ORIGINAL ARTICLE

UDC: 616.28-008.14-057
DOI: 10.2298/VSP140416119M

The effects of industrial noise of higher spectrum on workers' auditory perception abilities

Uticaj industrijske buke povišenog spektra na sposobnost slušne percepcije kod radnika

Dobrivoje Mihailović*, Nenad Djurić†, Ivana Kovačević*, Djordje Mihailović‡

***Faculty of Organizational Sciences, University of Belgrade, Belgrade, Serbia; †General Affairs and Training Department, Military Medical Academy, Belgrade, Serbia; ‡High Technology School of Profesional Studies, Arandjelovac, Serbia**

Abstract

Background/Aim. Results of previous studies gave support to the idea that machines in power plants produce noise of different levels of loudness and frequency, and that it could cause deterioration of the hearing ability of workers. As a matter of fact, noise-induced hearing loss is the most widespread occupational disease nowadays. As noise is a complex acoustic phenomenon, more factors have to be considered when studying it, such as frequency, intensity and the period of exposure. The aim of this study was to find if there are differences in the absolute threshold of hearing between workers in the factory production lines that are constantly exposed to the industrial noise of higher spectrum and those exposed to the noise of standard spectrum at different frequencies of sound. **Methods.** In the research plan, there were 308 workers employed in the production line of the Factory "Knjaz Miloš", Aranđelovac. A total of 205 of them were working in the conditions of higher spectrum noise (4,000 Hz – 8,000 Hz) and 103 workers were exposed to standard noise spectrum (31.5 Hz – 2,000.0 Hz). The objective measures of noise (frequency and amplitude) were acquired by phonometer, and measures of absolute threshold of hearing for both ears were obtained by audiometer by exposure to nine sound frequency levels. Data were statistically analyzed by establishing the significance of differences between absolute thresholds of hearing for both groups and for all nine frequency levels. **Results.** It was found that the absolute threshold of hearing is significantly higher for the group exposed to high-frequency noise at the 4,000 Hz and 8,000 Hz levels of frequency. **Conclusion.** Reduction of hearing sensitivity is evident for those exposed to higher spectrum noise, which is particularly evident at the higher frequency levels. Employees are often unaware of its effects because they are the results of prolonged exposure. Therefore, working in those conditions requires preventive measures and regular testing of the hearing ability.

Key words:
noice, occupational; occupational exposure; serbia; hearing disorders; auditory perceptual disorders.

Apstrakt

Uvod/Cilj. Rezultati ranijih studija govore u prilog ideji da mašine koje u proizvodnim halama prave buku različite frekvencije i jačine, mogu prouzrokovati slabljenje slušne sposobnosti radnika. Gubitak sluha prouzrokovan bukom jedno je od najrasprostranjenijih profesionalnih oboljenja. Buka je složeni fenomen, te je stoga potrebno u razmatranje uzeti više faktora, kao što su frekvencija, jačina i dužina izloženosti. Cilj istraživanja bio je da se proveri da li postoje razlike u apsolutnom slušnom pragu između zaposlenih koji su dugotrajno izloženi buci visokog spektra i onih koji su izloženi buci umerenog spektra, pri različitim frekvencijama zvuka. **Metode.** Istraživanje je obuhvatilo 308 zaposlenih u proizvodnom pogonu preduzeća „Knjaz Miloš" u Aranđelovcu. Ukupno 205 zaposlenih radilo je u uslovima buke povišenog (4 000–8 000 Hz), dok je njih 103 radilo u uslovima buke standardnog spektra (31,5–2 000,0 Hz). Objektivne mere buke (frekvencije i amplitude) dobijene su pomoću fonometra, a mere apsolutnog slušnog praga za oba uha pomoću audiometra, pri izlaganju zvuku na devet nivoa frekvencija. Podaci su analizirani proverom statističke značajnosti razlika u pogledu apsolutnog praga draži za obe grupe, na svih devet frekventnih nivoa. **Rezultati.** Rezultati su pokazali da je apsolutni slušni prag značajno viši kod ispitanika izloženih buci višeg spektra i to na frekventnim nivoima od 4 000 i 8 000 Hz. **Zaključak.** Smanjenje čulne osetljivosti primetno je kod onih radnika koji su izloženi buci višeg spektra, što je naročito vidljivo pri merenjima na višim frekventnim opsezima. Zaposleni su često nesvesni ovih efekata jer su oni posledica dugotrajne izloženosti. Stoga se preporučuju preventivne mere i redovno audiometrijsko testiranje čula sluha.

