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Research article

ASSESSING INTENSITY OF IMPACTS EXERTED BY OCCUPATIONAL FACTORS ON HEALTH OF WORKERS EMPLOYED AT COPPER-NICKEL ORE MINES PER OCCUPATIONAL HEALTH RISK CRITERIA

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Promoting working population's health is the key task within the state policy aimed at prolonging life expectancy and working longevity. At present, occupational risk assessment is considered a key instrument for identifying potential health threats including risks associated with long work records by the moment workers are close to the retirement age. Harmful working conditions are the basic reason for high occupational morbidity. Work under exposure to elevated noise and vibration is seen by many researchers as a leading factor able to cause occupational pathologies.

The aim of this study was to assess both individual and group occupational health risks for workers of basic ore mining occupations. Prior and posterior group and individual occupational health risks were assessed in conformity with methodical approaches and criteria stipulated in the Guide R 2.2.3969-23.

We performed comparative analysis of health risks associated with leading work-related factors for workers of basic underground mining occupations employed by a copper-nickel ore mining enterprise; the analyzed health risks were caused by various occupational diseases. As a result, the highest occupational health risks were established to be associated with vibration disease developing under exposure to total and local vibration at workplaces of drift miners ($3.98 \cdot 10^{-2}$; the health risk is high, unacceptable) and sensorineural hearing loss developing under exposure to noise ($1.07 \cdot 10^{-3}$; the health risk is moderate, unacceptable). Individual occupational risks due to vibration diseases were within the range between $1.45 \cdot 10^{-6}$ and $9.18 \cdot 10^{-4}$; those caused by sensorineural hearing loss, between $8.34 \cdot 10^{-7}$ and $4.48 \cdot 10^{-2}$.

Drift miners are an occupational group under the highest exposure to adverse physical factors at workplace. We established unacceptable group and individual occupational health risks for drift miners associated with developing vibration disease and sensorineural hearing loss. The growth rates of individual occupational risks were between $2.97 \cdot 10^{-1}$ and $3.04 \cdot 10^{-1}$ for vibration disease and between $1.72 \cdot 10^{-4}$ and $4.50 \cdot 10^{-2}$ for sensorineural hearing loss by the moment workers reached 60 years of age.

Keywords: *hygienic assessment, occupational risk, vibration disease, sensorineural hearing loss, drift miners, individual risk, group risk, mathematical modeling.*

The state policy sets strategic goals to increase life expectancy and working longevity [1]. In this respect, promotion of workers' health, a decline in non-communicable incidence and minimization of human potential losses due to temporary or permanent disability are becoming especially significant tasks [2, 3]. Finding solutions to them requires implementation of up-to-date methods for assessing and predicting diseases in workers upon long-term exposure to harmful occupational factors.

At present, occupational risk assessment is considered a key instrument for identifying potential health threats including risks associated with long work records by the moment workers are close to the retirement age [4]. Performing such assessments, both at present and in long-term outlook, makes it possible to develop a set of preventive activities aimed at prolonging occupational longevity.

In accordance with the Item 3, Provisions on the Federal State Information System for

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Sanitary-Epidemiological Data (approved by the RF Government Order issued on December 02, 2021 No. 2178)[1], this system has to tackle several tasks including organization of activities aimed at preventing occupational diseases among workers with specific occupations or employed in specific branches as well as prediction of a sanitary-epidemiological situation using statistical methods and mathematical models developed by Rospotrebnadzor's scientific institutions.

Multiple studies give evidence of occupational factors producing complex effects that induce negative health outcomes in the body [5–7] and reduce workers' work ability [8]. Harmful working conditions are the basic reason for high occupational morbidity; they influence high prevalence of general somatic pathology among workers employed in key industrial branches [9].

Experts highlight such leading factors able to induce occupational pathology as exposure to elevated levels of occupational noise [10–13] and vibration [14–16]. Vibration exposure is the key reason for high occupational morbidity, which is directly represented by vibration disease (vibration hand-arm syndrome) and polyneuropathies [17]. Occupational sensorineural hearing loss (SHL) is the most prevalent occupational disease caused by elevated noise exposure [18].

