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Tarbiat Modares University

Ergonomic Risk Assessment of Manual Drilling in an Underground Copper Mine: Fatigue Assessment

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Authors

Mohammad Negahdary[1], MSc
Omran Ahmadi[1], PhD

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[1]Department of Occupational Health and Safety Engineering. Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran.

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*** Correspondence**
Department of Occupational Health and Safety Engineering, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran
P.O. Box: 14115-111
Tel: 0098 21 82884504
Fax : 0098 21 82884555
E-mail o.ahmadi@modares.ac.ir

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ABSTRACT

Aims: This study evaluated manual drilling to identify high-risk activities and quantify the risks of muscle fatigue and cumulative low back injury.

Method and Materials: This descriptive study involved direct observation of a full work shift. Three tools were used, including Hierarchical Task Analysis (HTA) to deconstruct and time tasks, Muscle Fatigue Assessment (MFA) to identify high-risk body parts, and the Lifting Fatigue Failure Tool (LIFFT) to calculate cumulative damage to the low back from lifting tasks.

Findings: The HTA revealed that the drilling the wall task was the most time-consuming, accounting for 50% of the total shift time. The MFA results identified this task as posing a very high risk to the shoulders and back, and a high risk to the wrists/hands/fingers. The LIFFT analysis yielded a cumulative damage score of 0.09895, corresponding to an estimated 67% probability of low back injury, classifying the job as high-risk. The tasks of drilling and moving tools contributed to over 99% of the total cumulative damage.

Conclusion: Manual drilling is a high-risk occupation with significant ergonomic hazards for the shoulder, back, and upper limbs. The alignment of these results with epidemiological data validates the assessment. Targeted interventions to reduce biomechanical loading are strongly recommended to mitigate the high risk of musculoskeletal disorders.

Keywords: Musculoskeletal disorders, Lifting, Fatigue, Ergonomics

Introduction

Work-Related Musculoskeletal Disorders (WMSDs) represent a primary occupational health challenge in physically demanding industries worldwide, including mining. These disorders are a leading cause of work-related illness and are responsible for high costs dueto reduced productivity and employee health issues [1-3]. In mining, workers are frequently exposed to a combination of risk factors such as repetitive tasks, awkward postures, and high physical workloads, all of which contribute to the prevalence of WMSDs [4, 5]. A comprehensive systematic review and meta-analysis on the prevalence of WRMSDs among miners identified the upper back as the most commonly affected body region, with a prevalence of 50.39%, followed by the neck (29.75%) and shoulders (29.72%) [5]. This high prevalence highlights the hazardous nature of mining tasks.

A key factor contributing to the development of WMSDs is muscle fatigue, resulting from reduced metabolic and neuromuscular function, making it challenging to sustain muscle contraction over time [6]. Fatigue can reduce muscle strength, cause pain and discomfort, and, in the long term, increase the likelihood of cumulative trauma disorders. In fact, recent evidence suggests that WMSDs may result from a fatigue failure process, in which cumulative tissue damage is a function of both the magnitude of the load and the number of repetitions [7]. This makes assessing fatigue a critical component of ergonomic analysis in high-risk occupations.

To systematically analyze and mitigate these risks, several ergonomic assessment tools have been developed. Hierarchical Task Analysis (HTA) was initially devised by Annett and Duncan in 1967 as a method for deconstructing a job into a hierarchy of goals and operations, providing a structured framework for understanding task demands[8-10].

For assessing muscle fatigue, the Muscle Fatigue Assessment (MFA) method, developed by Rodgers in 1978, is a functional job evaluation technique that considers three key variables: level of effort, duration of effort, and frequency of effort across different body parts [11, 12]. Previous studies have widely applied the MFA method to evaluate the risk of WRMSDs in various occupations, including workers in the transportation department of the brick factory [13], workers in a household manufacturing company [14], and assembly-line operators [15], demonstrating its practicality in identifying high-risk body regions and prioritizing ergonomic interventions. The validity and reliability of this method have been confirmed [16]. For a more in-depth analysis of lifting tasks, the Lifting Fatigue Failure Tool (LIFFT) was developed based on fatigue failure theory that has been validated [17]. This method calculates a daily dose of cumulative loading on the low back using only three variables: the load weight, the horizontal distance from the spine, and the number of repetitions. This study aims to provide a descriptive ergonomic evaluation of the manual drilling task in an underground copper mine using HTA, MFA, and LIFFT to identify high-risk activities and quantify the risk of muscle fatigue and cumulative injury.

