La Medicina del Lavoro

Original Article

Med. Lav. 2026; 117 (1): 18043
DOI: 10.23749/mdl.2026.18043

Prevalence and Multivariate Impact of Musculoskeletal Disorders on General Health, Occupational Fatigue, and Productivity in an Industrial Workforce

Alireza Choobineh[1], Mohammad Karami[2], Yaser Sahranavard[2], Mohammad Reza Fakhraei[2], Fatemeh Ghanbari Mohammad[2], Fatemeh Alibeygian[2], Somayeh Hossainie Nasab[2], Azam Alizadeh[2], Mina Shahbazi[3], Reza Tahmasebi[3,*]

[1] Research Centre for Health Sciences, Institute of Health, Shiraz University of Medical Sciences, Shiraz, Iran
[2] HSE Department, Sarcheshemeh Copper Complex, Rafsanjan, Iran
[3] Student Research Committee, Department of Ergonomics, School of Health, Shiraz University of Medical Sciences, Shiraz, Iran

Keywords: Musculoskeletal Disorders; Occupational Fatigue; Productivity; Copper Industry; Occupational Health

Abstract

Background: *Musculoskeletal disorders represent a leading occupational health challenge in heavy-industry settings, yet their combined impact on workers' general health, fatigue, and productivity remains underexplored. This study aims to quantify the relationship between multisite musculoskeletal symptom burden and key health and performance outcomes among copper-industry employees.* **Methods:** *A cross-sectional survey of 585 workers used the Standardized Nordic Musculoskeletal Questionnaire, the 28-item General Health Questionnaire, the SOFI-20 fatigue inventory, and the HPQ-26 productivity survey. Spearman's rank correlation was used to examine bivariate relationships, and multivariable linear regression models, generally adjusting for demographic, work-related, and psychosocial factors, were employed to estimate the independent effect of the number of painful sites on health, fatigue, and productivity outcomes.* **Results:** *Fifty-seven percent of workers reported pain in at least one region during the preceding 12 months, with an average of 2.6 painful sites per person (standard deviation 2.4). The number of painful sites showed a moderate positive correlation with poorer general health scores ($\rho = 0.43$, $p < 0.001$) and higher fatigue scores ($\rho = 0.53$, $p < 0.001$), and a moderate negative correlation with productivity ratings ($\rho = -0.30$, $p < 0.001$). In adjusted regression analyses, each additional painful site was associated with a 1.9-point worsening in general health score (95% CI 1.5 to 2.2), an 8.4-point increase in fatigue score (95% CI 7.3 to 9.6), and a 1.6-point decrease in productivity score (95% CI –2.0 to –1.2), all with p-values < 0.001.* **Conclusions:** *There is a clear dose–response relationship between the number of painful anatomical sites and declines in health, increases in fatigue, and reductions in productivity among copper-industry workers. To address this multifaceted impact, interventions should integrate ergonomic workstation design, task rotation, optimized break schedules, and comprehensive health-promotion services targeting both physical and psychosocial risk factors.*

Received 10.10.2025 – Accepted 07.01.2026

*Corresponding Author: Reza Tahmasebi; E-mail: tahmasebi.re@gmail.com

1. INTRODUCTION

Musculoskeletal disorders (MSDs) are widely recognized as one of the foremost occupational health concerns of the twenty-first century, exacting profound costs on employees, employers, and national economies alike. Annual global estimates attribute approximately 25% of all work-related illnesses to MSDs, with affected workers incurring higher rates of sickness absence, reduced functional capacity, and long-term disability [1-3]. In heavy-industry environments where manual handling of ores, protracted static postures at assembly lines, and exposure to whole-body vibration are commonplace, 12-month prevalence rates frequently exceed 50% [4-6]. Economically, direct medical expenditures and compensation payments for work-related MSDs absorb up to 2% of gross domestic product in many high-income nations. At the same time, indirect costs, such as lost productivity, recruitment, and training of replacement staff, can double that figure [7, 8]. Despite the availability of ergonomic guidelines and assistive technologies, implementation remains uneven, particularly in resource-constrained processing facilities and subcontracted operations, perpetuating a cycle of injury risk and unmet prevention needs.

Beyond the overt musculoskeletal impairments, chronic low-back pain, rotator cuff tendinopathy, and degenerative knee pathology, MSDs precipitate a constellation of adverse psychosocial outcomes that erode workers' mental health and social functioning. Population-based surveys spanning manufacturing, mining, and construction sectors report that employees with pain at multiple anatomical sites are two to three times more likely to exhibit clinically relevant depressive symptoms, anxiety, and sleep disturbances than those with isolated complaints [9-11]. According to the biopsychosocial model, this interplay is bidirectional: heightened stress and poor sleep quality exacerbate pain sensitivity through central sensitization, while persistent nociceptive input fuels mood dysregulation and cognitive fatigue [12]. Moreover, interpersonal tensions with supervisors and colleagues often escalate as productivity falters, fostering presenteeism and social withdrawal [13]. Coping strategies vary widely from adaptive problem-solving and social support to maladaptive withdrawal or substance use, highlighting the need for integrated interventions that address both ergonomic risk factors and mental health promotion in high-strain work environments.