Ključne reči:
buka na radnom mestu; profesionalna izloženost; srbija; sluh, poremećaji; slušna percepcija, poremećaji.

Correspondence to: Dobrivoje Mihailović, Faculty of Organizational Sciences, University of Belgrade, Jove Ilića 54, 11 000 Belgrade, Serbia. E-mail: mihailovic.dobrivoje@fon.bg.ac.rs

Introduction

Noise is one of the most frequent environmental, as well as workplace pollution factors [1]. Noise pollution is the third in scope, following air and water pollution [2]. There is no doubt that noise is pervasive and affects more than a billion people. It is also one of the threats to human well-being and work ability [3, 4]. The presence of noise is the result of mass usage of different production appliances, technological processes and audiovisual and explosive devices [5].

Psychologically, noise is unwanted sound and sound is created by rapidly changing air pressure and provoking vibrations in the eardrum [6]. There are two main physical parameters to consider while analyzing the sound. First, there is the question of frequency (of waves) which is perceived as a higher or lower pitch, and the question of the height (amplitude) of waves that we experience as loudness [6]. Besides its intensity and durability, it also has a quality of dynamics in appearance, tone, harmony and resonance [5].

Although we often use physical measures of sound, we are really more interested in the brain`s interpretation of sound stimuli. Interpretation of the sound as a noise depends on physical and psychological factors [1]. It is a complex acoustic phenomenon often manifested as diffuse collection of sounds evoking unpleasantness and annoyance among those exposed to them. More precisely, noise is defined by the sounds in amplitude of frequencies between 16 and 20 000 Hz, with the intensity of 5 to 100/120 dB [7]. In terms of physical quality, sound is defined as the prevalent frequency wavelength of the source of sound. Human auditory sense has a different sensitivity and different threshold for different frequencies [1]. So, on some levels it is considerably higher than on the others. The general rule is that the sensitivity is amplified at medium levels of frequency in the area of human speech and slightly above it, and that it is lower at the beginnings and ends of the intervals of human hearing [7].

Alberti [8] claimed that noise-induced hearing loss happens to be the most widespread occupational disease in industrialized countries. Also, previous studies show that there are some occupations that are particularly hazardous due to exposure to higher levels of noise and that the noise-induced hearing loss is a common symptom [9]. Occupational noise is one of the physical characteristics of the work setting to which the workers have to adapt. Their capacity for adaptation depends on different parameters of noise, its quality and meaning. Also, in office and industrial settings the nature of work tasks and activities are relevant [1]. Further, the consequences of noise exposure are connected with its controllability [10], duration[4], personal characteristics [11] and current state of organism [12]. In cases of chronic noise exposure, which are frequent in industry, there is a decrease in performance combined with a wide spectrum of different behavioral aftereffects [13].

Finally, noise is seen as an environmental stressor [1] that has serious effects on the workers mood [14], attention [15], job satisfaction [16], psychological well-being [5, 7], stress [17] and performance [18]. Nevertheless, researches did not find direct effects of noise on productivity in industry [7]. Bell et al. [1] believe that the influence is indirectly mediated by other psychological consequences of noise. In the work protection practice and in a few studies [4, 9, 19, 20] the focus is on the intensity and duration of sound that generates noise. Despite the humans` huge potential to adapt to noise and to carry on performing quite well [7], it has its costs and consequences on health. Among other negative effects (on the functioning of the autonomic nervous system [1, 5] and on mental health [1, 5]), prolonged work in the conditions of industrial noise of higher spectrum has adverse effects on auditory perception abilities of workers [21]. More than a few researchers confirmed that exposure to noise of high intensity may cause momentary or even permanent hearing damage [9, 21]. This effect is more serious than the effects of noise of standard spectrum, especially when the exposure to noise is recurring [2, 4, 8, 22, 23].

Following the given trend of speculation, our research goal was to find if there were differences between long-time effects of industrial noise of high and moderate intensity at different frequency levels, on audio perceptual abilities of exposed workers performing relatively simple tasks at the production line in the liquid production industry. There was an implicit idea to put the focus on detecting the characteristics of effects of higher spectrum noise (4,000 Hz – 8,000 Hz).

