen subjects participated in this part of experiment and all of them participated in the previously described part of research. The threshold measurements were carried out according to the standards [9, 25] 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 what 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 +/- 1.5 dB, +/- 3 dB and finally +/- 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 corrections parameters in low, middle 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 TASCAM DA-30 DAT recorder. As a trial of test stimuli samples have been presented in pairs, where the first one contained the original (non-equalized signal) and the second one – the processed signal. The time interval between samples was set at 1 s, and between pairs as 2 seconds. 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 minutes. The test signals contained pieces of various musical styles (pop-rock, jazz, symphony, chamber music, heavy metal). The musical material used as a disturbing noise contained mostly pop&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 [27] as a reflection of typical distributions of sound pressure levels in musical selections performed by American rock&roll groups [26]. This way 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 paid for 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's 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 [22, 24].

9.2.4. Detection of short level changes vs. TTS

The aim of this part of research was to find the ability of short-time level changes detection. The test signals contained the same samples as in previous part of research but prepared in specific way: in musical signals the level changes over of one-second-interval had been introduced, and the changes had been determined as 1.5 dB, 3 dB and 6 dB. The subjects' task was to detect and denote if they perceived the change and the test samples were presented after 60, 90 and 120 minutes exposure of loud music. The rise and decay time durations were equal to 100 ms. The time interval between samples was fixed at 1 s, and one trial contained 15 samples, the break between trials was set at 5 s. The repetition of the sample was not allowed. The test sequences contained also the samples without any changes of the envelopes in order to control if the listeners' attention was still active and responses to the tasks were uniform.

The sound material (the test signals as well as the disturbing noise) was the same as in previously described parts of experiment. The listening team was exactly the same as in previously described part of research.

9.3. Analysis of the results

9.3.1. Average hearing threshold

Fig. 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 7-8 dB. In order to confirm the results, the various types of statistical testing have been applied. When calculated value of particular statistics for a tested factor is less than the critical value depending mainly on a number of repetitions and the level of significance α (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 χ^2 thus it can be applied even to a small population. This kind of test enables to confirm a homogeneity 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 ($\chi^2 = 28.653 < \chi^2_\alpha = 39.977$, at $\alpha = 0.05$) for all frequencies. According to the classification of the International Bureau for Audiophonology [1], the four 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 to the slow tendency to begin of 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.

Some of tested people have been working in the profession up to 7 years. By analyzing these data it can be concluded that even 3-4 years of working at an entertainment industry, especially as the front-of-house engineers may cause a slight loss of hearing ability. In Fig. 2 there are presented hearing thresholds depending on the profession. These values have been averaged over the people within the particular group of profession as well as “amateur” listeners.

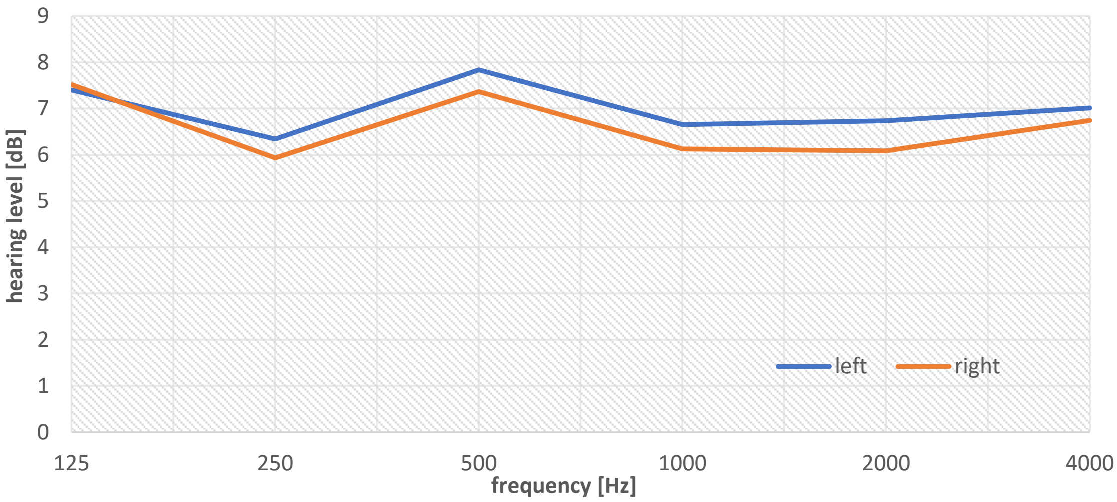


Fig. 1. The average values of the threshold of hearing shift for the tested population
Rys. 1. Średnie wartości progu przesunięcia słuchu dla badanej populacji

