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Effects of Ultrasonic Noise on the Human Body—A Bibliographic Review

Bożena Smagowska

Central Institute for Labour Protection – National Research Institute, Poland

Małgorzata Pawlaczyk-Łuszczyńska

Department of Physical Hazards, Nofer Institute of Occupational Medicine, Łódź, Poland

Industrial noise in the working environment has adverse effects on human hearing; literature and private studies confirm that. It has been determined that significant changes in the hearing threshold level occur in the high frequency audiometry, i.e., in the 8–20 kHz frequency range. Therefore, it is important to determine the effect of ultrasonic noise (10–40 kHz) on the human body in the working environment. This review describes hearing and nonhearing effects (thermal effects, subjective symptoms and functional changes) of the exposure to noise emitted by ultrasound devices. Many countries have standard health exposure limits to prevent effects of the exposure to ultrasonic noise in the working environment.

ultrasonic noise effect working environment

1. INTRODUCTION

Ultrasonic noise is used in many areas of life, especially in hydrolocation and underwater telecommunication, industry and medicine [1]. The frequency range of ultrasounds is very wide and depends on their use, e.g., from 20 kHz in industrial devices to 10 MHz in medical diagnostics and therapy. In industry, ultrasounds are used in consumer devices such as burglar alarms, dog whistles, bird and rodent repellents, humidifiers and inhalers. The increasing number of people exposed to ultrasounds is the consequence of its increasingly common use of ultrasounds in technology, medicine and everyday life. This generates interest in the impact of ultrasounds on the human body and health. The frequency that separates different mechanisms of biological impact of ultrasounds on the human body is 100 kHz.

Many countries (e.g., Germany and France) are working on assessing harmfulness of occupational noise exposure and amending admissible values in the ultrasonic range. Most countries assess ultrasonic noise by measuring equivalent sound pressure level in one-third-octave bands referred to 8-h noise exposure at workstations [2]. France determines admissible values of ultrasonic noise and recommends limiting noise exposure in the high audible frequency range (8–20 kHz) and the low-frequency ultrasonic range (20–50 kHz). In Poland, ultrasonic noise is assumed, for practical reasons, as noise whose spectrum includes high audible and low ultrasonic frequencies (i.e., 10–40 kHz) [3].

The main sources of ultrasonic noise in the working environment are low-frequency ultrasonic devices like ultrasonic washers, welding and erosion machines, manual soldering irons

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Correspondence should be sent to Bożena Smagowska, CIOP-PIB, ul. Czerniakowska 16, 00-701 Warszawa, Poland. E-mail: bosma@ciop.pl.

and tanks for tinplating [4, 5, 6, 7]. Ultrasounds produced in these devices are necessary for technological processes. Industrial ultrasonic noise is also produced as a side effect of aerodynamic or mechanical processes [8]. High-frequency ultrasounds (over 0.8 MHz), which are used in medicine, mainly in therapy and diagnostics, do not belong to the category of ultrasonic noise; therefore, this article does not discuss them.

First reports on the negative effects of ultrasonic noise on the human body were published in the 1940s and 1950s. In this period, the now-obsolete term ultrasonic disease described symptoms associated with exposure to noise, including low-frequency ultrasonic, mostly subjective symptoms of exposed workers [9, 10, 11]. Currently, the effects of exposure to ultrasonic noise are classified as effects of hearing, thermal effects, subjective symptoms and functional disorders [12].

Low-frequency ultrasonics of high intensities may also cause mechanical effects on the human body like cavitation in liquids. This effect is negligible in ultrasounds propagated in the air, because only level over 190 dB could cause it in the human body [13]. However, this is practically impossible as a lethal sound pressure level for the human body is ~180 dB [14].

2. EFFECTS OF ULTRASONIC NOISE ON HEARING

Human hearing covers frequencies between 20 Hz and 20 kHz. With the ageing process, the range narrows in high frequencies. The results of environmental and laboratory studies in the 1960s showed that the temporary threshold shift (TTS) and the permanent threshold shift (PTS) of 0.25–10 kHz resulting from exposure to ultrasonic noise did not exceed 10–15 dB or was not observed at all if sound pressure level did not exceed ~120 dB [9].