The impairment of the workers` hearing abilities would be detected and inferred based on measuring of baseline amplitude thresholds at different (nine) noise frequencies. It is a well-known fact that, "when a hearing loss occurs at the given frequency, it requires more than the normal amplitude (in dB) for a person to hear that frequency" [1]. It means that amplitude threshold would be greater in the situations of hearing decline. Subsequently, the hypothesis emerged and we expected that there would be significant differences in threshold levels between workers exposed to high and moderate intensity noise with the greater hearing amplitude threshold for subjects exposed to high intensity noise. That should be especially true for higher spectrum noises (from 4,000 Hz up to 8,000 Hz). So, there was an assumption that higher thresholds would be assessed among workers in the group exposed to high-frequency noise with the stronger effect obtained on measures at the high level of frequencies than on standard frequency levels.

Methods

This study is a part of the longitudinal research with the same procedure administered in 1985, 1995, 2005, and, finally, data presented here were obtained in 2012 at an industrial plant (bottling plants of 1 and 2 factory lines) of the "Knjaz Miloš" corporation at Aranđelovac, Serbia. During the years, some technological innovations were introduced. In the last decade improvements of the working conditions included the reconstruction of the old halls and better sound isolation of the ceiling and walls. Also, as sources of noise, machines were protected with acoustic planking, and the main technological improvement was achieved by providing the gradual slowdown of the transporting conveyor in order to prevent bottles from striking one another and generating unwanted sound. A remarkable fact in the context of health

protection of workers is the availability of silicone antiphons for each worker. Yet, as we unofficially found out, a great percentage of them avoid using this kind of sound protection. Therefore, the problem of noise remains.

In order to test the hypothesis that there are differences in the hearing ability of subjects continually exposed to noise of standard and high intensity, two instruments were used at the different levels of frequency range. Measuring of the objective presence of noise was carried out within the periodical (semi-annual) control of microclimate conditions with phonometer (sound level meter) and analyzer (Iskra-Kranj). Assessment was conducted at the workplace during the working hours. The instrument was positioned at seven working locations. The first measures were obtained in the first production line at the stationary for washing bottles. The second was conducted in the middle of the hall. Subsequently, the measures of noise were obtained from the second production line at the stationary for washing bottles and then at the bottling stationary. At these locations a high-frequency noise was recorded. On the other hand, measures at the compressor station, accumulation plant and on carpenters‘ were of low frequency. The measures of noise intensity are collected in the context of different noise frequencies.

Noise amplitude, subjectively perceived as loudness, is given in dB although it is objectively measured. As a matter of fact, the size of the amplitude wave expresses the energy or pressure in the sound wave, where the greater the pressure, the louder the sound. So, the objective measure of the noise intensity is given in microbars. Nevertheless, decibels (dB) are taken as the basic units of sound being the logarithmic function of microbars [1]. It is also given as a measurement unit in instructions for the instrument. Due to the fact that we use decibels as a measure unit, we bear in mind that the human ear is differently sensitive to sounds at different frequencies and we made some comparisons between these cases.

In this research, we limited our interests to measuring the absolute hearing threshold for different noise frequencies. The human ear can register frequencies between 20 and 20,000 Hz and the absolute threshold is the minimal quantity of energy (physical and chemical) sufficient to produce the first barely recordable sensation [5]. This measure is often used for establishing perception abilities. The inability to hear pure tones below 25 dB indicates hearing problems [7]. The measuring procedure in the study was determined by technical possibilities for measuring and common practice. The procedure was completely safe and not harmful for subjects. The absolute threshold of hearing among workers was determined using the test apparatus audiometer (Siemens RA2000) that registers atlas-audiogram. The minimum volume required to hear each tone was graphed. The audiogram was used for both ears. During the procedure of measuring one ear, the other was blocked and pure tones of controlled intensity were delivered to one ear at a time. The subjects were expected to indicate that they heard the sound by raising their hand.

The measures were taken at frequencies of 31.5; 63; 125; 250; 500; 1,000; 2,000; 4,000 and 8,000 Hz. We conducted 9 assessments for the left and 9 for the right ear *per* worker. So, it took 18 assessments *per* subject. If there were (which was rare) differences in measures for the left and right ear, we took the average value for the hearing threshold parameter. Considering that the measuring procedure takes about 10–15 min for 9 frequency levels, we spent approximately 20 min *per* each subject, which implies that we ideally needed about 100 h for conducting the research. In reality, we conducted the field study for over a month. Data was collected during the month of December. The reason for choosing that period is that it is the month with the most intense production. So, the field study was conducted during the working hours throughout the month of December 2012.