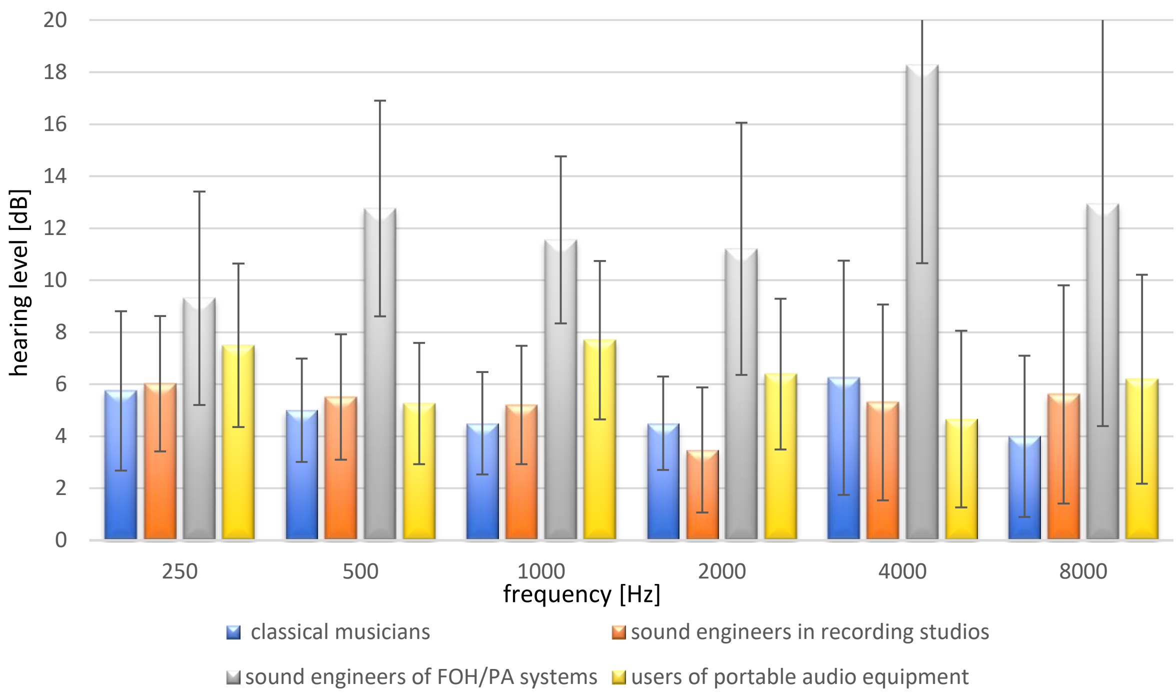


Fig. 2. Thresholds of hearing depending on the profession. Standard deviation values are presented as vertical lines on the tops of the bars

Rys. 2. Progi słyszenia w zależności od wykonywanego zawodu. Wartości odchylenia standardowego przedstawiono w postaci pionowych linii na wierzchołkach słupków

On the base 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, F_α – 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 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 situation in order to increase the total loudness impression.

9.3.2. Temporary Threshold Shift (TTS)

In the Fig. 3 there are presented the results of Temporary Threshold Shift (TTS) measured after 60, 90 and 120 minutes of exposure to the loud music. They have been averaged over all 16 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 a change is monotonic for all investigated frequencies. Moreover, the differences between the TTSs after the loud music exposure of 1 and 2 hours are about 3 - 4 dB, for all frequencies. These values are greater than those resulting from the detection ability presented in Fig.1 because of the different stimuli used in both tests, although the character of changes is similar.