However, ultrasonic noise of over 8 kHz may cause noise-induced hearing loss (NIHL). According to Parrack, TTS of 8–18 kHz resulted from a short-term exposure to signals of 17–37 kHz and intensity of 148–154 dB [14]. In their environmental studies, Grzesik and Pluta observed NIHL at 13–17 kHz in workers exposed to ultrasonic noise over several years of work with washers and welding machines at level exceeding 80 dB [15]. They also reported that high-frequency hearing loss would aggravate at a rate of 1 dB per year of work in workers exposed to noise emitted by those machines.

A study of dentists using dental scalers (25–42 kHz) showed that a short exposure to ultrasonic noise did not cause hearing loss at 0.5–8 kHz, except for a slight hearing impairment at 3 kHz [16]. However, in that study, hearing thresholds with the range of higher frequencies, i.e., 8–16 kHz, were not established for dentists.

There are several reports on studies on hearing perception of sounds with frequencies over 20 kHz. According to Henry and Fast, most listeners in their study registered sounds with sound pressure level of 124 dB and a frequency of 24 kHz [17]. Ashihara, Kurakata, Mizunami, et al. obtained similar results by registering responses to tone signals with a frequency of 24 kHz and sound pressure level not over 88 dB [18].

Reports on the perception of ultrasounds transmitted through the bone pathway with frequencies over 24 kHz are valuable. Fujimoto, Nakagawa and Tonoike [19] and Lenhardt [20] showed that bone-conducted ultrasounds masked (increased the detection threshold) signals of 10–14 kHz and even up to 19 kHz transmitted through the air pathway [14]. Ultrasounds of 12–16 kHz masking bone-conduction caused an increase in the hearing threshold by 15–22 dB. Furthermore, masking curves for noise of middle frequencies (26 and 39 kHz) resembled an average audiogram of people with hearing deficiencies caused by years of exposure to ultrasonic noise.

According to Lenhardt, exposure to audible high-frequency sounds and ultrasonic signals exceeding the hearing range may increase the risk of hearing damage as a result of an overlap of stimuli originating from both these signals in the inner ear [20].

3. THERMAL EFFECTS

Studies in small animals showed that thermal effects of ultrasonic noise appeared at relatively high sound pressure level. According to Allen, Rudnik and Frings, a mouse dies from overheating after 10 s to 3 min of exposure to a signal of 20 kHz and level of 160 dB [10]. According to Danner, a lethal level for signals of 18–20 kHz for an unshaven mouse were 144 dB and for a shaven mouse 155 dB [21]. Acton obtained similar results and extended studies to larger animals such as guinea pigs and rabbits [22]. The mismatch of acoustic impedance between the air and human skin tissue prevents, at considerable extent, penetration of ultrasonic energy in the human body and, therefore, only relatively high intensities of ultrasonic waves can be dangerous for the human body.

First reports, written in 1948, on the thermal effects of ultrasounds on the human body described burns on the hand skin between fingers from accidental exposure to a signal with a frequency of 20 kHz and level of 165 dB [10, 11]. Ultrasounds at level of 159 dB may cause moderate warming of the surface of the human body; according to computational simulations, exposure to ultrasounds for ~50 min at level of at least 180 dB may be fatal [13].

Results of environmental studies on 20 workers working with ultrasonic devices showed that, after a day of work, body temperature of 40% of workers increased by 0.5 °C and in some cases even by 1–2 °C [9].

4. SUBJECTIVE SYMPTOMS OF EXPOSURE TO ULTRASONIC NOISE

Many studies confirmed the appearance of subjective symptoms of exposure to noise emitted by ultrasonic devices like dizziness, balance disturbances, tinnitus and fatigue [4, 23]. It is assumed that those symptoms result from the effect of noise on the vestibular system; however, further studies are necessary [12].

According to the results of studies in the 1960s and 1970s, "audible" components of the noise spectrum are, above all, responsible for subjective symptoms among workers exposed to noise emitted by ultrasonic devices [9]. However, according to Smith, Nixon and von Gierke, signals with frequencies over ~17 kHz and level exceeding 70 dB may cause negative symptoms among exposed workers such as excessive fatigue, nausea, ear fullness and headache [24].

Holemberg, Landström and Nordström exposed 10 workers for 2 min to noise of an ultrasonic washer, then the workers assessed discomfort and irritation. They concluded that noise emitted by ultrasonic washers with level over 75 dB(*A*) caused annoyance and discomfort [25].

