PAN
ARCHIVES OF ACOUSTICS
Vol. **41**, No. 2, pp. 323–330 (2016)

DOI: 10.1515/aoa-2016-0033

Perception of Changes in Spectrum and Envelope of Musical Signals vs Auditory Fatigue

Maurycy J. KIN, Andrzej DOBRUCKI

Department of Acoustics and Multimedia, Faculty of Electronics
Wrocław University of Science and Technology
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland; e-mail: {maurycy.kin, andrzej.dobrucki}@pwr.edu.pl

(*received March 10, 2016; accepted April 22, 2016*)

The paper presents results of research on an influence of listening fatigue on the detection of changes in spectrum and envelope of musical samples. The experiment was carried out under conditions which normally exist in a studio or on the stage when sound material is recorded and/or mixed. The equivalent level of presented sound samples is usually 90 dB and this is an average value of sound level existing in control room at various recording activities. Such musical material may be treated as a noise so Temporary Threshold Shift phenomenon may occur after several sessions and this may lead to a listening fatigue effect. Fourteen subjects participated in the first part of the experiment and all of them have the normal hearing thresholds. The stimuli contained the musical material with introduced changes in sound spectrum up to ±6 dB in low (100 Hz), middle (1 kHz) and high frequency (10 kHz) octave bands. In the second part of research five subjects listened to musical samples with introduced envelope changes up to ±6 dB in interval of 1 s. The time of loud music exposure was 60, 90 and 120 minutes and this material was completely different from the tested samples. It turned out that listening to the music with an $L_{eq} = 90$ dB for 1 hour influences the hearing thresholds for middle frequency region (about 1–2 kHz) and this has been reflected in a perception of spectral changes. The perceived peaks/notches of 3 dB have the detection ability at 70% and the changes of low and high ranges of spectrum were perceived at the similar level. After the longer exposure, the thresholds shifted up to 4.5 dB for the all investigated stimuli. It has been also found that hearing fatigue after 1 hour of a listening influences the perception of envelope which gets worse of 2 dB in comparison to the fresh-ear listening. When time of listening to the loud music increases, the changes in envelopes which can be detected rise to the value of 6 dB after 90-minutes exposure and it does not increase with further prolongation of listening time.

Keywords: perception of spectral changes; temporary threshold shift; listening fatigue.

1. Introduction

The act of listening to musical sounds is usually considered as a kind of recreation, or an impulse to take a rest. Several studies (Chiou-Jong *et al.*, 2007; Jaroszewski, Rakowski, 1994; Kozłowski, Młyński, 2014) 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 Temporary Threshold Shift (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. From previous studies, a temporary decrease in auditory sensitivity in a normal ear was found after exposure to continuous noise levels above 80 dBA 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 (Ristovska *et al.*, 2015; Scharf, 1992) 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 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 (Chiou-Jong *et al.*, 2007). Although the studies mentioned above took into consideration the noise in this particular form as unwanted, mostly unpleasant sounds characteristic for industry, not for the art. But the music can also be considered as a noise not only from the musical structure and composers' point of view (Rakowski, 1996) – in some cases the listening to the music may not be only a kind of recreation – for particular professions this is the working activity. Reinforcement and recording engineers as well as sound producers 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. 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 during their preparation while the noise means that particular signal is assessed as awful and unpleasant. Also, the time-frequency structure of musical signals differs from the noise's consistence what makes the listening to music a pleasant act. But working with louder music as well as listening to it over a long period of time systematically may lead to a permanent hearing damage (Moore, 2016; Pawlaczyk-Łuszczynska *et al.*, 2011; Royster *et al.*, 1991) or a listening fatigue what makes the proper attention being impossible. The higher sound levels usually influence human concentration in a negative way, like the chaotic visual structures (Marcora *et al.*, 2009) what is based on psychology of perception. The results of a permanent hearing threshold shift of the people working in an entertainment industry as well as the influence of the kinds of equipment used has been widely presented (Dobrucki *et al.,* 2013; Rintelmann *et al.*, 1972). The recommendations of a daily-doze of noise for sound makers are not stated because of the nature of work beside the fact that it may cause permanent or temporary hearing damages. The typical effect of the listening to loud sounds is the TTS, which plays a huge role in the ability of the proper assessment of sound while working in a recording studio. The negative effects of temporary threshold shift may occur when someone is under the noise, or another loud acoustical signal, exposure for a particular time interval having a rest only after the whole work without breaks for recreation process.