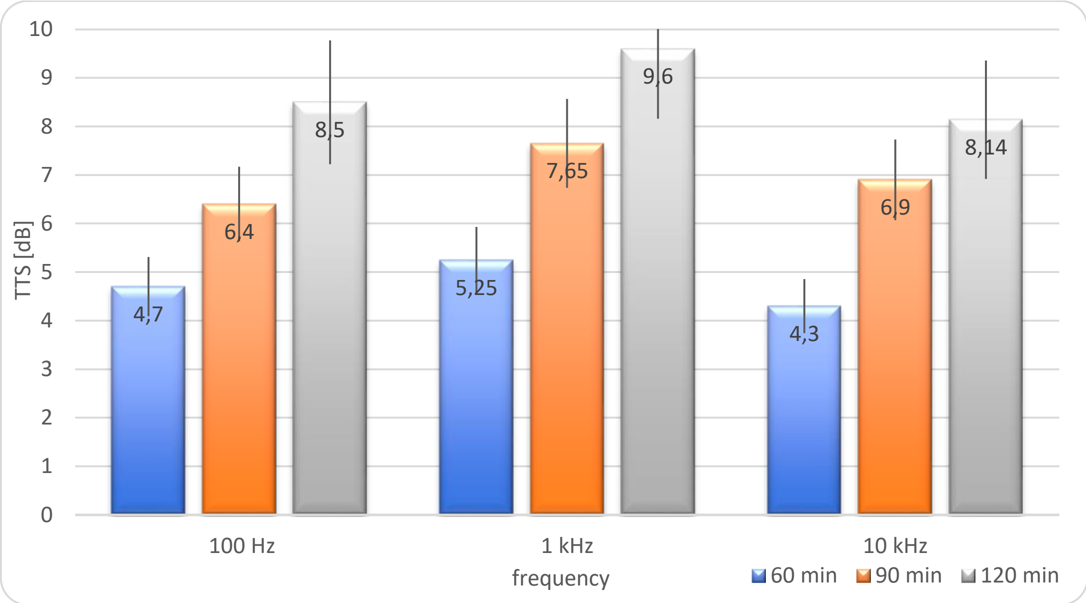
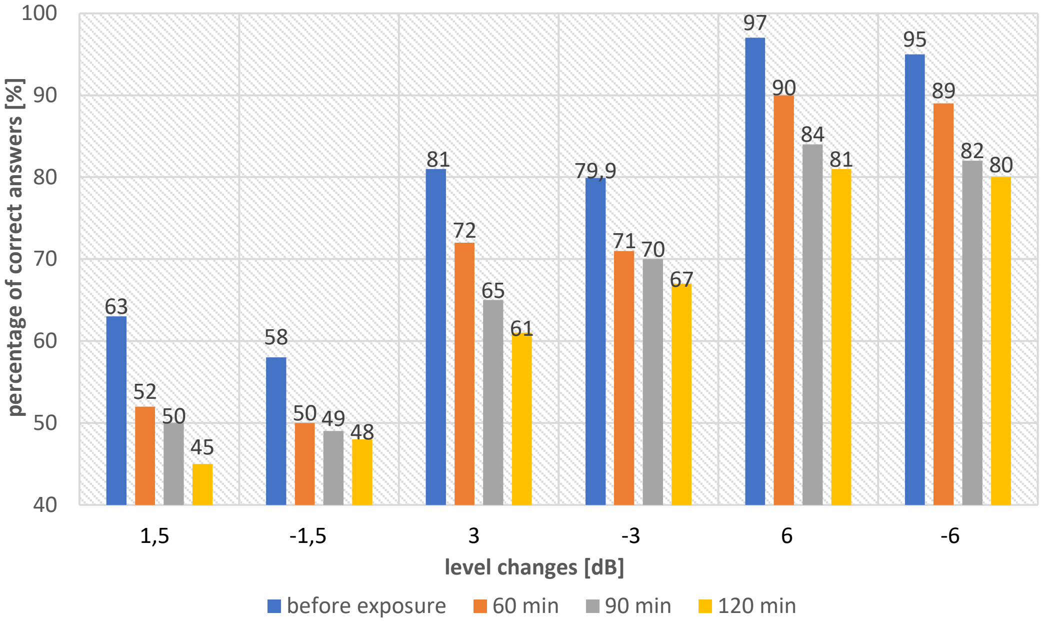


Fig. 3. Average values of TTS after noise exposure of 1 hour, 1.5 hour and 2 hours
Rys. 3. Średnie wartości TTS po ekspozycji na hałas przez 1 godzinę, 1,5 godziny i 2 godziny

9.3.3. Detection of spectral changes vs. auditory fatigue

In the Figures 4 - 5 there are presented results of this part of the research. 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 had to denote if they perceived them. Thus, results may be expressed as a percentage of correct answers in a dependence of a kind of introduced spectral changes after several noise-like time of exposure. For statistical treatment the Bartlett's test was applied allowing to confirm a homogeneity of variances of obtained results. On the base of this test, for every time of the exposure, the results were homogeneous ($\chi^2 = 8.172 < \chi^2_\alpha = 28.869$, 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 ($\chi^2 = 9.103 > \chi^2_\alpha = 5.986$, at $\alpha = 0.05$).

a)



b)