In 2005, studies on exposure to noise were conducted among 166 production plants workers, who reported high-frequency and ultrasonic noise at their workstations. The workers defined it as wheezing, whistling or squeaky. Over 84% of workers had follow-up hearing examinations. Subjective assessment showed that 13% of participants had poor hearing and 50% had difficulties with hearing normal speech [26, 27, 28, 29].

Pawlaczyk-Łuszczyńska, Dudarewicz and Śliwińska-Kowalska studied the effect of ultrasonic noise among 25 operators of ultrasonic welding machines, mainly women aged 20–56 [30]. Participants subjectively assessed acoustic conditions at workstations, complaints and sensations related to noise at the workplace, and self-assessed their hearing and health. About 29.4% of the workers did not report any complaints related to noise at the workstations. The rest complained of fatigue (36.8%), headache (12.1%), somnolence (5.3%), dizziness (5.3%) and palpitations (5.3%). The workers described noise as loud (52.6%), uneven (44.4%), sharp and unpleasant (44.4%), annoying (36.8%), irritating (36.8%) and interfering with work (16.7%). About 26.3% of the workers complained that noise interfered with conversations, listening to the radio (21.1%) and made concentration impossible (5.6%).

It is worth mentioning that some subjective effects of exposure to ultrasonic noise such as fatigue, headache, discomfort or irritation may disturb human cognitive functions [31, 32, 33, 34].

5. EFFECTS OF ULTRASONIC NOISE ON FUNCTIONAL CHANGES

Workers using ultrasonic devices suffered from functional changes such as neurastenia, cardiac neurosis, hypotension, heart rhythm disturbances (bradycardia) and adrenergic system disturbances [32]. Studies showed that exposure to sounds with a frequency of 21 kHz and level of 110 dB for 3 h daily for 10–15 days caused functional changes in the cardiovascular and central nervous systems [35]. Workers exposed to noise emitted by ultrasound devices suffered from increased neural excitability, irritation, memory problems and difficulties with concentration and learning [34].

Roshchin and Dobroserdov indicated that levels of 90–110 dB within the range of lower frequencies (21 kHz) and 110–115 dB within the range of higher frequencies (40 kHz) constituted the limit of occurrence of functional changes [36].

6. HEALTH STANDARDS

Health standards are to prevent subjective effects of exposure to ultrasonic noise and hearing damage. Individual researchers at the turn of the 1960s and 1970s prepared first proposals of health standards on occupational exposure [9, 37, 38, 39]. They were based on two basic assumptions: (a) high audible frequencies (10–20 kHz) may cause annoyance, tinnitus, headache, fatigue and nausea and (b) ultrasound components (over 20 kHz) with high sound pressure level may cause hearing damage. Therefore, admissible values were determined at a level that does not eliminate hearing damage and subjective effects (fatigue, headache, nausea, tinnitus, vomiting, etc.) [40, 41, 42, 43].

Sound pressure level in one-third-octave frequency bands of 12.5–50 kHz related to 8-h noise exposure (daily noise exposure level) is, in many countries, the basic value used for assessing exposure to ultrasonic noise at workstations [42, 43]. Table 1 presents admissible values of the

TABLE 1. Admissible Values of the Noise Parameter for Assessing Exposure to Ultrasonic Noise [41]

f (kHz)	Japan (1971)	Australia (1981)	France (1985)	Poland (1986)	USSR (1989)	Canada (1991)	Sweden (1992)	Poland (2001)
6.3	90							
8	90							
10	90	75	75	80				80
12.5	90	110	75	80	80			80
16	90	110	75	80	80	75		80
20	110	110	75	90	100	75	105	90
25	110	110	110	105	105	110	115	105
31.5	110		110	110	110	110	115	110
40	110		110	110	110	110	115	110
50	110		110	110	110	110	115	
63				110	110		115	
80				110	110		115	
100				110	110		115	
125							115	
150							115	
160							115	
200							115	

Notes. *f* = middle frequency one-third-octave frequency bands.

noise parameter for assessing exposure to ultrasonic noise. Major differences are in the high audible range, i.e., up to 20 kHz; over 25 kHz, the admissible value is 110 dB [41].

In Poland, the first proposals of health standards on ultrasonic noise were prepared in the late 1970s [38, 39]. However, ultrasonic noise was on the list of maximum admissible intensities (MAI) of factors harmful for health in the working environment only in 1989. Standard No. PN-86/N-01321 was developed three years earlier [44]. In 2001, MAI values of ultrasonic noise were updated [45]; those changes are still in force [3] (Table 2).