The whole sample consisted of 308 respondents with the exposure period to noise from one to 28 years. They were working in two shifts with a half-hour break. The sample was convenient, but comprising about 90% of all employees in the production line of the “Knjaz Miloš” industrial plant. There were no overt objections to participating in the study, but those 10% of workers not included in our sample were absent from the workplace. So, this relatively low rate of rejection is a consequence of the procedure. As a matter of fact, our study was conducted as part of the regular systematic examination of the workers` health condition. Further, the sample might be representative of the workers who are exposed to noise in the glass production line with similar technological method due to the fact that this is the largest bottler plant with glass packaging in our country. Nevertheless, we could not extrapolate data on other employees in the plant engaged on different jobs and in different work conditions.

According to the results of the measuring of loudness and frequency, workers were surrounded with the constant source of sound, and we agreed that their workplace physical conditions were defined by constant occupational noise. Nevertheless, their working tasks were not cognitively demanding, which is an important factor due to the fact that noise might diminish cognitive performance [7]. The background noise may also interfere with relevant communication among employees. The work process was organized in such a way that the tempo was dictated by the machine (production line) and the communication among workers was not required.

The research sample was divided into the group of 205 workers exposed long-term to noise in the production hall (washing and bottling machines) and a group of 103 workers exposed to noise while working at three locations outside the production line (compressor and accumulator station, machine, electro and carpenters studios). So, we could conclude that the working conditions varied according to which production line they were assigned to and due to the nature of their working tasks, they were exposed to lower or higher levels of noise intensity.

Both groups were approximately equal in age: in the first group the average age was $\bar{x} = 33.2$ and in the second group it was $\bar{x} = 35.4$. Further, the average age of workers in the conditions of acoustic pressure for the first group was $\bar{x} = 10.4$ and for the second group $\bar{x} = 11.4$. Although previously conducted researches on the topic did not find si-

gnificant differences between genders [5], it might be informative to say that 41% of the sample included female workers and 59% were male. A total of 42% of females were working in louder conditions, while 58% of the female sample worked in the conditions of moderate frequency noise. Some of these parameters are given in Table 1.

Statistical analysis of the obtained data was conducted with appropriate techniques. The hypothesis was tested by establishing the existence of statistically significant difference between the means using *t*-test for independent sample.

Results

The results of the comparison of auditory perception abilities of the two groups of workers exposed to industrial noise of high and moderate noise levels might be better understood in the context of exposure duration over the years (Table 1). Accordingly, we could see a similar trend in the distribution of workers in the high and moderate intensity noise exposure groups. Nevertheless, the highest percentage of workers in the production hall was in the category of those working from 9 to 12 years (37.1%), compared to the group of workers in the other subsample (working outside the production hall) working from 17 to 20 years were prevalent (48.54%).

Also, the number of female and male workers in both groups was approximately equal and, what is more important, there were no significant differences in the average absolute threshold of hearing (ATH). For female workers at the frequencies of f = 4,000 Hz it was ATH $\bar{x}$ = 39.01 dB, and for male workers ATH $\bar{x}$ = 40.59 dB. For those working in the moderate noise conditions, at the same frequency, it was found that the average ATH was $\bar{x}$ = 35.72 dB for females and $\bar{x}$ = 35.92 dB for males. At f = 8,000 Hz, the difference was almost similar, although values for thresholds were lower. For female workers working in the conditions of higher noise average ATH was $\bar{x}$ = 29 dB, and for males ATH was $\bar{x}$ = 27.23 dB. In moderate noise conditions average ATH was $\bar{x}$ = 28.93 dB for female workers and $\bar{x}$ = 27.55 dB for males (Table 1).

According to the objective parameters obtained by the phonometer for the group exposed to high-frequency noise, noise level near the machines for washing bottles at the production line 1 was 99 dB; noise level in the middle of the production hall was 94 dB; noise level near the machines for washing bottles at the production line 2 was 96 dB; noise level near the machines for bottling at the production line 1 was 96 dB; noise level near the machines for bottling at the production line 2 was 98 dB.

Octave analysis of sound in this hall (production lines 1 and 2) gave results shown in Table 2.

Table 2 shows that noise exceeds the acceptable level in frequency area between 4,000 and 8,000 Hz.

On additional premises placed outside the production hall, the acoustics was analyzed in several positions: noise level in compressor station was 96.5 dB; noise level in accumulation plant was 81.5 dB; in carpenter station 91.5 dB. Octave analysis of noise in these locations is given in Table 3.