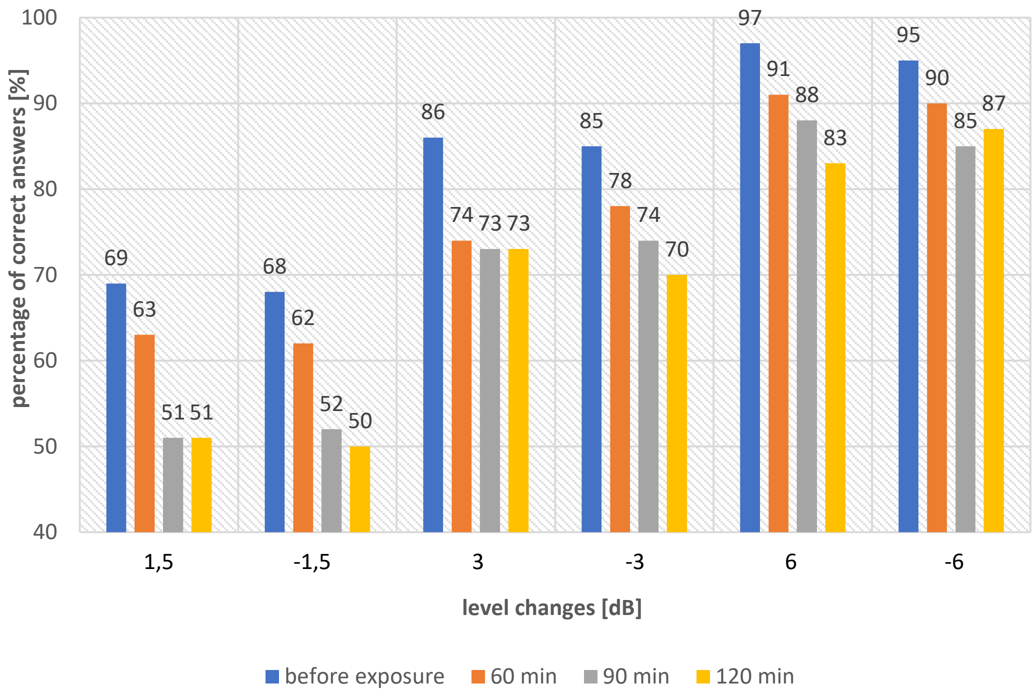


Fig. 4. Detection of spectrum changes for frequencies of 125 Hz (a), 1 kHz (b) for different values of level changes in particular octave band

Rys. 4. Detekcja zmian widma dla częstotliwości 125 Hz (a), 1 kHz (b) dla różnych wartości zmian poziomu w poszczególnych pasmach oktawowych

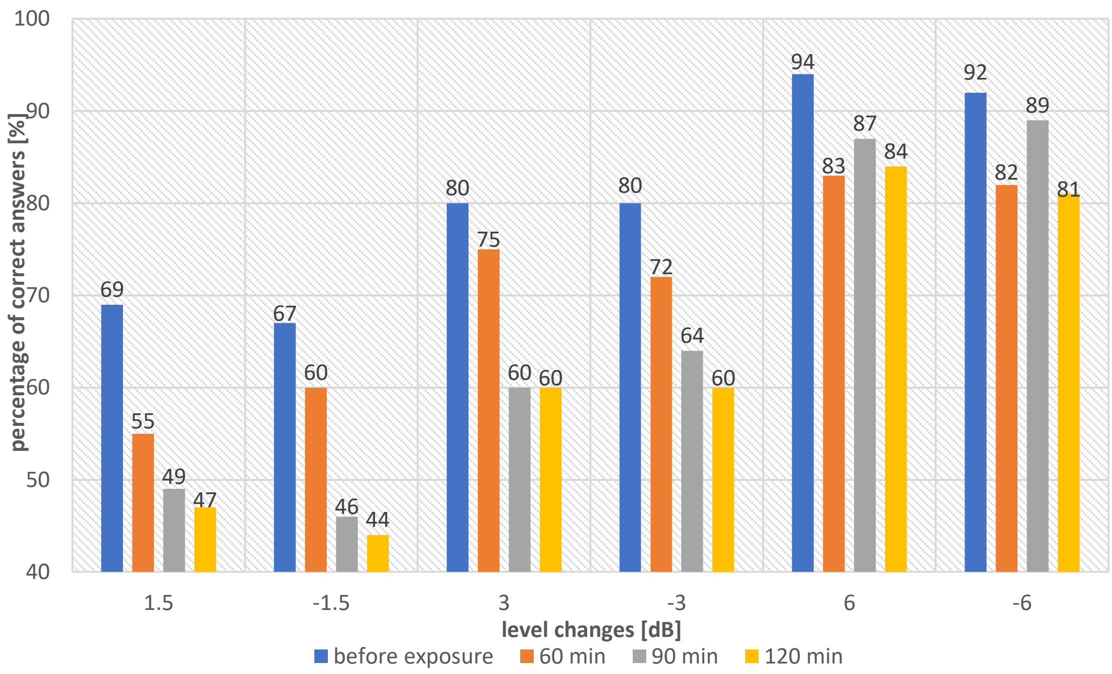


Fig. 5. Detection of spectrum changes for frequency of 8 kHz for different values of level changes in particular octave band