In a recording and sound reinforcement trade, there is unwritten suggestion that working on some material should be no longer than two hours without a break. But during this time, the TTS may occur, and as a negative effect of this phenomenon a wrong balance in a whole frequency range may appear. It is known from literature (Scharf, 1992) 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. 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 (Moore, 2016). In a trade of recording and reinforcement the small corrections of sound spectrum as well as in time structure shall be done very often, and every change should be assessed in real time. When TTS phenomenon occurs, this is not possible to make these activities precisely enough to keep sound quality as good as possible. Thus, there is a need to define the maximum length of working in such environment, with different conditions enhanced by workload and heat stress (Chiou-Jong *et al.*, 2007). Another non-acoustical factor that influences the TTS values and returning to the original normal hearing threshold is also the psychophysics conditions of a listener's mind and especially his/her fatigue of listening, or attention. For example, when extreme intensities (greater than 95 dB SPL) or for susceptible ears at even the minimum level occur, the recovery time course is extremely long (e.g. 21 days). Thus, some authorities suggest to work in such environment with the use of earplugs or acoustical screens as hearing protectors (O'Brien, Beach, 2016) but many recording and reinforcement engineers do not prefer these means: there is a common opinion that they may disturb in working and do not allow to achieve a good quality of sound.

The main aim of this work was to measure the possibility of auditory system to detect relatively small changes of temporal and spectral structures of musical sounds for subjects working in a recording industry, after typical acoustical conditions being in a studio and other areas where the entertainment processes take place. The experiment was divided into two parts. In the first one, it was found how the listeners may recognize the relatively small changes introduced in spectra of the musical material. The second part of experimental research has its main aim to determine the smallest introduced changes in temporary structure of musical signal. Both experiments were provided before in-between and after exposure to the loud musical material which may simulate the typical conditions of studio, or stage nature of work.

2. Description of experiments

The detection of spectrum changes of musical signals was the subject to investigate in the first part of the research. Fourteen 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. Moreover, they have already started to occasionally practice mostly as assistants of reinforcement or recording engineers. They featured the normal hearing, i.e. the absolute threshold was no more that 10 dB HL in the entire frequency range (125 Hz to 15 kHz) what was confirmed by the air conduction measurements with the Maico M53 audiometers. The threshold measurements were carried out according to the applicable standards (ISO 8253-1:2010; PN-EN 26189) 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 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 were equalized at octave bands of 100 Hz, 1 kHz and 10 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 with Samplitude X-Professional editor. 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 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). 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 (Rintelmann *et al.*, 1972) as a reflection of typical distributions of sound pressure levels in musical selections performed by American rock&roll groups. 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 (Morawski, 1967).

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 what enabled to observe the TTS caused by the 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.

The second part of experiment was devoted to the ability of short changes detection in envelope of musical signals. The short increase of the envelope over of 1 second-interval was determined as 1.5 dB, 3 dB, 4.5 dB and finally 6 dB levels, and the subjects' task was to detect and denote if they perceived the change. The increase of the level was created in similar way as in the case of SISI test (Jestadt *et al.*, 1977; Sherrick, 1959). The rise and decay time durations were 100 ms. The repetition of the sample was not allowed. The time interval between samples was set at 1 s, and one trial contained 15 samples. The break between trials was set at 5 s. The scenery was typical as for the classical percentage of correct-answer procedure (Miller, 1948). The test sequences contained also the samples without any changes of envelope in order to control if the listeners' attention is still active and responses to the task are homogeneous. The sound material (the test samples as well as the disturbing noise) was the same as in the previous part of research. Five listeners were the subjects at this part of experiment – all of them participated the previous part of research.