Method and Materials

This study utilized a multi-step ergonomic assessment approach based on direct observation and analysis of the tasks performed by all 10 manual drillers over a full work shift in an underground copper mine. This group represented the entire population of manual drillers employed at this specific site. Given that the study's objective was a comprehensive, descriptive analysis of this high-risk job, assessing the complete population was deemed the most appropriate and thorough method.

This descriptive study used a multi-step ergonomic assessment based on HTA, with direct observation and analysis of a manual driller's tasks over a full work shift in an underground copper mine.

A systematic approach was adopted to select the risk assessment tools, following the framework of the American Industrial Hygiene Association (AIHA) Ergonomics Assessment Toolkit [18]. An initial assessment was conducted to confirm the presence of risk. Subsequently, based on the identified primary risk factors, more detailed and specific risk analysis tools were selected.

Rodgers' MFA was utilized as a screening tool to evaluate the risk of muscle fatigue. This functional job evaluation technique assesses three main variables across different body regions: effort level, duration of effort, and frequency of effort. The combination of scores for these variables yields a priority level for corrective action (Low, Medium, High, or Very High).

For a more in-depth analysis of tasks involving manual lifting, the LIFFT was used to assess the risk of lower back injury. This tool, based on fatigue failure theory, calculates a Cumulative Damage (CD) value by accounting for the load's weight, the horizontal distance from the spine, and the number of lifts performed. The resulting CD score indicates a probabilistic risk of developing a low back disorder.

Findings

The HTA of the driller's job identified a sequence of primary tasks. The overall goal was to "Perform Drilling Job in Underground Copper Mine" (Goal 0). The operational plan follows a general sequence of tasks, with conditional steps for equipment repair. The main functions and their average durations are detailed in Figure 1.

The analysis of task duration shows that drilling the wall consumes 50% of the total shift time and approximately 63% of the productive work time, as shown in Table 1. This makes it the most critical task from an exposure standpoint.

The MFA was conducted on the most physically demanding tasks identified during the observation. The results, summarized in Error! Reference source not found., show the Effort Level (EL), continuous Effort Duration

(ED), and Effort Frequency (EF) scores, along with the final priority level for corrective action.