Rys. 5. Detekcja zmian widma dla częstotliwości 8 Hz (a) dla różnych wartości zmian poziomu w poszczególnych pasmach oktawowych

The obtained results can also be discussed in a light of TTS values presented in Fig. 3. 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 a change is monotonic for all investigated frequencies. Moreover, the differences between the TTSs after the loud music exposure of 1 and 2 hours are about 4 dB, for all frequencies. These values are greater than those resulting from the detection ability presented in Figures 4 - 5 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 accurately as possible, especially if one works 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 deviation values of obtained results presented in Tables 1 - 3. These values may show that after every time of sound exposure the attention of listeners gets lower causing an increase of uncertainty for evaluation of processed sound samples.

Table 1

Standard deviations of percentage of correct answer for spectra changes of musical samples equalized at 125 Hz measured at different time of loud music exposure (in %)

Spectral change / standard deviation	- 1.5 dB	+ 1.5 dB	- 3 dB	+ 3 dB	- 6 dB	+ 6 dB
σ_0	18.2	14	8.4	6.6	4.8	3.9
σ_{60}	27.3	22.8	20.3	18.6	15	11.5
σ_{90}	31.1	33.2	24.7	24.3	13.2	12.7
σ_{120}	36	34.3	25.3	24.2	16.5	15.8

Table 2

Standard deviations of percentage of correct answer for spectra changes of musical samples equalized at 1000 Hz measured at different time of loud music exposure (in %)

Spectral change / standard deviation	- 1.5 dB	+ 1.5 dB	- 3 dB	+ 3 dB	- 6 dB	+ 6 dB
σ_0	10.8	9.9	6.5	6.1	4.3	3.9
σ_{60}	22.1	20.3	16.3	15.2	10.8	10.2
σ_{90}	23.6	22.8	16.8	16.2	11.3	10.9
σ_{120}	28.2	30.8	16.5	16.6	11	11.2

Table 3

Standard deviations of percentage of correct answer for spectra changes of musical samples equalized at 1000 Hz measured at different time of loud music exposure (in %)

Spectral change / standard deviation	- 1.5 dB	+ 1.5 dB	- 3 dB	+ 3 dB	- 6 dB	+ 6 dB
σ_0	9.8	9.5	7.5	6.8	4.2	3.9
σ_{60}	20.7	21.2	12.3	13.5	11	10.7
σ_{90}	25.7	25.8	17.9	15.9	13.3	14.9
σ_{120}	26.3	24.5	17.8	16.3	16.8	15.5

It can be seen that precision in spectral changes detection increases when these changes are greater (+/- 6 dB, in this case). Another interesting fact is that after every time of acting noise (ranging from 60 to 120 minutes) 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 ($\chi^2 = 4.121 < \chi^2_\alpha = 5.986$, at $\alpha = 0.05$), and sometimes this influence is significant (as for 125 Hz band, where $\chi^2 = 13.016 > \chi^2_\alpha = 7.802$, at $\alpha = 0.05$). This means that the uncertainty for sound colour evaluation for small differences of spectra is relatively high when some masking sounds appear simultaneously what makes an increase of the hearing system fatigue. For the lowest investigated equalization (+/- 1.5 dB) the standard deviation for results after loud music listening takes values greater than those presented for +/- 3 dB correction. Without the noise-like signal exposure, the standard deviation is almost the same as for +/- 3 dB (before a loud music listening) and this is in a good agreement with previously reported research [16, 17, 19] for not 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 colour assessment but the relation is not proportional: the great increase has been noted when time exposure is 90 minutes and further prolongation of noise exposition up to 2 hours 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 as modified frequency band than for higher frequencies what clearly means that uncertainty of spectrum change detection is worse for lower frequencies.