Both tests as well as audiometric measurements were performed in the recording studio of the Wroclaw University of Science and Technology which fulfills recommended acoustical conditions (EBU, 1999; ITU-R, 1997). The whole material was exposed via Yamaha HS-50 stereo set at the equivalent level of 92.6 dB (max 101.6 dB). The time of listening was set as 60, 90 (60+30) and 120 (60+30+30) minutes and directly after every exposure time the test sequences for detection of spectral or envelope changes were presented. The differences between the three values obtained for particular frequencies or level of increase after the several time of exposure may show the nature of listening fatigue which reflects the ability of relatively small changes detection.

3. Results of measurements

In the Fig. 1 there are presented results of the first part of the research. They are expressed as the percentage of correct answer number obtained before and after the loud music exposure. For statistical treatment the Bartlett's test, which could be a generalized case of F-Snedecor testing (Gren, 1978), was applied. The statistics of the Bartlett's test features the distribution

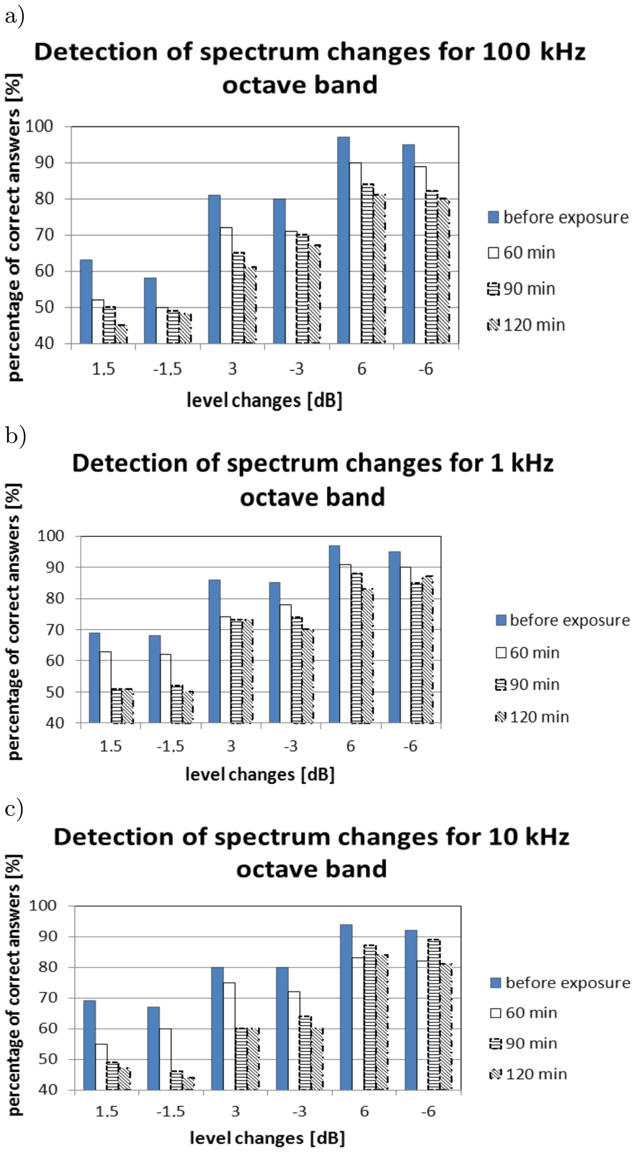


Fig. 1. Detection of spectrum changes for frequencies of 100 Hz (a), 1 kHz (b) and 10 kHz (c) for different values of level changes in particular octave band.

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. On the base of this test, for every time of the exposure, the results were homogeneous ($\chi^2 = 2.967 < \chi^2_\alpha = 28.869$, at $\alpha = 0.05$). Hence, 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 ($\chi^2 = 11.907 > \chi^2_\alpha = 5.986$, at $\alpha = 0.05$).