Verification of the hypothesis that prolonged work in conditions of industrial noise of higher spectrum (4,000 –

Table 1

Distribution of noise exposure time (in years) among the employees working in the production hall compared with the employees working outside the production hall

Exposition time (years)	Work location, n (%)	
	Production hall	Outside production hall
≤ 4	5 (0.29)	6 (4.85)
5–8	60 (29.23)	18 (17.46)
9–12	74 (37.10)	18 (17.46)
13–16	20 (9.76)	16 (15.53)
17–20	17 (8.29)	20 (48.54)
21–24	17 (8.29)	14 (13.59)
≥ 25	12 (5.85)	11 (10.68)
Total	205 (100.00)	103 (100.00)

Table 2

Noise intensity measures for different noise frequencies at three locations outside the production hall

Average values of noise frequency amplitude (area) (Hz)	Noise intensity (dB)			
	Washing mashine – production line 1	In the middle of the hall	Washing mashine – production line 2	Bottling machine – production line 2
31.5	32.0	31.5	34.5	30.0
63.0	37.0	32.5	38.0	35.5
125.0	39.5	35.0	39.5	38.0
250.0	43.5	42.0	45.0	41.0
500.0	44.0	44.0	47.0	42.5
1000.0	50.0	48.0	52.0	48.5
2000.0	62.5	60.0	63.0	62.0
4000.0	90.0	89.5	91.0	88.5
8000.0	91.0	99.5	92.5	99.5

Table 3

Noise intensity measures for different noise frequencies at three locations outside the production hall

Average values of noise frequency (Hz)	Noise intensity (dB)		
	Compressor station	Accumulation plant	Carpenters`
31.5	73.5	71.0	71.0
63.0	76.0	73.0	73.0
125.0	78.5	78.5	77.0
250.0	81.5	84.0	80.0
500.0	93.0	94.5	93.5
1,000.0	87.0	88.0	87.5
2,000.0	72.0	74.0	71.0
4,000.0	57.5	52.5	49.0
8,000.0	30.0	39.0	39.5

8,000 Hz) has stronger effect on the deterioration of perception abilities in the domain of the hearing sense, than work in the conditions of noise of standard spectrum (31.5 – 2,000 Hz), when those two categories of noise have approximately equal intensity and duration of exposure chracteristics, was accomplished by analyzing the differences between means obtained for the two groups. Specifically, the effects of noise on perception abilities of workers were verified by testing the significance of differences between the means of absolute threshold of audio perception of the group working in the production hall (where noise intensity exceeded the acceptable level in higher levels of frequency) and group working outside the production hall. Differences were analyzed on each and every nine levels of frequency and the results are given in Table 4.

Table 4

Differences between the means of the absolute thresholds of hearing on each frequency level, for the group exposed to high intensity noise and the group exposed to moderate intensity noise (working outside and in the production hall)

Frequency level (Hz)	Mean difference	*p*	df
125	1.17	n.s.	307
250	0.15	n.s.	307
500	1.20	n.s.	307
1,000	0.11	n.s.	307
2,000	0.89	n.s.	307
3,000	2.08	n.s.	307
4,000	7.55	< 0.01	307
6,000	1.80	n.s.	307
8,000	11.89	< 0.01	307

Data given in Table 4 show that differences in the ATH between the employees working in the conditions that exceed the noise intensity at some frequency levels (in the production hall), and those working in conditions of moderate intensity noise (outside the production hall) are detectable only at the particular frequency levels. As a matter of fact, we could imply that the absolute threshold for the high frequency tones continues to increase as the level of frequency approaches extreme levels (2,000 Hz). So, with the frequency increasing, the difference between absolute thresholds of the two groups rises. Nevertheless, we could notice that the differences of means for ATH hearing were statistically significant at the level of $p < 0.01$ only at the frequency areas of 4,000 Hz and 8,000 Hz. No statistically significant differences between the means were found on other measured levels of frequency. The results of the study gave us support for the main hypothesis that threshold levels of hearing abilities are higher among those industrial workers who are continually exposed to higher noise intensity levels at the higher-frequency spectrum with one limitation (at the frequency areas of 6,000 Hz).

Discussion

When comparing general hearing capabilities of the employees working in conditions of different levels of noise intensity at the workplace, there were no data enough to conclude unambiguously that noise intensity itself increases the ATH. Moreover, we could not be sure, if the difference occurs, whether it is temporary or a noise-induced permanent threshold shift. Only by observing thresholds at different levels of noise frequency we can gain better understanding of the phenomenon.