9.3.4. Detection of short level changes vs. TTS

The detection of short increase in level refers to ability of loudness discrimination of short impulse presented with the continuously played musical material. Those, the results of this part can be considered as discrimination of intensity changes in dependence of listening fatigue. Although in the literature one can find a normal hearing fresh-ear or impaired hearing ability to this kind of stimuli [5, 21, 31], the situation after a long exposition to the disturbing loud music resulting in TTS phenomenon, can be compared to listening by the impaired persons with small hearing loss [10]. In Fig. 6 the results of detection ability of the changes of envelope in dependence on time of loud music exposure are presented. It can be seen that ability of short changes in envelope of musical signals gets worse for the all investigated levels of changes. The lowest detectability has been obtained for lowest changes in envelope what is not surprisingly in the light of SISI testing widely presented in the literature [13, 32] where the short increase of sinusoidal envelope occurs with the level of 1 dB. When the changes of envelopes (what results in changes of loudness impression) are done with greater levels, their detectabilities significantly increase ($\chi^2 = 11.813 > \chi^2_\alpha = 7.682$, at $\alpha = 0.05$). Although it should be noted that in all cases of level change, the detection ability decreases after every time of loud music exposure what shows the significant influence of listening fatigue on the accuracy and attention of performed work.

It turned out that results of presented experiment are in a good agreement to the data reported earlier: for fresh, non-fatigued ear, the perception ability of short increase of the loudness level takes values of 2-3 dB, and it slightly decreases after long exposure to the noise, reaching values of 3-5 dB.

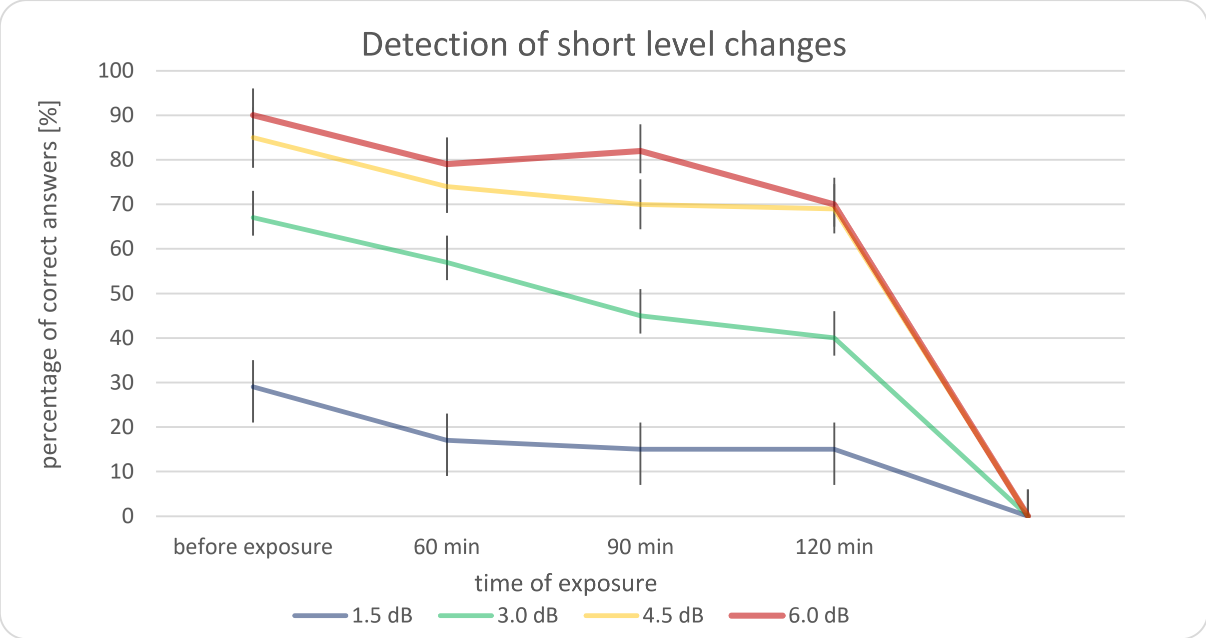


Fig. 6. The results of short level increase detection as the function of the noise exposure time (with the standard deviation values presented by vertical lines)

Rys. 6. Wyniki detekcji prawidłowych odpowiedzi w funkcji czasu ekspozycji na hałas (wartości odchylenia standardowego przedstawiono liniami pionowymi)

9.4. Discussion

The audibility of spectral modifications that reflect on sensation of timbre depends on the frequency of modified region, the amplitude of peak (or notch) as well as the band-width. As it is reported in 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 [33]. The most important results of presented 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 a good agreement to the ones reported in the literature as results of profile analysis [6] as well as a “classical” view on the timbre changes perception [2]. 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 what coincides with our results: the attenuation/amplification must be at 6 dB to be perceived with the greatest accuracy after longer (more than 1 hour) presentation of loud music.

On the base 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 [30] 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 literature. According to these results, the TTS measured immediately after loud music exposure ranges from 10 dB to 30 dB, in a dependence of the level, time and the temporal and spectral structure of noise or loud music [11, 12]. Moreover, if one can assume that TTS phenomenon causes the 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, i.e. temporal and frequency resolution as well as loudness perception may be distorted or deteriorated. This effect may be observed on the discotheque attendants or for the people who are exposed to the noise level greater than 90 dB [10].