Occupational risks caused by physical exposures are a significant reason for temporary or permanent disability, which emphasizes how important it is to quantify their effects [19] both at the group and individual level. Results obtained by such quantification will allow developing targeted preventive activities to mitigate negative health outcomes. It is noteworthy that underestimation of occupational morbidity together with high proportions of workplaces not conforming to safe standards is still a relevant issue. Given that, it is necessary to identify occupations with the highest health risks [20] so that available resources are allocated in the most optimal way and occupational longevity is preserved for the most susceptible occupational groups.

This study aimed to assess both individual and group occupational health risks for workers of basic underground mining occupations, who were employed in copper and nickel ore mining.

Materials and methods. Hygienic assessment of working conditions was performed in conformity with the Guide R 2.2.2006-05 Hygienic Assessment of Factors Related to Working Environment and Work Process / Criteria and Classification of Working Conditions[2] using data obtained by Special Assessment of Working Conditions (SAWC).

Prior and posterior group and individual occupational health risks were quantified in conformity with methodical approaches and criteria stipulated in the valid Guide R 2.2.3969-23 Assessment of Occupational Health Risk for Workers[3]. Likelihood of occupational diseases was assessed considering the number of such diseases and the staff list covering basic mining occupations typical for copper and nickel ore mines in 2020–2024. Posterior assessment of occupational health risks determined by occupational diseases relied on using data about occupational dis-

[1] Ob utverzhdenii Polozheniya o federal'noi gosudarstvennoi informatsionnoi sisteme svedenii sanitarno-epidemiologicheskogo kharaktera: Postanovlenie Pravitel'stva RF ot 02.12.2021 № 2178 (red. ot 27.09.2023) [On Approval of the Provisions on the Federal State Information System for Sanitary-Epidemiological Data: the RF Government Order issued on December 02, 2021 No. 2178 (edited as of September 27, 2023)]. *GARANT: information and legal support*. Available at: https://base.garant.ru/403158507/ (May 06, 2025) (in Russian).

[2] Guide R 2.2.2006-05. Rukovodstvo po gigienicheskoi otsenke faktorov rabochei sredy i trudovogo protsessa. Kriterii i klassifikatsiya uslovii truda [Hygienic Assessment of Factors Related to Working Environment and Work Process. Criteria and Classification of Working Conditions]. Moscow, Rospotrebnadzor's Federal Center for Hygiene and Epidemiology, 2005, 142 p. (in Russian).

[3] Guide R 2.2.3969-23. Rukovodstvo po otsenke professional'nogo riska dlya zdorov'ya rabotnikov. Organizatsionno-metodicheskie osnovy. Printsipy i kriterii otsenki [Assessment of Occupational Health Risk for Workers. Organization and Methodical Essentials, Principles and Assessment Criteria]. Moscow, 2023, 77 p. (in Russian).

eases and staff lists of workers with basic mining occupations in 2020–2024. Leading occupational factors with the greatest negative effects on health of workers with the analyzed occupations were quantified by calculating prevalence of diseases and levels of occupational health risks including severity of health outcomes for workers.

Occupational health risks, including their assessment at the individual level, were analyzed for drift miners as a specific mining occupation within individual health risk assessment in accordance with the Guide on Occupational Risk Assessment (R 2.2.3969-23[3]). The study sample included 125 workers from this occupational group aged between 25 and 55 years and work records between 1 and 11 years.

Results and discussion. Occupational incidence was assessed among workers with basic mining occupations typical for underground copper-nickel ore mining. As a result, it was established that overall more than 200 occupational diseases (with the confirmed diagnosis) were detected among workers from five analyzed divisions over 2020–2024.

Analysis of occupational incidence showed that diseases caused by exposure to physical factors and work hardness occupied the leading places. The first place belonged to vibration disease accounting for more than 75 % of the total number of occupational diseases detected over the analyzed period. It was followed by sensorineural hearing loss and diseases of the musculoskeletal system (both accounting for more than 10 % of the total number of occupational diseases). Bronchial asthma and cancer were much rarer, almost singleton cases, the former accounting for a bit more than 2 % and the latter for less than 1 %.