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In many countries, the basic value used for assessing exposure to ultrasonic noise at workstations is sound pressure level in one-third-octave frequency bands of 12.5–50 kHz related to 8-h noise exposure [42].

TABLE 2. Admissible Values of Equivalent and Maximum Sound Pressure Level for Ultrasonic Noise at a Workstation [3]

	$L_{f,eq,8h,adm}$ (dB)			
f (kHz)	Workers in General	Pregnant Women	Young People	$L_{f,max,adm}$ (dB)
10, 12.5, 16	80	77	75	100
20	90	87	85	110
25	105	102	100	125
31.5, 40	110	107	105	130

Notes. f = middle frequency one-third-octave frequency bands, $L_{f,eq,8h,adm}$ = admissible values of equivalent sound pressure level, $L_{f,max,adm}$ = admissible values of maximum sound pressure level.

7. SUMMARY

Ultrasonic noise may affect hearing and nonhearing parts of the body. Because audible noise is also present in industrial conditions, it is difficult to interpret the results of environmental studies on the effects of ultrasounds on hearing [37, 38, 39]. Furthermore, the age of study participants and the potential presence of chemical factors in the working environment are also important. Nevertheless, some reports indicated that components with ultrasonic frequencies may cause sound sensations associated with hearing defects within the high frequency range, which audiometric tests do not always taken into account [15, 20]. Subjective symptoms like headache and dizziness, tinnitus, balance disturbances and nausea are typical for workers exposed to ultrasounds of low frequencies. Health standards are to prevent subjective effects of exposure to ultrasonic noise and hearing damage. Proposals of these standards were based on two basic assumptions: (a) high

In conclusion, studies conducted to date in Poland and worldwide indicate that ultrasonic noise may cause excessive fatigue, headache, discomfort and irritation. There are some analogies between ultrasonic and audible noise. Audible noise with sound level not exceeding 80 dB(*A*) is perceived as causing discomfort and having a negative effect on human cognitive functions. Irritation caused by ultrasonic noise may cause reduced work effectiveness [46, 47].

REFERENCES

1. Śliwiński A. Ultradźwięki i ich zastosowania [Ultrasounds and their applications]. Warszawa, Poland: WNT; 2001.
2. Ultraschall–Arbeitsplatz–Messung, Bewertung, Beurteilung und Minderung [Ultrasound–workplace–measurement, assessment, judgement and reduction] (Technical rule: guideline). Association of German Engineers (VDI). 2012.