Converging evidence suggests that the presence and severity of MSDs substantially exacerbate both peripheral and central dimensions of occupational fatigue, creating a self-reinforcing cycle of pain and tiredness that undermines worker resilience [14, 15]. Chronic nociceptive input from injured tissues induces prolonged muscle co-contraction and altered movement strategies, increasing metabolic demand and accelerating the onset of peripheral fatigue during even routine manual tasks [16, 17]. Simultaneously, persistent pain activates central stress pathways, elevating levels of proinflammatory cytokines such as interleukin-6 and tumor necrosis factor-α, which cross the blood–brain barrier to impair neurotransmitter balance and cortical excitability, thereby magnifying cognitive fatigue and slowing psychomotor responses [18, 19]. Moreover, sleep fragmentation is common among workers with MSD-related discomfort, further diminishing restorative processes, lowering pain thresholds, and heightening subjective fatigue the following day [20]. Despite these mechanistic insights, few studies have simultaneously quantified the relative contributions of pain intensity, anatomical distribution of disorders, and sleep quality to distinct fatigue domains within heavy-industry cohorts.

Work in mineral-processing environments exposes employees to a confluence of physical, chemical, and psychosocial hazards that synergistically undermine physiological homeostasis and psychological resilience. Extreme ambient temperatures, airborne particulates, and high noise levels induce thermal strain, respiratory irritation, and auditory damage. At the same time, chronic exposure to heavy metals and chemical solvents disrupts endocrine function and cellular metabolism [21, 22]. Prolonged shifts and rotating schedules further compromise circadian regulation and sleep architecture, exacerbating cognitive fatigue and mood disturbances [23, 24]. Simultaneously, elevated production targets, stringent supervision, and perceived job insecurity fuel chronic psychosocial stress, marked by sustained cortisol elevations and maladaptive coping behaviors [25]. The relative isolation of remote processing sites also diminishes social support networks, heightening susceptibility to anxiety and depressive symptoms [26]. Collectively, these intertwined stressors potentiate MSD progression and deepen fatigue by altering pain perception, impairing immune responses, and eroding motivation, thereby compromising overall well-being and resilience among copper-industry workers.

Accordingly, this cross-sectional investigation focuses on employees of the copper industry to examine the independent relationship between multisite musculoskeletal symptom count and key health and performance metrics. By quantifying how symptom burden correlates with general psychological and somatic health, multidimensional occupational fatigue, and self-reported work productivity while accounting for demographic, psychosocial, and ergonomic covariates, this study will generate robust evidence tailored to the mineral-processing milieu. The resulting insights are expected to inform the development of targeted ergonomic modifications, fatigue-mitigation strategies, and organizational policies to reduce musculoskeletal burden, safeguard worker health, and optimize operational efficiency in copper-processing facilities.

2. METHODS

2.1. Study Design and Participants

This cross-sectional study was conducted at a copper-processing facility. A stratified random sampling approach was employed to ensure representativeness across work units and shift schedules. The sampling frame was constructed using the company's human resources roster, stratified by department (e.g., smelting, casting, maintenance) and shift type (day vs. rotating).

The operational departments included smelting, casting, crushing and milling, concentrate handling, maintenance, laboratory and quality control, and logistics. Core activities across these units included material handling, equipment operation, thermal processing, inspection, and mechanical servicing, each with varying biomechanical and environmental demands. Within each stratum, employees were selected by simple random sampling to reach a target of 585 participants. The number of participants selected from each department and shift group was proportional to the size of that stratum in the workforce roster; therefore, sample sizes were not equal across groups.

Eligible individuals were full-time staff with at least one year of continuous employment; those with a prior clinical diagnosis of musculoskeletal pathology or a clinically documented psychiatric disorder (as recorded in occupational health files) were excluded. It should be noted that the operational workforce in this facility is composed exclusively of male employees; therefore, all study participants were male. Written informed consent was obtained from all participants, and the study protocol was approved by the institutional ethics committee under approval code IR.SUMS.SCHEANUT.REC.1404.064. All questionnaires were self-administered, with researchers present to provide procedural guidance if needed without influencing responses.

2.2 Data Gathering Tools

2.2.1. Demographic and Occupational Questionnaire

A self-administered form was used to collect sociodemographic data (age, sex, marital status, number of children, educational attainment) and occupational parameters (years of work experience, daily and weekly working hours, employment status, shift type, job title, and department). This instrument was pilot-tested with 20 workers to ensure the clarity and appropriateness of the response options.