Occupational diseases were detected in workers with the following mining occupations: blast-hole driller, blaster, working face miner, timber-man, hatch handler, blaster foreman, mining foreman, electric gas welder, electrician, mechanic, repairman on duty, LHD operator, drilling unit operator, slusher operator, drift miner, and electric locomotive driver.

Table 2 provides distribution of occupational incidence per the outlined occupations.

LHD operators, blast-hole drillers, working face miners, electric locomotive drivers, blasters, timber-men, and drift miners were priority occupational groups with occupational diseases diagnosed in them contributing more than 5 % to the total number of occupational diseases caused by exposure to physical factors and work hardness.

Our analysis of SAWC results (obtained over 2016–2021) revealed main occupational factors potentially contributing to both general and occupational pathology development. They included physical factors (noise and vibration), high physical loads and aerosols with fibrogenic effects in workplace air.

Hygienic assessment based on special assessment of working conditions showed noise, total and local vibration, and work hardness to be the most significant harmful occupational factors (Table 3).

Table 1

Occupational diseases in workers involved in underground copper-nickel ore mining in 2020–2024

Occupational disease (diagnosis)	Number of cases, abs	Proportion of the total number of occupational diseases, %
Vibration disease	174	75.98
Sensorineural hearing loss	24	10.48
Diseases of the musculoskeletal system	23	10.05
Bronchial asthma	6	2.62
Cancer	2	0.87
Total	229	100

Table 2

Occupational diseases caused by exposure to physical factors and work hardness; distirbution per basic occupations over 2020–2024

Occupation	Number of cases, abs	Proportion of the total number of occupational diseases, %	Mean rank place
1	**2**	**3**	**4**
LHD operator	74	33.64	1
Blast-hole driller	39	17.73	2
Working face miner	28	12.73	3
Electric locomotive driver	19	8.64	4
Blaster	18	8.18	5
Timber-man	15	6.82	6.5
Drift miner	15	6.82	6.5
Repairman responsible for equipment	2	0.91	8.5
Electric gas welder	2	0.91	8.5
Hatch handler	1	0.45	13.5
Blaster foreman	1	0.45	13.5
Mining foreman	1	0.45	13.5
Drilling unit operator	1	0.45	13.5
Slusher operator	1	0.45	13.5
Electrician	1	0.45	13.5
Electrician / repairman on duty	1	0.45	13.5
Underground self-propelled machine operator	1	0.45	13.5
Total	220	100	-

Table 3

Workers with basic occupations typical for underground copper-nickel ore mining distributed per the results of hygienic assessment of working conditions

Occupation	Exposure					
	Noise	Total vibration	Local vibration	Work hardness	Chemicals	The final hazard class (subclass) of working conditions
LHD operator	3.1–3.3	2–3.2	2–3.1	2. 3.2	2–3.1	3.2–3.3
Blast-hole driller	3.2–3.3	2–3.1	2	2–3.2	2	3.3
Working face miner	3.1–3.3	2–3.1	2. 3.2	2–3.2	2–3.1	3.2–3.3
Electric locomotive driver	3.1–3.3	2–3.1	2	1–2	2	3.2–3.3
Blaster	3.2	2	2	3.2	2	3.3
Timber-man	3.1–3.2	1–2	1–2	3.1–3.2	2–3.1	3.2–3.3
Drift miner	3.1–3.3	1–2	2. 3.2	3.1–3.2	2	3.2–3.3

According to hygienic assessment, working conditions for blast-hole drillers and blasters belonged to the hazard class 3.3; other occupations, the hazard classes 3.2–3.3. In accordance with the Order by the Ministry of Health of the Russian Federation No. 141n dated March 21, 2025[4], exposure to these factors is expected to cause occupational diseases

