Preplanned Studies

Analysis of Intelligent Equipment Usage for Work-Related Musculoskeletal Disorders Prevention in Miners — Shanxi Province, China, 2023

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Summary

What is already known about this topic?

Work-related musculoskeletal disorders (WMSDs) are prevalent in the workforce and occur across various industries. Surveys show that the prevalence of WMSDs among miners is generally over 50%.

What is added by this report?

High levels of intelligent equipment usage (IEU) can decrease the prevalence of WMSDs among miners by 7.49% and reduce pain by 13.69% on average. Stepwise regression analysis proved that IEU can reduce the harmful effects of workload on WMSDs.

What are the implications for public health practice?

New Quality Productive Forces (NQPF) should also focus on health productivity. Disease prevention departments should consider the impact of NQPFs on occupational health and actively guide intelligent equipment design.

Work-related musculoskeletal disorders (WMSDs) are health problems of the locomotor apparatus that are induced or aggravated by work. If the mechanical workload exceeds the musculoskeletal system's load-bearing capacity, injuries to ligaments, bones, muscles, and tendons are typical consequences (*1*). Coal mining is characterized by heavy workloads, and miners typically engage in prolonged postures requiring repetitive operations and heavy load carrying, which can easily trigger local muscle fatigue and ultimately lead to the development of WMSDs. According to research from the China CDC, the prevalence of WMSDs in the population working in key industries was estimated to be 41.2% (*2*). One survey of Indian underground coal miners reported that approximately 65.45% of them complained of WMSD pain (*3*). Data from another study in China indicate that the total symptom prevalence of WMSDs among coal miners has reached 75.6%; the five body parts with the highest symptom prevalence include the lower back (54.1%), neck (42.1%), shoulder (37.2%), knee (29.1%), and back (28.1%), in order of prevalence (*4*). The "National Occupational Disease Prevention and Control Plan (2021–2025)" prioritizes research on the causes of WMSD damage (*5*).

China is vigorously developing new quality productive forces (NQPF) and upgrading traditional industries with AI and other technologies. In 2020, the Chinese government released the "Guiding Opinions on Accelerating the Intelligent Development of Coal Mines." This document proposed that all coal mines will realize intelligent mining by 2035. The essence of intelligent mining is using intelligent equipment to replace miners engaged in dangerous, heavy, and repetitive labor. One example is the use of inspection robots. According to the "Typical Case Collection of Intelligent Construction in Coal Mines" published by the China National Energy Administration in 2023, inspectors at the Tang Kou coal mine previously inspected the mine hoist 22 times daily, with each inspection taking 30 minutes. With the intelligent inspection robot, the robot completes all on-site inspections, and the inspector only needs to operate it remotely from the control room (*6*). Therefore, intelligent mining can potentially reduce the prevalence of WMSDs among miners. However, relevant literature is lacking, and this study aims to investigate this issue from the perspective of intelligent equipment usage (IEU).

In June–July 2023, this study used single-stage cluster sampling to select underground miners from six coal mines with different levels of intelligent automation in Shanxi Province for a questionnaire survey. Three coal mines were designated as intermediate intelligent coal mines and three as primary intelligent coal mines. A total of 2,245 questionnaires were collected, of which 2,165 were deemed valid. All participants were male and employed in underground production units, such as excavation, mining, maintenance, ventilation, and transport teams. According to labor law in China, female workers are prohibited from working in underground mines. All questionnaires were electronic and distributed to miners through the coal mine human resources departments. The entire process was completed under the guidance of investigators at the participants' workplaces.

The questionnaire collected data on four areas: IEU, workload, WMSDs prevalence, and pain level. Self-reported IEU data were collected using questionnaires covering two aspects: 1) direct IEU ("I work with a lot of intelligent equipment," IEU-D); and 2) indirect IEU ("There is a lot of intelligent equipment in my workplace," IEU-I). Questionnaire responses were scored on a 5-point Likert scale (from 1 to 5), ranging from "very inconsistent" to "very consistent." Scores were classified as low (1 and 2), medium (*3*), and high (4 and 5). The workload scale, adapted from a similar scale developed by Johansson et al. in 1991 (*7*), comprised four questions: 1) "In the course of your work, are you exposed to inappropriate work postures (e.g., bending, twisting)?"; 2) "Do you have to lift heavy objects at work?"; 3) "Do you sweat every day at work?"; and 4) "Do you think your job is unsafe?" Responses were scored on a 5-point scale (from 1 to 5), ranging from "never" to "always." Miners' WMSDs prevalence was measured using the Chinese Musculoskeletal Disorder Questionnaire (CMDQ) developed by the China CDC. WMSDs were defined as pain, numbness, or limited movement in a relevant body part lasting >1 week, or lasting <1 week but occurring >2 times in the past 12 months; response options were yes or no. Miners' pain levels in different body parts were assessed using a visual analog scale (VAS). Scores ranged from 0 to 10, indicating "no pain" to "unbearable and severe pain." The questionnaire's Cronbach's α coefficient was 0.858, and its Kaiser-Meyer-Olkin (KMO) value was 0.719, demonstrating good reliability and validity.