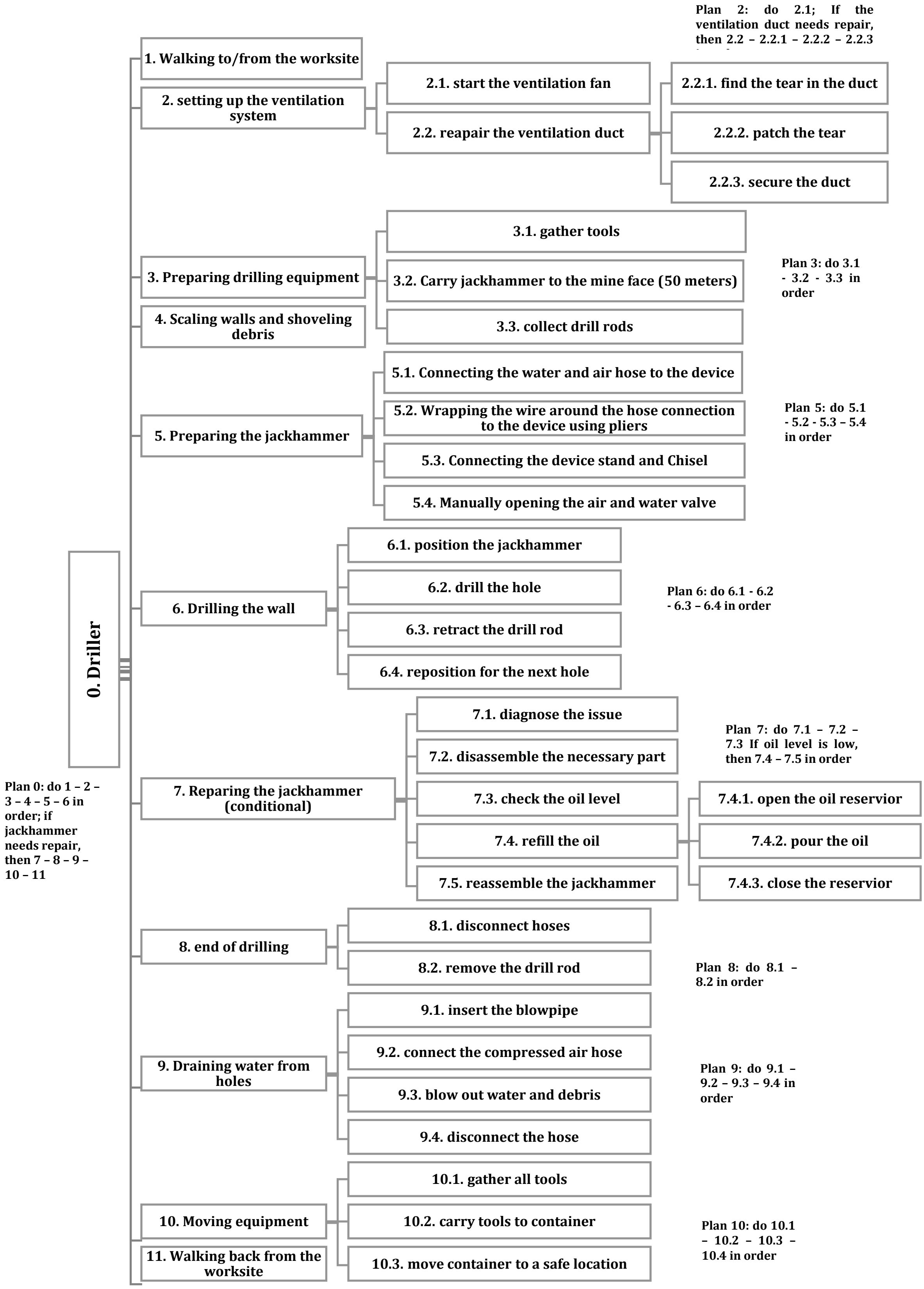

Figure 1) Driller Hierarchical Task Analysis (HTA).

Table 1) Description and Duration of Tasks for a Manual Driller's Shift

Task	Duration (minutes)	Percentage (%) of Duration for each task	Photo
Walking (to and from the worksite)	60 (30 each way)	60 (12.5)	
Setting up ventilation	20	20 (4.2)	
Preparing drilling tools	10	10 (2.1)	
Scaling and shoveling	18	18 (3.7)	 
Preparing the jackhammer	15	15 (3.1)	
Drilling the wall	240	240 (50)	
End of drilling	2	2 (0.4)	
Draining water from holes	7	7 (1.5)	

Repairing the jackhammer	9	9 (1.9)	
Moving equipment	2	2 (0.4)	
Other	97	97 (20.2)	
Total productive Time	383	383(79.8)	
Total shift Time	480	480 (100)	

Table 2) Muscle Fatigue Assessment scores and priority levels for key drilling tasks

Task	Neck	Shoulder	Back	Arms/Elbows	Wrists/Hands/Fingers	Leg/Knees	Ankle/Foot/Toes
	EL, ED, EF (P)	EL, ED, EF (P)	EL, ED, EF (P)	EL, ED, EF (P)	EL, ED, EF (P)	EL, ED, EF (P)	EL, ED, EF (P)
Drilling the wall	1,1,1 (L)	3,4,2 (VH)	2,4,2 (VH)	1,1,2 (L)	2,2,3 (H)	1,1,1 (L)	1,1,1 (L)
Scaling	2,1,2 (L)	1,1,1 (L)	1,1,1 (L)	2,1,3 (M)	2,1,3 (M)	1,1,1 (L)	1,1,1 (L)
Shoveling	1,1,1 (L)	3,1,3 (H)	3,1,1 (L)	2,2,3 (H)	2,1,3 (M)	2,1,3 (M)	2,1,3 (M)
Preparing tools	1,1,1 (L)	3,1,1 (L)	3,1,1 (L)	2,1,1 (L)	1,1,1 (L)	3,1,1 (L)	3,1,1 (L)
Preparing jackhammer	1,1,2 (L)	2,2,2 (M)	2,1,2 (L)	2,1,2 (L)	2,1,3 (M)	2,1,1 (L)	2,1,1 (L)
Repairing jackhammer	1,1,1 (L)	2,2,2 (M)	2,1,2 (L)	2,1,2 (L)	2,1,2 (M)	2,1,1 (L)	2,1,1 (L)

EL= Effort Level, ED= Continuous Effort Duration, EF= Effort Frequency, P=Overall Priority
L: low; M: moderate; H: High; VH: Very High
Note: The scores represent the typical demands observed for each standardized task, which are applicable to the entire assessed population of drillers (N=10)

Several tasks during the driller's shift involve manual lifting of heavy or awkward objects. These tasks were identified and analyzed using the LIFFT tool (Error! Reference source not found.). The inputs and outputs of the LIFFT analysis are shown in Error! Reference source not found.. The tool calculates the cumulative damage from each lifting activity and sums them to provide a total daily damage score and an estimated risk of injury.