[4] Ob utverzhdenii perechnya professional'nykh zabolevanii: Prikaz Ministerstva zdravookhraneniya Rossiiskoi Federatsii ot 21.03.2025 № 141n [On Approval of the list of occupational diseases: the Order by the RF Ministry of Health issued on March 21, 2025 No. 141n]. *GARANT.RU: information and legal portal*. Available at: https://www.garant.ru/products/ipo/prime/doc/411797022/ (May 11, 2025) (in Russian).

associated with noise (chronic two-sided sensorineural hearing loss), total and local vibration (vibration disease), work hardness (diseases of the musculoskeletal system and the connective tissue: polyneuropathy of the upper extremities, compression mononeuropathies, and other diseases form this nosologic class), and chemicals (nickel, diiron (III) oxide, chromium (VI) trioxide, saturated aliphatic hydrocarbons, prop-2-en-1-al, nitrogen oxides, and carbon oxide) (bronchial asthma and malignant neoplasms).

Prior (preliminary) occupational health risk assessment was accomplished in conformity with Clauses 3.4.1 and 6.1 of the Guide Assessment of Occupational Health Risk for Workers. Organization and Methodical Essentials, Principles and Assessment Criteria (R 2.2.3969-23[5]). It established high health risks for blasters and blast-hole drillers (work hardness and noise being priority factors). Occupational health risks were ranked as medium or high for other occupations depending on a workplace (Table 4).

These levels of occupational risk were associated with exposure to noise, total vibration and work hardness for LHD operators; noise, local vibration and work hardness for working face miners and drift miners; noise and work hardness for timber-men.

Impermissible occupational health risks (between $6.15 \cdot 10^{-03}$ and $3.98 \cdot 10^{-02}$) were established for workers of all basic occupations typical for underground mining by posterior assessment of occupational health risk caused by vibration disease (Table 5).

Posterior assessment of occupational health risks associated with sensorineural hearing loss for workers with basic occupations in underground mining revealed working conditions with moderate (impermissible) risk only for drift miners (Table 6). These occupational

Table 4

Prior health risk assessment for workers with basic occupations typical for underground copper-nickel ore mining

Occupation	Occupational health risk category					
	Noise	Total vibration	Local vibration	Work hardness	Chemical	Final assessment
LHD operator	medium – high	low – medium	low – moderate	low – medium	low – moderate	medium – high
Blast-hole driller	medium – high	low – moderate	low	low – medium	low	high
Working face miner	moderate – high	low – moderate	low – medium	low – medium	low – moderate	medium – high
Electric locomotive driver	moderate – high	low – moderate	low	negligible – low	low	medium – high
Blaster	medium	low	low	medium	low	high
Timber-man	moderate – medium	negligible – low	negligible – low	moderate – medium	low – moderate	medium – high
Drift miner	moderate – high	negligible – low	low – medium	moderate – medium	low	medium – high

[5] Guide R 2.2.3969-23. Rukovodstvo po otsenke professional'nogo riska dlya zdorov'ya rabotnikov. Organizatsionno-metodicheskie osnovy. Printsipy i kriterii otsenki [Assessment of Occupational Health Risk for Workers. Organization and Methodical Essentials, Principles and Assessment Criteria]. Moscow, 2023, 77 p. (in Russian).

Table 5

Posterior assessment of occupational health risk caused by vibration disease for workers with basic occupations typical for underground mining over 2020–2024

Occupation	Likelihood of occupational disease	Severity of occupational disease	Risk levels caused by vibration disease	Risk category
Blast-hole driller	0.072	0.304	$2.19 \cdot 10^{-2}$	Medium risk
Blaster	0.043	0.304	$1.30 \cdot 10^{-2}$	Medium risk
Working face miner	0.020	0.304	$6.15 \cdot 10^{-3}$	Moderate risk
Timber-man	0.064	0.304	$1.94 \cdot 10^{-2}$	Medium risk
LHD operator	0.095	0.304	$2.89 \cdot 10^{-2}$	Medium risk
Electric locomotive driver	0.058	0.304	$1.76 \cdot 10^{-2}$	Medium risk
Drift miner	0.131	0.304	$3.98 \cdot 10^{-2}$	High risk