The results may also reflect the mental fatigue which occurred after several time durations of permanently played loud sounds. Such conditions of working in a noisy environment referred to the natural scenery of the studio work and the obtained results suggest a reduction of the worktime activities because of an exhaustion that causes the decrease of accuracy in solving several tasks [20].

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 still actual what will cause not the TTS phenomenon but Permanent Threshold Shift (PTS).

The most dangerous factor influencing the human hearing system reported in literature [4, 12, 28] is also the type of headphones used for every day listening. Most of young people listen to the music through inside earphones what causes that the length of outer ear channel is reduced, 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 in loss of ability to discriminate words spoken in soft whisper or quiet voice. Listening to music is becoming a disease primarily among young people, but this fact has been ignored in the mainstream media for a long time.

9.5. Conclusions

Listening to the music can cause a temporary or permanent loss of hearing sensitivity not only in the middle frequency region. Moreover, it is an integral part of work in the recording studio or on the stage. For all the people who participated the tests the worsening of listening ability has been observed. The biggest changes were shown for frequency 1000 Hz and reached up to 3 - 5 dB if one take into consideration the perception of spectral changes as well as the detection of small growth in loudness. It can be said that most of sound engineers working on audio material for a long time does not realize the importance of this problem. When listening to the mix even after a short break, with ears rested, one can perceive many differences in timbre, which were inaudible before. This follows from a fact that their hearing abilities were fatigued after a long period of loud sound exposure. For example, the last process of work over the audio material (mastering) is always done with high-intensity sound pressure resulting in TTS as well as in a mental exhaustion. During the mastering process small differences like 1 to 3 dB are very important, e.g. properly adjusted equalization [28], where the presented results of spectral or envelope changes measured in the experiment are higher almost twice. The recovery from TTS after an exposure to noise depends on the severity of the hearing shift, individual susceptibility, and the type of exposure. Hearing relaxation time is not uniquely defined and depends on the duration and level of exposure to the sound. This time may vary from 10 minutes up to 24 hours, as it has been reported previously [3, 21, 29].

It could also be stated that in order to work more effectively and efficiently in recording industry it is greatly important to make regular breaks. Additionally, it is very important to have an alternative pair of studio monitors during the work, because of the fact that after a long listening to the sound transmitted via the particular monitors all details may not be perceived as a result of accommodation. Switching on and off between different loudspeakers may minimize partially that effect in terms of changing the listening environment.

Another very important aspect of listening is to set the proper value of sound level. The aesthetic impression of music will be different when the level of playback also changes. To keep hearing abilities fresh for longer time periods we should turn-down this volume. It can be achieved by using sound pressure level meters in the recording studio to be aware of how high this level is. Because some people claim that only working with loud sounds slight differences can be heard it is important to combine both methods mentioned above. One still has to remember that long exposure to the sound, even if the music seems to be pleasant can lead to a permanent hearing loss [21, 23] what has been observed in group of professional musicians. In order to ensure the comfort of work in a recording studio or on stage it is necessary to take regular breaks and lower the volume, or use the other methods to avoid straining ears and thus continuous exposure to loud sounds.