It can be noted that the decrease of ability to detect the spectrum changes for longer noise exposure has been observed particularly for lower changes and all frequency regions. Moreover, the number of false alarms is less than 4% of the number of total answers at specific condition what means that listeners mostly have not perceived the small changes in spectra. The changes of ±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 spectrum of musical signals is less effective. For the noise exposure longer than 1 hour the ability gets worse, especially for 10 kHz octave band where the only larger (±6 dB) equalization of the musical sounds may be perceived properly. For octave bands of 100 Hz as well as for 1 kHz, the perceived spectral changes at the level of 70% have been noted for ±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 answers reflecting the ability of detection of changes in spectrum of musical signal 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 changes between fresh-ear listening and perception after 2 hours 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 (de Bruijn, 1978; Green, 1983; Toole, Olive, 1988): the values reported in a literature are equal to 2–3 dB for similar frequency regions, what 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 a light of TTS values presented in Fig. 2. 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

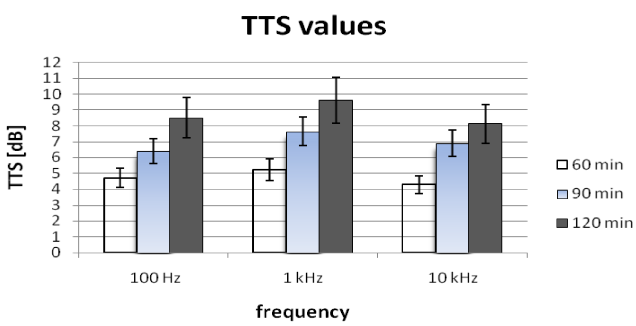
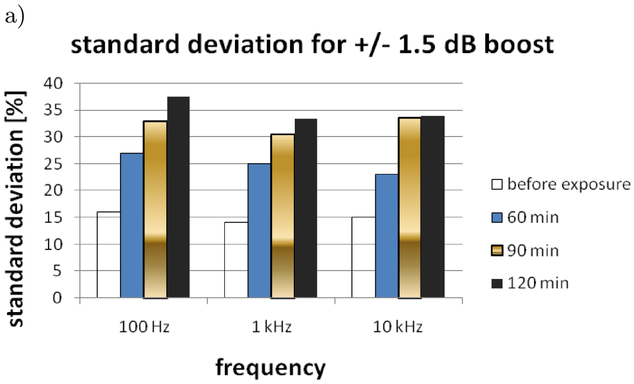


Fig. 2. Average values of TTS after noise exposure of 1 hour, 1.5 hour and 2 hours.

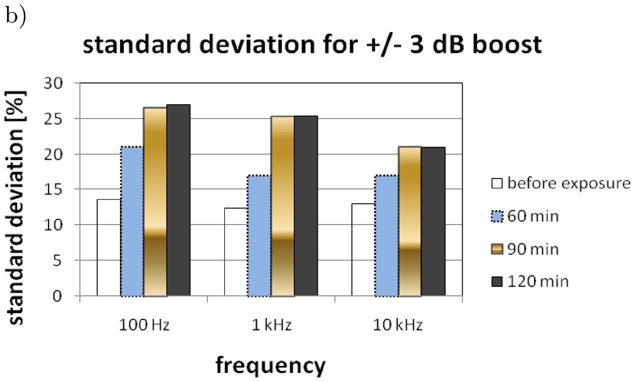
loud music exposure of 1 and 2 hours are about 4 dB, for all frequencies. These values are greater than those resulting from the detection ability presented in Fig. 1 because of the different stimuli used in both tests, although the character of changes is similar.