Table 6

Posterior assessment of occupational health risk caused by sensorineural hearing loss for workers with basic occupations typical for underground mining over 2020–2024

Occupation	Likelihood of occupational disease	Severity of occupational disease	Risk levels caused by vibration disease	Risk category
Blast-hole driller	0.009	0.045	$3.92 \cdot 10^{-4}$	Low risk
Blaster	0.018	0.045	$8.23 \cdot 10^{-4}$	Low risk
Working face miner	0.002	0.045	$7.92 \cdot 10^{-5}$	Negligible risk
Timber-man	0.011	0.045	$4.79 \cdot 10^{-4}$	Low risk
LHD operator	0.007	0.045	$3.14 \cdot 10^{-4}$	Low risk
Electric locomotive driver	0.008	0.045	$3.47 \cdot 10^{-4}$	Low risk
Drift miner	0.024	0.045	$1.07 \cdot 10^{-3}$	Moderate risk

health risks were low (permissible) for blast-hole drillers, blasters, timber-men, LHD operators and electric locomotive drivers and negligible for working face miners.

In this study, we performed comparative analysis of health risks associated with leading occupational factors at workplaces of workers with basic occupations employed at underground copper-nickel ore mining and caused by various occupational diseases. The analysis revealed the highest levels of occupational health risks caused by vibration disease for drift miners as an occupational group; they reached $3.98 \cdot 10^{-2}$ (high and unacceptable risk). A similar situation was identified for occupational risk caused by sensorineural hearing loss upon exposure to occupational noise. Its maximum level reached $1.07 \cdot 10^{-3}$ (moderate and unacceptable risk) for drift miners.

Drift miners were an occupational group with the highest levels of group occupational health risks. Therefore, they were used as an example in simulating likelihood of vibration disease upon exposure to vibration and sensorineural hearing loss upon exposure to occupational noise depending on an exposure level, work records in a basic occupation, and age at the moment the study was being carried out. This made it possible to establish parameters of reliable and adequate mathematical models (per the criteria $p < 0.05$, Chi-square (χ^2) > 5.99): for sensorineural hearing loss, $b_0 = -17.9028$, $b_1 = 0.245$, $b_1 = 0.01$; for vibration disease, $b_0 = -12.8802$, $b_1 = 0.1977$, $b_1 = 0.0036$.

The data analysis showed occupational risks of sensorineural hearing loss to vary between negligible ($8.34 \cdot 10^{-7}$) and high ($4.48 \cdot 10^{-2}$)

in the analyzed group. It is noteworthy that 36 % of the examined workers were already exposed to unacceptable risk. Predictive calculations indicate that all these workers without except will be exposed to high risk ($4.497 \cdot 10^{-2}$ – $4.50 \cdot 10^{-2}$) of this occupational disease by the age of 60 years due to exposure to occupational noise. If the existing working conditions are not changed and any preventive activities are not implemented, even minimal risk levels will transfer into this category.

Our findings gave evidence that the current occupational health risks associated with vibration disease were between $1.45 \cdot 10^{-6}$ (negligible risk) to $9.18 \cdot 10^{-4}$ (low risk). We did not find any workers exposed to unacceptable health risks within this study. However, predictive calculations indicate that this risk will reach very high levels ($2.97 \cdot 10^{-1}$ – $3.04 \cdot 10^{-1}$) for all workers by the age of 60 years. If the existing working conditions are not changed and any preventive activities are not implemented, even minimal risk levels will transfer into this category.

Conclusion. Within this study, we assessed occupational health risks for workers with basic mining occupations employed at underground copper-nickel ore mining. The assessment established priority occupational risk factors influencing prevalence of occupational diseases, namely, such physical factors as noise and vibration. Drift miners as an occupational group turned out to be the most susceptible to negative effects produced by these occupational exposures. Our analysis of working conditions and incidence among drift miners showed unacceptably high levels of occupational health risks caused by two main occupational diseases, vibration disease and sensorineural hearing loss.