Table 1 shows the miners' WMSDs prevalence rates at different IEU-D levels. Higher levels of IEU-D correspond to lower WMSDs prevalence rates. Based on the odds ratio (*OR*), the differences in WMSDs prevalence rates were statistically significant at different levels of intelligent automation. Compared with the low IEU-D group, the high IEU-D group showed a 7.49% average decrease in WMSDs prevalence rates. The most notable improvements were in the knees, upper back, and neck. Compared with the low IEU-D group, the prevalence of WMSDs in these areas decreased by more than 8% in the high IEU-D group.

Table 2 describes the differences in body pain at different levels of IEU-D, suggesting that IEU can significantly improve pain associated with WMSDs. Compared to the low IEU-D group, the average pain in all body parts was 13.69% lower in the high IEU-D group. The most pronounced pain reduction occurred in the following body parts, ranked in order of pain severity: hips/thighs, elbows, knees, upper back, ankles/feet, and neck. Pain decreases in these areas were all greater than 10%.

The primary occupational hazards for WMSDs include heavy physical loads, repetitive operations, and poor posture, categorized as workload (*8*). Age, position, and length of service are definitive individual influencing factors (*9*). Although not included in this study, these individual factors can influence regression results and were controlled for in the analysis. The following regression equation describes the moderation:

$$P = \beta_0 + \alpha_1 A + \alpha_2 L + \alpha_3 J + \beta_1 W + \beta_2 I + \beta_3 WI + \varepsilon \quad (1)$$

P value represents the degree of pain in different body parts. Age (A), length of service (L), and job position (J) are control variables. Workload (W) is the independent variable. The moderator variable is IEU level (I). β_1 and β_2 represent the direct effects of W and I, and β_3 represents the moderator effect. If $\beta_3 \neq 0$, it proves that there is a moderating effect.

It can be seen in Table 3, we gradually added the following variables to the stepwise regression model: independent variable (W), moderator variable (I), and interaction term (W×I). From Model 1 to Model 4, the effects of all variables were significant, with Model 4 demonstrating the most significant results. $\beta_1 = 0.068$ and $\beta_2 = -0.068$ show that workload positively affected the degree of body pain, while IEU negatively affected it. $\beta_3 = -0.183$ indicates that IEU acts as a negative moderator, diminishing the effect of workload on the degree of body pain.

The analysis above explains the effect of IEU on WMSDs. IEU not only directly reduces the prevalence of WMSDs but also significantly reduces the harmful effects of workload on WMSDs.

DISCUSSION

As a chronic condition, WMSDs place a substantial burden on healthcare systems and decrease productivity. Epidemiological data on WMSDs in coal miners, a high-risk group, are representative of trends

TABLE 1. WMSDs prevalence of miners with different levels of IEU-D in Shanxi Province, China, 2023.

Body part	IEU-D	Number	Number of WMSDs	Rate of WMSDs(%)	*OR* (95% *CI*)	*P*
Neck	Low	559	417	74.597	1.473	<0.050
	Medium	729	544	74.623	1.475	<0.050
	High	877	584	66.591	1	
Shoulders	Low	559	360	64.401	1.254	<0.050
	Medium	729	476	65.295	1.304	<0.050
	High	877	518	59.065	1	
Upper back	Low	559	348	62.254	1.409	<0.050
	Medium	729	465	63.786	1.504	<0.050
	High	877	473	53.934	1	
Lower back	Low	559	381	68.157	1.336	<0.050
	Medium	729	493	67.627	1.304	<0.050
	High	877	540	61.574	1	
Wrists/hands	Low	559	316	56.530	1.346	<0.050
	Medium	729	406	55.693	1.301	<0.050
	High	877	431	49.145	1	
Elbows	Low	559	291	52.057	1.375	<0.050
	Medium	729	374	51.303	1.334	<0.050
	High	877	387	44.128	1	
Hips/thighs	Low	559	260	46.512	1.341	<0.050
	Medium	729	331	45.405	1.282	<0.050
	High	877	345	39.339	1	
Knees	Low	559	339	60.644	1.429	<0.050
	Medium	729	437	59.945	1.388	<0.050
	High	877	455	51.881	1	
Ankles/feet	Low	559	276	49.374	1.374	<0.050
	Medium	729	350	48.011	1.302	<0.050
	High	877	364	41.505	1	

Abbreviation: WMSDs=work-related musculoskeletal disorders; IEU-D=direct intelligent equipment usage; *OR*=odds ratio; *CI*=confidence interval.