Table 3) LIFFT Risk Assessment Results

Task	Lever Arm (cm)	Load (N)	Moment (N · m)	Repetitions (per shift)	Cumulative Damage	% Total Damage
Drilling the wall	95	250	237.4	4	0.04972	50.2
Shoveling	120	50	59.98	20	0.0003	0.3
Scaling	65	50	32.49	4	0.00002	0.0
Moving and Preparing Tools	85	300	254.89	2	0.04891	49.4
Total Cumulative Damage:					0.09895	100%
Probability of High-Risk Job* (%):					66.7	
* "High Risk Job" is defined as a job experiencing 12+ injuries per 200,000 hours worked, as defined by Marras et al [19].						

The final cumulative damage score of 0.09895 corresponds to an estimated injury risk of approximately 67%, classifying the job as high-risk for cumulative low back disorders. The tasks of drilling the wall and moving and preparing tools are the primary contributors, accounting for over 99% of the total cumulative damage to the lower back.

Discussion

This ergonomic assessment of manual drilling in an underground mine utilized HTA, MFA, and LIFFT to analyze risks. According to the HTA assessment, the primary drilling task consumes the majority of the shift, resulting in prolonged exposure. The MFA flagged the shoulder and back as very high-risk regions. The LIFFT analysis further reinforces these findings by quantifying the cumulative load on the lower back. The high cumulative damage score (~67% injury probability) is largely driven by the lifting of the heavy jackhammer during drilling and equipment transport. This demonstrates that even tasks with a low number of repetitions can contribute significantly to cumulative damage if the load and posture (horizontal distance) are substantial. The fact that two separate assessment methods (MFA and LIFFT) both identified the drilling and associated material-handling tasks as high-risk provides strong evidence of the hazardous nature of this job.

When comparing with published prevalence data in mining drillers, the pattern is strikingly similar. For example, meta-analytic surveys of mine workers report that back pain is by far the most common complaint (with upper-back pain prevalence on the order of 50% [5]), and shoulder/neck disorders are also highly prevalent. Notably, occupational exposure to heavy vibration (characteristic of pneumatic and hydraulic drilling) is well-known to be associated with shoulder and neck musculoskeletal disorders [20], and our analysis similarly flags the shoulder region as high-risk. Likewise, hand–arm vibration hazards in drilling are linked to wrist/hand disorders, consistent with our finding of elevated risk in those body regions. Importantly, drillers themselves have been identified as a mining subgroup with exceptionally high MSD incidence. A long-term cohort study found that drillers had the highest rate of WRMSDs among all underground mine trades [21]. This consonance suggests that the high-risk zones predicted by our ergonomic analyses correspond to the body regions where drillers commonly experience pain or injury in real work settings.

This comparative exercise underscores the utility of coupling ergonomic risk assessment with epidemiological benchmarking. It has been argued that when predicted risk zones overlap with high-prevalence pain sites, confidence in the assessment outcome is strengthened. Our findings suggest that preventive strategies (e.g., redesign of drilling posture, mechanical supports, vibration damping, rotation schedules) should most critically address shoulder, back, and wrist loading in drillers. Future work should expand the sample size, include real-time force and vibration measurements, and, ideally, correlate predicted risk with longitudinal monitoring of musculoskeletal symptoms in drilling crews.

Conclusion

In conclusion, this study's multi-method ergonomic assessment (MFA and LIFFT) identified manual drilling as a high-risk job, flagging the shoulder, back, and upper-limb (wrist/hand) regions as critical risk zones. This was primarily driven by the prolonged duration (50% of the shift) and the high-force nature of the main drilling task, resulting in a high probability of cumulative low back injury (67%). These findings are strongly validated by their direct concordance with epidemiological reports of miner pain prevalence. This alignment between our predicted risks and observed injury patterns confirms that targeted interventions to reduce biomechanical loading on the spine, shoulders, and wrists are strongly warranted. Future research using direct measurements is needed to solidify these predictive links.

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Authors' Contribution

MN as the Main Researcher, conceived and designed the study, performed the data analysis, and wrote the initial draft of the manuscript and the Introduction. OA conducted the Methodology, supervised the entire project, and wrote the Discussion. All authors have read and approved the final version.