Predictive calculations of individual occupational health risks for workers by the age of 60 years established expected changes in individual risk category from negligible to extremely high for vibration disease and from negligible to high for sensorineural hearing loss. Growth rates for occupational health risk were as follows: from $2.97 \cdot 10^{-1}$ to $3.04 \cdot 10^{-1}$ for vibration disease; from $1.72 \cdot 10^{-4}$ to $4.50 \cdot 10^{-2}$ for sensorineural hearing loss. Quantitative data on severity of effects produced by physical exposures on drift miners' health can be used within developing preventive activities aimed at reducing prevalence and severity of occupational diseases in this occupational group.

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References

1. Shestakova E.E. Aktivnoe dolgoletie i zadachi formirovaniya i sokhraneniya chelovecheskogo potentsiala lits starshego vozrasta [Active longevity and formation and preservation of the human potential of elderly people]. *Vosproizvodstvo natsional'nogo chelovecheskogo potentsiala v usloviyakh global'nykh vyzovov: collection of papers*, 2023, pp. 250–282 (in Russian).

2. Gagarina G.Yu., Gorokhova I.V., Gretchenko A.I. Sustainable Development of Human Potential as Strategic Priority of Providing National Security. *Vestnik of the Plekhanov Russian University of Economics*, 2024, no. 3, pp. 77–91. DOI: 10.21686/2413-2829-2024-3-77-91(in Russian).

3. Shaitan B.I., Mozhaev E.E., Geshel V.P. Conditions for the formation and efficient use of labor resources in the field of agricultural production. *Nauka, tekhnologii, kadry – osnovy dostizhenii proryvnykh rezul'tatov v APK: sbornik materialov Mezhdunarodnoi nauchno-prakticheskoi konferentsii. Tom Vypusk XV. Chast' 1*. Kazan', 2021, pp. 192–206 (in Russian).

4. Shabalin V.N., Shatokhina S.N. The influence of work activity on the duration and quality of life of older people (analytical review). *Vestnik meditsinskogo instituta «Reaviz»: reabilitatsiya, vrach i zdorov'e*, 2024, vol. 14, no. 3, pp. 127–137. DOI: 10.20340/vmi-rvz.2024.3.OZOZ.3 (in Russian).

5. Zemlyanova M.A., Koldibekova Yu.V., Ukhabov V.M. The influence of harmful physical factors and industrial dust on changes in some biochemical and functional indicators of the cardio-

vascular system and respiratory system in workers engaged in underground mining of ore. *Meditsina truda i promyshlennaya ekologiya*, 2019, vol. 59, no. 11, pp. 920–925. DOI: 10.31089/1026-9428-2019-59-11-920-925 (in Russian).

6. Myasnikov I.O., Kizeev A.N. Review of risks of developing occupational and production-related diseases in workers of mining and metallurgical enterprises in the Arctic Zone of the Russian Federation. *Rossiiskaya Arktika*, 2024, vol. 6, no. 3 (26), pp. 26–42. DOI: 10.24412/2658-42552024-3-26-42 (in Russian).

7. Aleshina Yu.A., Novikova T.A., Migacheva A.G., Kochetova N.A. Socio-hygienic health determinants of bearing production workers. *Meditsina truda i promyshlennaya ekologiya*, 2023, no. 3 (35), pp. 7–22. DOI: 10.24412/2411-3794-2023-10301 (in Russian).

8. Sorokin G.A., Kir'yanova M.N. Age dynamics of working capacity and fatigue risk of employees of industrial enterprises, education, and healthcare. *Meditsina truda i promyshlennaya ekologiya*, 2021, vol. 61, no. 5, pp. 311–317. DOI: 10.31089/1026-9428-2021-61-5-311-317 (in Russian).

9. Ulanova E.V., Blazhina O.N., Filimonov E.S., Korotenko O.Yu. Frequency of somatic pathology occurrence in workers of the main professions of coal pits in the South of Kuzbass. *Meditsina truda i promyshlennaya ekologiya*, 2022, vol. 62, no. 5, pp. 353–358. DOI: 10.31089/1026-9428-2022-62-5-353-358 (in Russian).