3. Rozporządzenie Ministra Pracy i Polityki Socjalnej w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia w środowisku pracy [Act on the highest permissible concentrations and intensities of health damaging factors in working environment]. Dz U. 2002;(217):item 1833.
4. Health Canada. Guidelines for the safe use of ultrasound: part II—industrial and commercial applications. Safety code 24. Ottawa, ON, Canada: Ministry of Supply and Services Canada; 1991. Retrieved March 28, 2013, from: http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/radiation/safety-code_24-securite/safety-code_24-securite-eng.pdf.
5. Koton J. Ultradźwięki [Ultrasounds]. Warszawa, Poland: Instytut Wydawniczy Związków Zawodowych; 1986.
6. Koton J. Przemysłowe źródła hałasu ultradźwiękowego [Industrial sources of ultrasonic noise]. Bezpieczeństwo Pracy. 1988;(10):11–5. In Polish, with an abstract in English.
7. Mikulski W, Smagowska B. Ultrasonic noise at selected workplaces (paper No. 903). In: Proceedings of the Thirteenth International Congress on Sound and Vibration [CD-ROM]. 2006.
8. Pawlaczyk-Łuszczyńska M, Dudarewicz A, Śliwińska-Kowalska M. Źródła ekspozycji zawodowej na hałas ultradźwiękowy—ocena wybranych urządzeń [Sources of occupational exposure to ultrasonic noise—evaluation of selected devices]. Med Pr. 2007;58(2):105–16. In Polish, with an abstract in English. Retrieved March 28, 2013, from: http://www.imp.lodz.pl/upload/oficyna/artykuly/pdf/full/2007/02-Pawlaczyk.pdf.
9. Grigorieva VM. [On the effect of ultrasonic vibrations on the attending personnel of the ultrasonic equipment]. Akusticheskij Zhurnal. 1965;11(4):469–98. In Russian.
10. Allen CH, Rudnik I, Frings H. Some biological effects of intense high frequency airborne sound. J Acoust Soc Am. 1948;20(1):62–5.
11. Davis H. Biological and psychological effects of ultrasonic. J Acoust Soc Am. 1948;20(5):605–7.
12. Pawlaczyk-Łuszczyńska M, Koton J, Śliwińska-Kowalska M, Augustyńska D, Komeduła M. Hałas ultradźwiękowy. Dokumentacja proponowanych wartości dopuszczalnych poziomów narażenia zawodowego [Ultrasonic noise. Documentation of propositions of new limit values for occupational exposure]. Podstawy i Metody Oceny Środowiska Pracy. 2001;(28):55–88. In Polish, with an abstract in English.
13. Neppiras EA. Acoustic cavitation. Phys Rep. 1980;61(3):159–251.
14. Parrack HO. Effects of airborne ultrasound. Int Aud. 1966;(5):294–308.
15. Grzesik J, Pluta E. Dynamics of high-frequency hearing loss of operators of industrial ultrasonic devices. Int Arch Occup Environ Health. 1986;57(2):137–42.
16. Wilson JD, Darby ML, Tolle SL, Sever JC Jr. Effects of occupational ultrasonic noise exposure on hearing of dental hygienists: a pilot study. J Dent Hyg. 2002;76(4):262–9.
17. Henry KR, Fast GA. Ultrahigh-frequency auditory thresholds in young adults: reliable responses up to 24 kHz with a quasi-free-field technique. Audiology. 1984;23(5):477–89.
18. Ashihara K, Kurakata K, Mizunami T, Matsushita K. Hearing threshold for pure tones above 20 kHz. Acoust Sci Technol. 2006;27(1):12–9.
19. Fujimoto K, Nakagawa S, Tonoike M. Nonlinear explanation for bone-conducted ultrasonic hearing. Hear Res. 2005;204(1–2):210–5.
20. Lenhardt ML. Ultrasonic hearing in humans: applications for tinnitus treatment. Int Tinnitus J. 2003;9(2):69–75.
21. Danner PA, Ackerman E, Frings HW. Heating in haired and hairless mice in high-intensity sound fields from 6–22 kHz. J Acoust Soc Am. 1954;26(1):141–2.
22. Acton WI. The effects of industrial air borne ultrasound on humans. Ultrasonics. 1974;12(3):124–8.
23. Lawton BW. Damage to human hearing by airborne sound of very high frequency or ultrasonic freq uency (Contract research report 343/2001). Sudbury, Suffolk, UK; Health and Safety Executive; 2001.

Retrieved March 28, 2013, from: http://www.hse.gov.uk/research/crr_pdf/2001/crr01343.pdf.