For a quality of the work activity in this particular profession it is important to detect these changes as accurately as possible, especially 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 what is presented in Fig. 3. These diagrams show that after every time of sound exposure the attention of listeners gets lower causing an increase of uncertainty during decision of evaluated musical samples.

a)



b)



c)

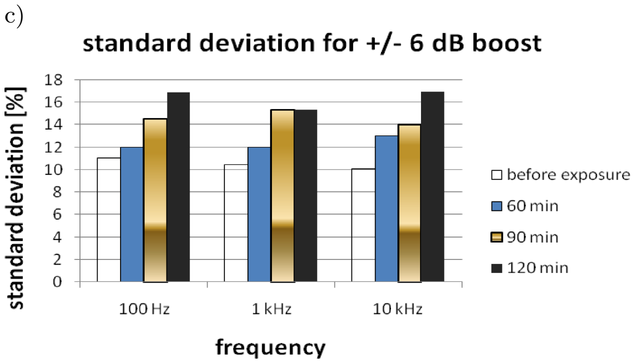


Fig. 3. Standard deviation values of percentage of correct answers for spectra changes of musical samples equal to: a) ±1.5 dB, b) ±3 dB and c) ±6 dB, measured at different time of loud music exposure.

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 monotonically: sometimes exposure time does not influence the value of SD ($\chi^2 = 2.871 < \chi^2_\alpha = 5.986$, at $\alpha = 0.05$), and sometimes this influence is significant (as for 100 Hz band, where $\chi^2 = 13.018 > \chi^2_\alpha = 7.802$, 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 causing 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 loud music listening) and this is in a good agreement with previously reported research (Kruk, Zawieja, 2013). 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 was 90 min. and further prolongation of noise exposition up to 120 min. does not influence the standard deviation values so it might be said that the concentration is kept at the same level. It should be also noted that the values of SD are higher for 100 Hz as modified frequency band than for higher frequencies what clearly means that uncertainty of spectrum change detection is worse for lower frequencies.

During the second part of experiment, noise exposure provided in the same way as previously (0, 60 min plus 30 min, plus 30 min) proceeded the test trials containing the samples in which a short increase of the envelope occurred over a period of 1 s with levels of 1.5 dB; 3 dB; 4.5 dB and 6 dB. The results are presented in Fig. 4. It can be seen that ability of short

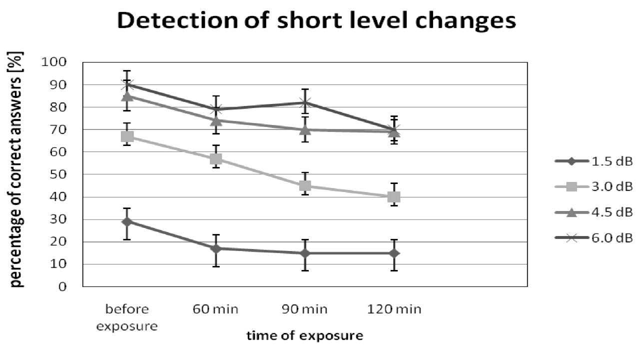


Fig. 4. The results of short level increase detection as the function of the noise exposure time (with the standard deviation values presented by vertical lines).

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 surprising in the light of SISI testing widely presenting in the literature (Jestadt *et al.*, 1977; Miller, 1948; Sherrick, 1959) where the short increase of sinusoid envelope occurs with the level of 1 dB. When the changes of envelopes (resulting in changes of loudness impression) are done with greater levels, their detection abilities significantly increase ($\chi^2 = 9.276 > \chi^2_\alpha = 7.682$, at $\alpha = 0.05$). Although, it should be indicated 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.

4. Discussion

The audibility of timbral modifications 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 (Toole *et al.*, 1998). 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 (Green, 1983) as well as a "classical" view on the timbre changes perception (de Bruijn, 1978). 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.

In the experiment, 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 in the light of intensity discrimination in dependence of listening fatigue degree. Although, in the literature one can find a normal hearing freshear or impaired hearing ability to this kind of stimuli (Green *et al.*, 1979; Takeshima *et al.*, 1988), 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 (Jaroszewski, Rakowski, 1994). It turned out that 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.