Conflicts of Interest

None declared by authors

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Before the study, all participants were provided with a full explanation of the research objectives and procedures. Written informed consent was obtained from each of the ten drillers. They were explicitly informed that their participation was voluntary and that they had the right to withdraw from the study at any time without consequence. The methodology was entirely non-invasive, consisting only of standard observational ergonomic assessments

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References

1. ILO. Recommendation concerning the list of occupational diseases and the recording and notification of occupational accidents and diseases (Recommendation R194). Geneva; ILO. 2002. [Available from: https://www.ilo.org/dyn/nor-mlex/en/f ?p=NORMLEXPUB:12100:0::NO:: P12100_IN-STRUMENT_ID:312532.
2. Khandan M, Koohpaei A, Kohansal Aghchay M, Ebrahimi MH, Khammar A, Arsang Jang S, et al. Assessing the factors predicting work-related musculoskeletal disorders among Iranian port's personnel using regression model. Iran Rehabil J. 2017;15(4):309-16.
3. Waehrer G, Leigh JP, Miller TR. Costs of occupational injury and illness within the health services sector. Int J Health Serv. 2005;35(2):343-59.
4. Dempsey PG, Kocher LM, Nasarwanji MF, Pollard JP, Whitson AE. Emerging ergonomics issues and opportunities in mining. Int J Environ Res Public Health. 2018;15(11):1-11.
5. Rabiei H, Malakoutikhah M, Vaziri MH, Sahlabadi AS. The prevalence of musculoskeletal disorders among miners around the world: a systematic review and meta-analysis. Iran J Public Health. 2021;50(4):676-688.
6. Ghasemi C, Jafari H, Jamshidi A. Temporal stability of torque parameters and induced perception following muscle fatigue. J Mod Rehabil. 2011;4(3 And 4):6-11.
7. Zheng B, Chen F, Wang J, Deng H, Li J, Zhou C, et al., editors. The prevalence and correlated factors of occupational stress, cumulative fatigue, and musculoskeletal disorders among information technology workers: A Cross-Sectional study in Chongqing, China. Healthcare. 2023;11(16):2322.
8. Annett J. Hierarchical task analysis. In: Handbook of cognitive task design. CRC Press; 2003. pp. 17-36.
9. Hodgkinson GP, Crawshaw C. Hierarchical task analysis for ergonomics research: An application of the method to the design and evaluation of sound mixing consoles. . Appl Ergon. 1985;16(4):289-99.
10. Lane R, Stanton NA, Harrison D. Applying hierarchical task analysis to medication administration errors. Appl Ergon. 2006;37(5): 669-79.
11. Azizi M, Motamedzade M. Working postures assessment using rula and ergonomic interventions in quality control unit of a glass manufacturing company. Iran J Ergon. 2013;1(1):73-9.
12. Rodgers SH. Muscle fatigue assessment: Functional job analysis technique. In: Handbook of human factors and ergonomics methods. CRC Press; 2004. pp. 130-41.
13. Kalte HO. Evaluation of work fatigue in loading workers using muscle fatigue assessment method (MFA): A case study in a Brick Factory. J Health Res Community. 2016;2(2):29-36.
14. Mohammadi Z, Ghanbary Sartang A, Attar Abdolabadi J. Relationship between risk and prevalence of musculoskeletal disorders in a household manufacturing company. J Prev Med. 2016;3(2):51-7.
15. Motamedzade M, Saedpanah K, Salimi K, Eskandari T. Risk assessment of musculoskeletal disorders by Muscle Fatigue Assessment method and implementation of an ergonomic intervention in Assembly industry. J Occup Hyg Eng. 2016;3(1):33-40.
16. Moradpour Z, Rezaei M, Torabi Z, Khosravi F, Ebrahimi M, Hesam G. Study of correlation between muscle fatigue assessment and cornell musculoskeletal disorders questionnaire in Shahroud Taxi Drivers in 2017: A descriptive study. J Rafsanjan Univ Med Sci. 2019;17(11):1031-42.
17. Gallagher S, Sesek RF, Schall Jr MC, Huangfu R, editors. Validation of the Lifting Fatigue Failure Tool (LiFFT). In: Congress of the International Ergonomics Association. Springer; 2018. pp .216–223.
18. Kotowski SE, Gibson S. Ergonomic Assessment Toolkit. AIHA, Falls Church, VA; 2023.
19. Marras WS, Lavender SA, Leurgans SE, Rajulu SL, Allread SG, Fathallah FA, et al. The role of dynamic three-dimensional trunk motion in occupationally-related. Spine. 1993;18(5):617-28.
20. Charles LE, Ma CC, Burchfiel CM, Dong RG. Vibration and ergonomic exposures associated with musculoskeletal disorders of the shoulder and neck. Saf Health Work. 2018;9(2):125-32.
21. Syurin SA. Occupational diseases in underground miners of the Kola Peninsula: a 14-year longitudinal observational study. Public Health Life Environ. 2024;32(5):42-52. doi:10.35627/2219-

5238/2024-32-5-42-52.