in other occupations. By replacing manual labor with intelligent equipment, IEU reduces the intense repetitive work required of miners, thereby lowering the risk of WMSDs and disease onset. Compared with low levels of IEU-D, high levels can reduce WMSDs prevalence rates among miners by 7.49% and decrease WMSDs pain by an average of 13.69%. This study found the following declines in the prevalence rate of WMSDs by body part: ankles/feet (15.94%), hips/thighs (15.42%), elbows (15.23%), knees (14.45%), upper back (13.36%), wrists/hands (13.06%), neck (10.73%), lower back (9.66%), and shoulders (8.29%). Declines in WMSDs pain by body part were as follows: hips/thighs (19.07%), elbows (16.47%), knees (16.39%), upper back (15.45%), wrists/hands (14.01%), ankles/feet (13.61%), neck (11.23%), shoulders (9.01%), and lower back (7.97%). Considering age, length of service, position, and workload, stepwise regression analysis revealed that IEU can reduce WMSDs pain and moderate the harmful effects of workload.

The NQPFs should also focus on health productivity. MSDs are the second leading cause of non-fatal disability worldwide, affecting over 1.63 billion people (*10*). WMSDs, a preventable subset of MSDs, can be mitigated by improving working conditions. As a form of NQPF, intelligence mining presents a win-win scenario for productivity and occupational health. However, evaluations of intelligence mining often neglect the associated occupational health benefits, leading to an underestimation of its positive impact. From a life-

TABLE 2. WMSDs pain with different levels of IEU-D in Shanxi Province, China, 2023.

Body part	Low IEU-D		Medium IEU-D		High IEU-D		F	*P*
	Number	Pain degree*	Number	Pain degree*	Number	Pain degree*		
Neck	559	3.322±2.773	729	3.361±2.651	877	2.949±2.743	5.540	<0.01
Shoulders	559	2.964±2.908	729	2.912±2.741	877	2.697±2.842	1.906	<0.01
Upper back	559	2.900±2.918	729	2.925±2.810	877	2.452±2.803	6.946	<0.01
Lower back	559	3.301±2.978	729	3.296±2.937	877	3.038±3.034	1.985	<0.01
Elbows	559	2.422±2.847	729	2.403±2.786	877	2.023±2.755	5.073	<0.01
Wrists/hands	559	2.599±2.888	729	2.517±2.823	877	2.235±2.782	3.441	<0.01
Hips/thighs	559	2.197±2.851	729	2.156±2.870	877	1.778±2.674	5.307	<0.01
Knees	559	2.995±3.069	729	2.864±2.980	877	2.505±2.967	5.314	<0.01
Ankles/feet	559	2.270±2.875	729	2.225±2.841	877	1.961±2.790	2.656	<0.01

Abbreviation: WMSDs=work-related musculoskeletal disorders; IEU-D=direct intelligent equipment usage; SD=standard deviation.
* Pain degree: Mean±SD.

TABLE 3. Step-wise regression results of the degree of pain associated with WMSDs.

Dependent variable	Coefficient	Model 1	Model 2	Model 3	Model 4
Intercept	β_0	0.485	0.024	0.835	0.170
Age (A)	α_1	0.194†	0.195†	0.199†	0.203†
length of service (L)	α_2	0.114†	0.111†	0.112†	0.131†
Job position (J)	α_3	−0.116†	−0.116†	−0.115†	−0.113†
Workload (W)	β_1		0.055*	0.024	0.068*
IEU level (I)	β_2			−0.092†	−0.068*
W×I	β_3				−0.183†
R^2		0.083	0.086	0.094	0.126
ΔR^2		0.083	0.003	0.008	0.032
F-test		65.626†	7.064*	18.034†	78.143†

Abbreviation: WMSDs=work-related musculoskeletal disorders.
* P<0.01;
† P<0.001.

cycle perspective, intelligence mining is valuable in preventing WMSDs in older miners. Public health departments can introduce occupational health evaluation standards and certification systems to provide a basis for assessing the health benefits of intelligent equipment. Notably, at high IEU-D, prevalence rates of WMSDs in the neck, shoulders, upper back, lower back, and wrists remain higher than 50%, indicating substantial potential for further WMSD control. Public health departments can provide increased technical support for intelligent equipment design, enhancing ergonomic compatibility. Coal mines, bearing primary responsibility for miners' health, should prioritize ergonomic requirements when selecting intelligent equipment. In positions necessitating poor posture, repetitive motions, or weight-bearing work, coal mines should implement regular job rotation.

This study was subject to some limitations. First, there was potential recall bias, as WMSD prevalence rates relied heavily on miners' recollections Second, the cross-sectional design precluded comparative analysis before and after intelligent mining implementation. As intelligent mining advances, the impact of IEU on WMSDs may evolve. Future studies could employ a follow-up cohort to analyze long-term effects.

Intelligent mining is not only a new quality productive force but also a health productivity force. WMSDs are preventable workplace diseases. Public health departments should capitalize on this opportunity, using coal mines as a pilot industry, to develop ergonomics certification for intelligent equipment. This will help companies integrate intelligent transformation with WMSDs prevention.

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