24. Smith SD, Nixon CW, von Gierke HE. Damage risk criteria for hearing and human body vibration. In: Vér IL, Beranek LL, editors. Noise and vibration control engineering: principles and applications. New York, NY, USA: Wiley; 1992. p. 598–600.
25. Holmberg K, Landström U, Nordström B. Annoyance and discomfort during exposure to high-frequency noise from an ultrasonic washer. Percept Mot Skills. 1995;81(3): 819–27.
26. Mikulski W, Smagowska B. The preliminary survey method of identification of ultrasonic sources based on the results of questionnaire [unpublished presentation]. 14th International Conference on Noise Control. 2007.
27. Smagowska B, Mikulski W. Identification of ultrasonic noise on the basis of a questionnaire method [poster]. 19th International Congress on Acoustics. 2007.
28. Mikulski W, Smagowska B. Assessing of occupational risk of ultrasonic noise exposure at workstation in Poland (paper AC09). In: Proceedings of the First International Conference on Industrial Risk Engineering [CD-ROM]. 2007. p. 127–36.
29. Smagowska B. Metoda badań laboratoryjnych wpływu hałasu ultradźwiękowego na organizm człowieka [The method of laboratory testing of influence of ultrasonic noise on the human body]. In: Proceedings of 56th Open Seminar on Acoustics. 2009. p. 407–14.
30. Pawlaczyk-Łuszczyńska M, Dudarewicz A, Śliwińska-Kowalska M. Theoretical predictions and actual hearing threshold levels in workers exposed to ultrasonic noise of impulsive character—a pilot study. International Journal of Occupational Safety and Ergonomics (JOSE). 2007; 13(4):409–18. Retrieved March 28, 2013, from: http://www.ciop.pl/24372.
31. Belojević G, Ohrström E, Rylander R. Effects of noise on mental performance with regard to subjective noise sensitivity. Int Arch Occup Environ Health. 1992; 64(4):293–301.
32. Schust M. Biologische wirkung von luftgeleitetem ultraschall [Biological effects of airborne ultrasound] (technical report). Bremerhaven, Germany: Federal Institute for Occupational Safety and Health; 1996.
33. Stansfeld SA, Matheson MP. Noise pollution: non-auditory effects on health. Br Med Bull. 2003;68:243–57.
34. Markiewicz L. Wyniki badań działania drgań ultradźwiękowych na organizm człowieka [Testing results of ultrasonic vibrations to exposure on human body]. Materiały do Studiów i Badań CIOP. 1978;(43):41–9.
35. Il'nitskaia AV, Pal'tsev IuP. [Combined action of ultrasonics and noise of standard parameters]. Gig Sanit. 1973;(5):50–3. In Russian.
36. Roshchin AV, Dobroserdov VK. [Reactions of the human auditory analysor to the effect of high frequency acoustic oscillations]. Gig Tr Prof Zabol. 1971;15(12):3–7. In Russian.
37. Acton WL. A criterion for the prediction of auditory and subjective effects due to airborne noise from ultrasonic sources. Ann Occup Hyg. 1968;11(3):227–34.
38. Konarska M. Biologiczne podstawy normowania ultradźwięków o małych częstotliwościach [Biological bases for standardization of low-frequency ultrasounds]. Materiały do Studiów i Badań CIOP. 1978;(43):49–56.
39. Grzesik J, Pluta E. Kryteria oceny oraz badania stanu zdrowia osób obsługujących urządzenia ultradźwiękowe [Criteria of assessment and medical test for human health during operating ultrasonic devices]. Materiały do studiów i badań CIOP. 1978;(43):30–40.
40. Grzesik J, Pluta E. High-frequency hearing risk of operators of industrial ultrasonic devices. Int Arch Occup Environ Heath. 1983;53(1):77–88.
41. Smagowska B. Stosowane w Polsce i na świecie kryteria oceny hałasu ultradźwiękowego na stanowiskach pracy; ocena hałasu ultradźwiękowego na stanowiskach obsługi typowych źródeł ultradźwiękowych [Criteria of ultrasonic at the workplaces in Poland

and in selected other countries; ultrasonic noise assessment at workstations where typical ultrasonic sources are operated]. In: Proceedings of 53th Open Seminar on Acoustics. 2006. p. 323–28.

42. Chatillon J. Limites d'exposition aux infrasons et aux ultrasons. Étude bibliographique [Infrasonic and ultrasonic noise exposure limits–a bibliographical study]. HST. Hygiène et sécurité du travail. 2006;(203):67–77. In French, with an abstract in English. Retrieved March 28, 2013, from: http://www.hst.fr/inrs-pub/inrs01.nsf/IntranetObject-accesParReference/HST_ND%202250/$File/ND2250.pdf.
43. Puzyna Cz, Pasterczuk E. Kryteria oceny oraz metodyka pomiarów hałasu w zakresie częstotliwości ultradźwiękowych [Criteria of assessment and measurement methods of noise in ultrasonic frequency range]. Prace CIOP. 1982;(112):47–58.
44. Polski Komitet Normalizacyjny (PKN). Hałas ultradźwiękowy. Dopuszczalne wartości poziomu ciśnienia akustycznego na stanowiskach pracy i ogólne wymagania dotyczące wykonywania pomiarów [Ultrasonic noise. Admissible sound pressure levels at work place and methods of measurements] (Standard No. PN-86/N-01321). Warszawa, Poland: Wydawnictwa Normalizacyjne; 1986.
45. Pawlaczyk-Łuszczyńska M, Koton J, Śliwińska-Kowalska M, Augustyńska D, Kameduła M. Hałas ultradźwiękowy. Procedura pomiarowa [Ultrasonic noise. Measurment procedure]. Podstawy i Metody Oceny Środowiska Pracy. 2001;(28):89–95. In Polish, with an abstract In English.
46. Ljungberg JK, Nelly G. Cognitive after-effects of vibration and noise exposure and the role of subjective noise sensitivity. J Occup Health. 2007;49(2):111–6.
47. Smith AP. Noise and aspects of attention. Br J Psychol. 1991;82(3):313–24.