Accordingly, we found that there were tendencies of the ATH to increase with the increment in frequency level. This inclination had some oscillations on lower levels of

frequencies and at the frequency of 6,000 Hz for both groups. So, data give evidence that a decline in hearing sensitivity was obvious in the high tones area and it could also be registered in working conditions of moderate intensity of noise. As a matter of fact, some studies imply that moderate levels of low frequency noise could also have adverse effects (annoyance [24] or sleepiness [25]), but there were no proofs for establishing the link with the physiological reactions and hearing impairment [25]. Analysis of the amplifying trend of the absolute threshold suggest that the difference between the groups will increase toward the higher tones, which was corroborated in this study. Also, the difference between workers exposed to sounds from the medium level of the audibility intensity could be explained in similar manner.

The fact that the main effects of noise found at frequency levels higher than 4,000 Hz could be explained, as in some previous researches, and in accordance with the results of those studies [9, 26, 27]. For example, according to the study of Pražić [21] initial acoustic trauma develops at the level of 4,096 Hz, as well as 4,186 Hz. At those frequencies, audiometrics showed a lowering of the ATH for about 30 db. Nevertheless, some contemporary studies do not support those points of initial trauma. Current researches stands on a position that the critical diapason of frequencies is between 3,500 and 5,000 Hz, depending on noise intensity and other sound characteristics. Also, Rachiotis et al. [9] found that 44% of electro production workers had hearing loss located mainly at 4,000 Hz. Interestingly, they found that smoking might be associated with the prevalence of hearing impairment among workers. Finally, the differences were found among workers exposed to noise of diverse intensity and frequencies spectrum posted in our hypothesis. The hypothesis that the ATH would be different for workers exposed to a variety of noise intensity in two diverse working conditions were proven for the two levels of frequency (4,000 Hz and 8,000 Hz). Sudden increase in absolute threshold in sound perception at the frequency of 4,000 Hz was rather expected, but not in so evident manner, which is especially distinct for the group working in conditions considered as being of higher intensity noise. Possible explanations could be found in the facts connected with the structure of sound as a stimulus. By octave analysis of sound in the production plant, the most intensive level was established at the amplitude between 2,000 and 8,000 Hz. These differences might also be explained in the context of similar studies considering the threshold effects of noise of different spectrum [8, 9, 19, 21–23, 26].

First of all, the perception of the loudness of sound is different at different frequency levels due to the fact that it depends on it [6]. Further, diminishing of the hearing sensitivity at a particular frequency level is detectable by the variation of baseline of amplitude thresholds. When more than usual (normal) amplitude is required for a person to hear particular frequencies (higher amplitude threshold), hearing problems occur. As a measure of declined acoustic sensitivity, scholars often use index of hearing loss, that indicates the number of decibels above the normal threshold required for reaching the new threshold [1]. At last, it is believed that high sound stimulation gradually leads toward the contraction of the cochlear blood vessels to cause hypoxia that slows down the metabolism of sensor cells and their functional processes [21]. Initial hearing loss, first found in the area of frequencies around 4,000 Hz, could be explained by the fact that the sensitivity for sound of this quality is localized in the part of the cochlea with the least blood supply. Constant exposition to the effects of sound affects more and more sensor cells, more and more regions of the cochlea [1, 21].

Alternatively, the results might be seen in the light of the sample characteristics. In our sample, workers working between 4 and 10 years were prevalent (72.59%). Among the subjects with this period of exposure to intensive noise, it was expected to find the effect of "initial acoustic trauma" that is particularly evident in the range of frequencies mentioned above [5]. According to the available, but not sufficiently verified data from the literature [2, 4, 8, 21, 23, 26] the first indices of professional hearing loss arrives later, with initial permanent impairment of auricular sensitivity. In the beginning, augmentation is subtle and the subject does not notice any changes and does not experience any defect. In this particular period, localization of the damage affects the area of high tones that are above the speech zone. The insensitivity of auricular could be found in frequency area between 3,000 and 6,000 Hz. Obvious hearing loss occurs while the hearing sensitivity broadens toward frequencies of 2,000 Hz and further toward 10,000 Hz and more. Further exposure to the hazardous conditions continues toward the more severe damage of auricular function [3, 19, 23, 28].