Finally, 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 (Scharf, 1992) 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 (Jaroszewski, Rakowski, 1994; Jaroszewski *et al.*, 1999). 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 percetion 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 (Jaroszewski *et al.*, 1998).

The results may also be influenced by the mental fatigue which occured after several time duration of permanently played loud sounds, together with demanding tasks. Such conditions involving the mental engagement in a noisy environment which refferred to the natural scenery of the studio work can significantly reduce the time of exhaustion what causes the decrease of accuracy in solving several tasks (Marcora *et al.*, 2009). 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 may cause not the TTS phenomenon but Permanent Threshold Shift (Dobrucki *et al.*, 2013).

5. Conclusions

Listening to the loud music, which is an integral part of work in the recording studio or on the stage, can cause a temporary or permanent loss of hearing sensitivity not only in the middle frequency region. For all the people who took part in the tests the worsening of listening ability was observed. The biggest changes were shown for frequency 1000 Hz and reached up to 3–5 dB if one takes into consideration the perception of spectral changes as well as the detection of small growth in loudness. On the base of the authors' observation, 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 (Rumsey, 2011), where the presented results of spectral or envelope changes measured in the experiment are higher almost twice. As it has been reported in literature (Chiou-Jong *et al.*, 2007), recovery from TTS after exposure cessation 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 (Chiou-Jong *et al.*, 2007; Scharf, 1992; Shailer, Moore, 1983) so it could 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. After a long listening to the sound transmitted via the particular monitors all artifacts may occur as a result of accommodation. Switching on and off between different loudspeakers may minimize partially that effect in terms of changing the listening environment. Because every loudspeaker features a different frequency response so reproduced signals may have a different sound colour, by switching devices our hearing system will not adapt. Thus, more effectively detecting details in the timbre of a sound is possible during the work.

Another vitally important aspect is to set the proper value of sound level. The aesthetical impression of music will be different when the level of playback also changes. To keep hearing abilities fresh for a longer time periods we should turn-down 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 enables them to hear slight differences, 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 what has been observed in group of professional musicians (Moore, 2016; Pawlaczyk-Łuszczynska *et al.*, 2011). To ensure the comfort of work in a recording studio or in a 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. This is the key to keep relaxed a hearing mechanism and a fresh perspective of the music that allows for making great recordings.

References

1. Chiou-Jong C., Yu-Tung D., Yih-Min S., Yi-Chang L., Yow-Jer J. (2007), *Evaluation of auditory fatigue in combined noise, heat and workload exposure*, Industrial Health, **45**, 4, 527–534.
2. de Bruijn A. (1978), *Timbre-classification of complex tones*, Acustica, **40**, 2, 108–114.
3. Dobrucki A.B., Kin M.J., Kruk B. (2013), *Preliminary study on the influence of headphones for listening music on hearing loss of young people*, Archives of Acoustics, **38**, 3, 383–387.
4. Green D.M., Nachmias J., Kearney J.K., Jeffress L.A. (1979), *Intensity discrimination with gated and continuous sinusoids*, J. Acoust. Soc. Amer., **64**, 1051–1056.
5. Green D.M. (1983), *Profile analysis: A different view of audiology intensity discrimination*, American Psychologist, **38**, 2, 133–142.
6. Gren J. (1978), *Statistics – models and exercises* [in Polish], PWN, Warszawa.
7. Jaroszewski A., Rakowski A. (1994), *Loud music induced threshold shifts and damage risk prediction*, Archives of Acoustics, **19**, 2, 311–321.
8. Jaroszewski A., Fidecki T., Rogowski P. (1998), *Hearing damage from exposure to music*, Archives of Acoustics, **23**, 1, 3–31.
9. Jaroszewski A., Fidecki T., Rogowski P. (1999), *Exposures and hearing thresholds in music students due to training sessions*, Archives of Acoustics, **24**, 2, 111–118.
10. Jesteadt W., Wier C.C., Green D.M. (1977), *Intensity discrimination as a function of frequency and sensation level*, J. Acoust. Soc. Amer., **61**, 169–177.
11. Kozłowski E., Młyński R. (2014), *Effects of acoustic treatment on music teachers' exposure to sound*, Archives of Acoustics, **39**, 2, 159–163.