10. Armah E.K., Adedeji J.A., Boafo B.B., Opoku A.A. Underground Gold Miner Exposure to Noise, Diesel Particulate Matter and Crystalline Silica Dust. *J. Health Pollut.*, 2021, vol. 11, no. 29, pp. 210301. DOI: 10.5696/2156-9614-11.29.210301

11. Etemadinezhad S., Amani A.S., Moosazadeh M., Rahimlou M., Samaei S.E. Occupational noise-induced hearing loss in Iran: a systematic review and meta-analysis. *Iran. J. Public Health*, 2023, vol. 52, no. 2, pp. 278–289. DOI: 10.18502/ijph.v52i2.11881

12. Camargo D.A., Munis R.A., Simões D. Investigation of exposure to occupational noise among forestry machine operators: A case study in Brazil. *Forests*, 2021, vol. 12, no. 3, pp. 299. DOI: 10.3390/f12030299

13. Yang P., Xie H., Li Y., Jin K. The effect of noise exposure on high-frequency hearing loss among Chinese workers: A meta-analysis. *Healthcare (Basel)*, 2023, vol. 11, no. 8, pp. 1079. DOI: 10.3390/healthcare11081079

14. Sánchez-Sellero I., Soto-Varela A. Relationship Between Occupational Exposure to Noise and Vibrations and Vertigo: A Prospective Case-Control Study. *J. Clin. Med.*, 2024, vol. 13, no. 22, pp. 6650. DOI: 10.3390/jcm13226650

15. Zhou S., Wen X., Huang Y., Wang S., Huang L., Yan M., Li X. Epidemiological characteristics and risk assessment of occupational diseases caused by physical factors in Guangdong Province, 2013–2022. *China Occupational Medicine*, 2023, pp. 279–284.

16. Thaper R., Sesek R., Garnett R., Acosta-Sojo Y., Purdy G.T. The combined impact of hand-arm vibration and noise exposure on hearing sensitivity of agricultural/forestry workers - a systematic literature review. *Int. J. Environ. Res. Public Health*, 2023, vol. 20, no. 5, pp. 4276. DOI: 10.3390/ijerph20054276

17. Gerger H., Søgaard K., Macri E.M., Jackson J.A., Elbers R.G., van Rijn R.M., Koes B., Chiarotto A., Burdorf A. Exposure to hand-arm vibrations in the workplace and the occurrence of hand-arm vibration syndrome, Dupuytren's contracture, and hypothenar hammer syndrome: a systematic review and meta-analysis. *J. Occup. Environ. Hyg.*, 2023, vol. 20, no. 7, pp. 257–267. DOI: 10.1080/15459624.2023.2197634

18. Liebenberg A., Oosthuizen J., Reed S. A current affair: worker perceptions of noise exposure and occupational hearing loss in Australian coal mines. *Ann. Work Expo. Health*, 2023, vol. 67, no. 9, pp. 1111–1120. DOI: 10.1093/annweh/wxad055

19. Bakirov A.B., Shaikhlislamova E.R., Volgareva A.D., Karimova L.K., Gimranova G.G. The results of research works on the assessment of risks to the health of employees under the industrial impact of physical factors. *Meditsina truda i promyshlennaya ekologiya*, 2021, no. 3 (27), pp. 7–13 (in Russian).

20. Musina A.A., Sarsenbayeva G.Zh., Amirseitova F.T., Suleimenova R.K. Health problems of workers of harmful industries. *Journal of Health Development*, 2022, vol. 4, no. 49, pp. 45–51. DOI: 10.32921/2225-9929-2022-4-49-45-51 (in Russian).

Fadeev A.G. Assessing intensity of impacts exerted by occupational factors on health of workers employed at copper-nickel ore mines per occupational health risk criteria. Health Risk Analysis, 2025, no. 3, pp. 52–60. DOI: 10.21668/health.risk/2025.3.06.eng

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