Consequently, traumatic changes in hearing might be irreversible and for the moment there is no curative. A single action that could be undertaken is to remove the victim from the acoustically perilous situation, so that the damage would not be total. This is the main reason why the more regular periodical audiometrical measuring of the hearing function of workers in risky occupations and jobs is extremely important [5]. This is particularly significant because workers are rarely aware of causality of their deafness [20]. It emerges rather in slow pace and progressively. Although studies continuously demonstrate that occupational noise appears to be the strongest predictor of hearing loss among workers (before aging and other factors), relatively modest attention is dedicated to this problem [9]. Some of the reasons are certainly its complexity and obscurity and some shortcomings of our studies are connected with this fact. We only tackled the issue by trying to keep work characteristics constant and to control the years of exposure, age and gender. The research design of our study is rather simplified due to the idea to prove working condition differences in noise intensity on hearing threshold levels along the spectrum of noise frequencies. Nevertheless, the effects of noise are not only hard to recognize, but they are complex. They cover a wide range of neurological and psychological symptoms. Measuring other physiological parameters along with the hearing threshold, as some studies did [14, 26], might give us a more precise perception of the deteriorating impact of high frequency and intensity noise. Also, the effect of potential stress related to the noise exposure is not controlled. Stress

reactions and stress related disorders are tightly related to prolonged noise exposure [19]. As a matter of fact, stress might interfere between noise and other functions, producing the well known side effects of unwanted sounds [29, 30]. Further, Leather et al. [17], found that lower levels of occupational noise could mitigate the negative impacts of job stress on health and job satisfaction variables. Also, the effects of noise might be modified by different personal and situational variables [12]. Studies often found the mediating effect of the individual characteristics of workers exposed to noise [11] as well as the effect of contextual variables (work characteristics) [14, 23, 25]. For example, in a study of Bjelojevic et al. [11] the lack of concentration and fatigue symptoms related to noise conditions occurred only in the group of introvert subjects, compared with extroverts who also performed faster in noise conditions. Some studies introduced the psychological parameters of depression, hostility, tension [14] with many different indicators of workers' well-being. Gopinath et al. [28] dealt with cardiovascular problems and even death.

On the other hand, while Eleftheriou [23] conducted the research to analyze a wide range of different occupational domains, Fernandez et al. [20] covered a variety of different tasks in the construction process, and there are studies that combine different microclimate features with noise pollution (vibration [29] and other atmospheric parameters [3]). Our research was focused only on the variety of conditions in one plant.

Previous researches show that prolonged noise of high intensity might cause serious health problems, even death [28]. Starting with the possibility to permanently damage the peripheral auditory organ, it can also cause changes in cortical responses to sounds even if there are no external indicies [18]. Therefore, further studies should go into two directions. First, there is an attempt to deal with individual differences that might interfere with noisness working conditions combined with the mental load of the activity undertaken. Second, different effects of noise should be taken into consideration, such as psychological and physiological health issues, as well as the performance. Further, although our study gave similar results as Rachiotis et al. [9] got in their research, they found the potential effect of smoking on hearing loss, the variable that we did not incorporate in our analysis.

Severity, reversibility, delicacy and pervasiveness of the phenomenon are the motives for authors to search for a palliative measures. Some authors propose modification of the workplace setting and equipment, usage of hearing protection devices and others try to find some other preventive solutions. We propose to establish and stick to the practice of regular control of hearing ability changes, as it is the only method of prevention of permanent hearing loss.

Conclusion

The results of this study support the idea that the noise of high-frequency spectrum, especially in the range 4,000 – 8,000 Hz, causes the augmentation of the absolute threshold of hearing, which is higher for the workers that constantly work in the conditions of intensive noise, compared to those working in the less intensive noise environment. These findings are consistent with the great body of research on the topic of industrial noise and effects of occupational noise. Yet, the possibilities for generalization of our study were limited by the characteristics of the sample and research procedure.