12. Kruk B., Zawieja B. (2013), *Improve the listening ability using e-learning methods*, 134th AES Convention, Rome, Italy, preprint 8870.

13. Marcora S.M., Staiano W., Manning V. (2009), *Mental fatigue impairs physical performance in humans*, Journal of Applied Physiology, **106**, 3, 857–864.

14. Miller G.A. (1948), *The perception of short burst of noise*, J. Acoust. Soc. Amer., **20**, 160–170.

15. Moore B.C.J. (2016), *Effects of sound-induced hearing loss and hearing aids on the perception of music*, J. Audio Eng. Soc., **64**, 3, 112–123.

16. Morawski S. (1967), *The aesthetical studies, Part IV* [in Polish], [in:] *The selection of aesthetic papers*, Universitas, Kraków, 2007.

17. O'Brien I., Beach E.F. (2016), *Hearing loss, earplugs use and attitudes to hearing protection among non-orchestral ensemble musicians*, J. Audio Eng. Soc., **64**, 3, 132–137.

18. Pawlaczyk-Łuszczynska M., Dudarewicz A., Zamojska A., Śliwińska-Kowalska A. (2011), *Evaluation of sound exposure and risk of hearing impairment in orchestral musicians*, International Journal of Occupational Safety and Ergonomics, **17**, 3, 255–269.

19. Rakowski A. (1996), *Noise as music*, Archives of Acoustics, **21**, 3, 267–274.

20. Ristovska L., Jachova Z., Atanasova N. (2015), *Frequency of the audiometric notch following excessive noise exposure*, Archives of Acoustics, **40**, 2, 213–221.

21. Rintelmann W.F., Lindberg R.F., Simiteley E.K. (1972), *Temporary Threshold Shift and recovery patterns from two types of rock-and-roll music presentation*, J. Acoust. Soc. Amer., **51**, 1249–1255.

22. Royster J.D., Royster L.H., Killion M.C. (1991), *Sound exposures and hearing thresholds of symphony orchestra musicians*, J. Acoust. Soc. Amer., **89**, 2793–2803.

23. Rumsey F. (2011), *Mastering – art, perception, technologies*, J. Audio Eng. Soc., **59**, 6, 436–440.

24. Scharf B. (1992), *Recent measurements of loudness adaptation and the definition of loudness*, Proc. of the 14th ICA.

25. Shailer M.J., Moore B.C.J. (1983), *Gap detection as a function of frequency, bandwidth and level*, J. Acoust. Soc. Amer., **74**, 467–473.

26. Sherrick C.E. Jr. (1959), *Effect of background noise on the auditory intensive difference limens*, J. Acoust. Soc. Amer., **31**, 239–242.

27. Takeshima H., Suzuki Y., Kono Shunici, Toshio Sone (1988), *Growth of the loudness of a tone burst with a duration up to 10 seconds*, J. Acoust. Soc. Jpn., **9**, 295–300.

28. Toole F.E., Olive S.E. (1988), *The modification of timbre by resonances: perception and measurement*, J. Audio Eng. Soc., **36**, 3, 122–142.

29. ITU-R: Recommendation 1284, (1997), *Methods for the subjective assessment of sound quality – general requirements*, Geneva, Switzerland.

30. EBU Technical Recommendation R22-1999, *Listening conditions for the assessment of sound programme material*, EBU Geneva, Switzerland.

31. ISO 8253-1:2010, *Acoustics – audiometric test methods – Part 1: Pure-tone air and bone conduction audiometry.*

32. PN-EN 26189, *The measurements of hearing threshold by audiometric air conduction for hearing protection* [in Polish].