Bibliography

1. BIAP Recommendation 02/1: Automatic classification of hearing impairment. October 26, 1996.
2. De Bruijn, A.: Timbre classification of complex tones. Acustica. 1978; 40 (2) 108-114.
3. Chiou-Jong C., Yu-Tung D., Yih-Min S., Yi-Chang L., Yow-Jer J.: Evaluation of auditory fatigue in combined noise, heat and workload exposure. Industrial Health. 2007; 45 (4): 527-534.
4. Dobrucki A.B., Kin M.J., Kruk B.: Preliminary study on the influence of headphones for listening music on hearing loss of young people. Archives of Acoustics. 2013; 38 (3): 383-387.
5. Green D.M., Nachmias J., Kearney J.K., Jeffress L.A.: Intensity discrimination with gated and continuous sinusoids, J. Acoust. Soc. Amer. 1979; 64, 1051-1056.
6. Green D.M.: Profile analysis: A different view of audiology intensity discrimination. American Psychologist. 1983; 38 (2): 133-142.
7. Gustafsson B.: The loudness of transient sounds as a function of some physical parameters. J. of Sound and Vib. 1974; 37: 389-398.
8. ISO 7029:2000. Acoustics: Statistical distribution of hearing threshold as a function of age.
9. ISO 8253-1:2010. Acoustics: Audiometric test methods - Part 1: Pure-tone air and bone conduction audiometry.
10. Jaroszewski A., Rakowski A.: Loud music induced threshold shifts and damage risk prediction. Archives of Acoustics. 1994; 19: 311-321.
11. Jaroszewski A., Fidecki T., Rogowski P.: Hearing damage from exposure to music. Archives of Acoustics. 1998; 23: 3-31.
12. Jaroszewski A., Fidecki T., Rogowski P.: Exposures and hearing thresholds in music students due to training sessions. Archives of Acoustics. 1999; 24: 111-118.
13. Jesteadt W., Wier C.C., Green D.M.: Intensity discrimination as a function of frequency and sensation level. J. Acoust. Soc. Amer. 1977; 61, 169-177.
14. Jokitulppo J., Ikäheimo M., Pääkkönen R.: Noise exposure measurements in real ears: an evaluation of MIRE-Technique use in the field and in the laboratory. Acta Acustica united with Acustica. 2008; 94 (5): 734-739.
15. Katz B.: Mastering Audio: The Art and the Science. Oxford: Focal Press; 2007.
16. Kin M., Dobrucki A.: Perception of changes in spectrum and envelope of musical signals vs. auditory fatigue. Archives of Acoustics. 2016; 41: 323-330.
17. Kozłowski E., Młyński R.: Effects of acoustic treatment on music teachers' exposure to sound. Archives of Acoustics. 2014; 39: 159-163.
18. Kruk B., Kin M.: Perception of timbre changes vs. Temporary Threshold Shift. In: Proc. of 138th AES Convention; May 2015; Warsaw. New York: Audio Engineeing Society. 2015; Preprint 9228.

19. Kumagai M., Ebata M., Sone T.: Effect of some physical parameters of impact sound on its loudness. J. Acoust. Soc. Japan. 1981;15-26.
20. Marcora S.M., Staiano W., Manning V.: Mental fatigue impairs physical performance in humans. J. of Applied Physiology. 2009;106 (3): 857-864.
21. Moore B.C.J.: Effect of sound-induced hearing loss and hearing aids on the perception of music. J. Audio Eng. Soc. 2016; 64 (3): 112-123.
22. Moore B.C.J.: An Introduction to the Psychology of Hearing. London: Academic Press; 1997.
23. Pawlaczyk-Łuszczyńska M., Dudarewicz A., Zamojska A., Śliwińska-Kowalska A.: Evaluation of sound exposure and risk of hearing impairment in orchestral musicians. Int. J. of Occupational Safety and Ergonomics. 2011; 17 (3): 255-269.
24. Pawłowski T.: Informational Aesthetics. [In:] Selection of Aesthetic Papers. Kraków: Universitas; 2010.
25. PN-EN 26189. The measurements of hearing threshold by audiometric air conditions for hearing protection (in Polish).
26. Rintelmann W.F., Lindberg R.F., Simiteley E.K.: Temporary Threshold Shift and recovery patterns from two types of rock-and-roll music presentations. J. Acoust.Soc. Am. 1972; 51: 1249-1255.
27. Royster J.D., Royster L.H., Killion M.C.: Sound exposures and hearing thresholds of symphony orchestra musicians. J. Acoust. Soc. Am. 1991; 89: 2793-2803.
28. Rumsey F.: Mastering-art, perception, technologies. J. Audio Eng. Soc. 2011; 59 (6): 436-440.
29. Scharf B.: Recent measurements of loudness adaptation and the definition of loudness. [In:] Proceedings of the 14th International Congress on Acoustics; International Commision on Acoustics. 1992.
30. Sherrick C.E. Jr.: Effect of background noise on the auditory intensive difference limen. J. Acoust. Soc. Amer. 1959; 31, 239-242.
31. Smaldino J.J., Crandell C.C., Kreisman B.M., John A., Kreisman N.: Room acoustics for listeners with normal hearing and hearing impairment. [In:] Valente M., Hosford-Dunn H., Roeser R.J., (eds): Audiology Treatment. New York - Stuttgart: Thieme; 2008.
32. Takeshima H., Suzuki Y., Kono S., Sone T.: Growth of the loudness of a tone burst with a duration up to 10 seconds. J. Acoust. Soc. Jpn. 1988; 9, 295-300.
33. Toole F.E., Olive S.E.: The modification of timbre by resonances: perception and measurement. J. Audio Eng. Soc. 1988; 36 (3): 122-142.
34. Vickers E.: The Loudness War - Do Louder, Hypercompressed Recordings Sell Better? J. Audio Eng. Soc. 2011; 59 (5): 346-352.