REFERENCES

1. *Bell PA, Greene TG, Fisher JD, Baum A.* Environmental psychology. 5th ed. Belmont, CA: Thomson Wadsworth; 2001.
2. *Bonetti L, Jambrošić K.* Haring loss as consequence of noise pollution: Multidsciplinary view of the problem and prevention options. 8th International Scientific Conference, Book of abstracts; Zagreb; 2012 September 27- 29. Zagreb: Faculty of Education and Rehabilitation Sciences, University of Zagreb; 2012. p. 115−8. (Croatian)
3. *Aluclu I, Dalgic A, Toprak ZF.* A fuzzy logic-based model for noise control at industrial workplaces. Appl Ergon 2008; 39(3): 368−78.
4. *Picard M, Girard SA, Simard M, Larocque R, Leroux T, Turcotte F.* Association of work-related accidents with noise exposure in the workplace and noise-induced hearing loss based on the experience of some 240,000 person-years of observation. Accid Anal Prev 2008; 40(5): 1644−52.
5. *Mihailović D, Ristić S.* Noise: Psychophysiological effects. Smederevo: Newpress; 2011. (Serbian).
6. *Ognjenović P.* Psychology of perception. Belgrade: Zavod za udžbenike i nastavna sredstva; 2002. (Serbian)
7. *Kryter K.* The handbook of hearing and the effects of noise. New York: Academic Press; 1994.
8. *Alberti PW.* Noise-induced hearing loss: Could be easily prevented. Br Med J 1992: 304(6826): 522.
9. *Rachiotis G, Alexopoulos C, Drivas S.* Occupational exposure to noise, and hearing function among electro production workers. Auris Nasus Larynx 2006; 33(4): 381−5.
10. *Glass DC, Reim B, Singer JE.* Behavioral consequences of adaptation to controllable and uncontrollable noise. J Exp Soc Psychol 1971; 7: 244−57.
11. *Belojevic G, Slepcevic V, Jakovljevic B.* Mental performance in noise: The role of introversion. J Environ Psychol 2001; 2: 209−13.
12. *Aranđelović M, Jovanović J.* Occupational Medicine. Niš: Faculty of Medicine, University of Niš; 2009. (Serbian)
13. *Walden R.* Work Environments. In: *Spielberger CD*, editor. Encyclopedia of Applied Psychology. Tampa: Elsevier Academic Press; 2004. p. 699−708.
14. *Chiovenda P, Pasqualetti P, Zappasodi F, Ercolani M, Milazzo D, Tomei G,* et al. Environmental noise-exposed workers: event-related potentials, neuropsychological and mood assessment. Int J Psychophysiol 2007; 65(3): 228−37.
15. *Tafalla RJ, Evans GW.* Noise, physiology, and human performance: The potential role of effort. J Occup Health Psychol 1997; 2(2): 148−55.
16. *Sundstrom E, Town JP, Rice RW, Osborn DP, Brill M.* Office Noise, Satisfaction, and Performance. Environ Behav 1994; 26(2): 195−222.
17. *Leather P, Beale D, Sullivan L.* Noise, psychosocial stress and their interaction in the workplace. J Environ Psychol 2003; 23(2): 213−22.

18. *Becker AB, Warm JS, Dember WN, Hancock PA*. Effects of jet engine noise and performance feedback on perceived workload in a monitoring task. Int J Aviat Psychol 1995; 5(1): 49−62.
19. *Brattico E, Kujala T, Tervaniemi M, Alku P, Ambrosi L, Monitillo V*. Long-term exposure to occupational noise alters the cortical organization of sound processing. Clin Neurophysiol 2005; 116(1): 190−203.
20. *Fernandez MD, Quintana S, Chavarria N, Ballesteros JA*. Noise exposure of workers of the construction sector. Appl Acoust 2009; 70: 753−60.
21. *Pražić M*. Professional hearing function damage in conditions of industrial noise: Work Medicine. Belgrade, Zagreb: Medicinska knjiga; 1986. p. 702−4. (Serbian)
22. *Rabinowitz PM*. Noise-induced hearing loss. Am Fam Physician 2000; 61(9): 2749−56.
23. *Eleftheriou PC*. Industrial noise and its effects on human hearing. Appl Acoust 2002; 63(1): 35−42.
24. *Benton S, Leventhall HG*. Experiments into the impact of low level, low frequency noise upon human behavior. J Low Freq Noise Vibr 1986; 5(4): 143−62.
25. *Bengtsson J, Waye PK, Kjellberg A*. Evaluations of effects due to low-frequency noise in a low demanding work situation. J Sound Vibr 2004; 278(1−2): 83−99.
26. *McReynolds MC*. Noise-induced hearing loss. Air Med J 2005; 24(2): 73−8.
27. *Mihailović D*. Analysis of detrimental influence of noise on workers in production plants. Aranđelovac, Bukovička Banja: Academy for Technology; 1977. (Serbian)
28. *Gopinath B, Thiagalingam A, Teber E, Mitchell P*. Exposure to workplace noise and the risk of cardiovascular disease events and mortality among older adults. Prev Med 2011; 53(6): 390−4.
29. *Ljungberga JK, Neelya G*. Stress, subjective experience and cognitive performance during exposure to noise and vibration. J Environ Psychol 2007; 27: 44−54.
30. *Rylander R*. Physiological aspects of noise-induced stress and annoyance. J Sound Vibr 2004; 277: 471−8.

Received on April 16, 2014.
Revised on July 13, 2015.
Accepted on July 31, 2015.
Online First May, 2016.