2.2.2. Nordic Musculoskeletal Questionnaire (NMQ)

The Standardized Nordic Musculoskeletal Questionnaire (NMQ) was employed to ascertain the 12-month and point-prevalence of musculoskeletal pain or discomfort across nine body regions (neck; shoulders; upper back; lower back; elbows; wrists/hands; hips/thighs; knees; ankles/feet). For each region, respondents indicated whether they had experienced ache, pain, or discomfort at any time over the past 12 months and right now. The NMQ has demonstrated high content validity and test–retest reliability (κ coefficients ≥ 0.70) in industrial populations [27]. An overall MSD_Count score (0–9) was calculated by summing the number of regions with positive 12-month responses.

2.2.3. General Health Questionnaire (GHQ-28)

Psychological well-being and somatic symptoms were measured using the GHQ-28, a widely used screening tool comprising 28 items across four subscales: somatic symptoms, anxiety/insomnia, social dysfunction, and severe depression. Each item employs a 4-point Likert scale (0 = "not at all" to 3 = "much more than usual"), yielding total scores from 0 to 84. In line with validated cut-points for industrial populations, a threshold of 24 was used to differentiate "Healthy" (< 24) from "Possible disorder" (≥ 24). The Persian version demonstrated excellent internal consistency (Cronbach's α = 0.90) [28].

2.2.4. Swedish Occupational Fatigue Inventory (SOFI-20)

Occupational fatigue was assessed via the SOFI-20, which captures five dimensions of fatigue (lack of energy, physical exertion, physical discomfort, lack of motivation, and sleepiness) through twenty 11-point items (0 = "not at all" to 10 = "to a very high degree"). The total score, therefore, ranges from 0 to 200. The SOFI-20 has established construct validity and internal consistency (α > 0.85) in ergonomic research [29]. Scores were categorized into three levels: Low fatigue (< 42.5), Moderate fatigue (42.5-117.5), and High fatigue (> 117.5).

2.2.5. Human Resource Productivity Questionnaire (HRP-26)

Worker productivity was assessed using the 26-item Human Resource Productivity Questionnaire (HRP-26), which evaluates seven domains of performance (Ability, Clarity, Help, Incentive, Evaluation, Validity, Environment). Each item is rated on a 5-point Likert scale (1 = "very poor" to 5 = "excellent"), yielding a total score range of 26–130 [30]. Total scores were then converted to a percentage of the maximum possible score and classified as Poor (< 50%), Moderate (50-70 %), or Strong (> 70 %).

2.3. Statistical Analysis

All statistical analyses were conducted in R version 4.3.0. Continuous variables were examined for central tendency and dispersion (mean ± SD, median, interquartile range, minimum–maximum), and categorical variables were summarized as frequencies and proportions. Normality of the key continuous outcomes MSD_Count, GHQ_Total, SOFI_Total, and HRP-26 percentage scores was assessed using the Shapiro–Wilk test and complemented by skewness and kurtosis indices. The 12-month prevalence of musculoskeletal symptoms in each anatomical region was estimated with binomial 95% confidence intervals.

Given significant deviations from normality (all Shapiro–Wilk $p < 0.001$), associations between MSD_Count and each outcome were quantified using Spearman's rank correlation (ρ), with Pearson's r computed in parallel to verify that $\Delta|\rho - r| < 0.03$. Unadjusted linear regression models then estimated the crude effect of MSD_Count on GHQ_Total, SOFI_Total, and HRP-26 scores (β coefficients, R^2, and p-values). To determine the independent contribution of MSD_Count, multivariable linear regression models were fitted, controlling for age, work experience, number of children, daily and weekly working hours, education level, marital status, shift type, and employment status. Multicollinearity was evaluated via variance inflation factors (all VIF < 5), and heteroskedasticity of residuals was assessed with the Breusch–Pagan test; where indicated (GHQ and SOFI models), heteroskedasticity-consistent (HC3) standard errors were applied. Model adequacy was judged by adjusted R^2 and diagnostic plots of standardized residuals versus fitted values and Cook's distance. Statistical significance was defined as α = 0.05 (two-tailed).

3. Results

3.1. Demographic and Occupational Characteristics

The study sample consisted of 585 copper-industry employees whose demographic and work-related profiles are detailed in Table 1. Participants were predominantly mid-career adults (mean age 39.2 ± 6.6 years) with substantial tenure (mean work experience 9.1 ± 6.4 years). On average, workers reported a 7.5-hour workday and a 42.1-hour workweek. Educational attainment varied: approximately 38% held a high school diploma or less, 20% had completed an associate degree, and 42% had a bachelor's degree or higher. The majority were married (88%) and under permanent contracts (76%). Shift distribution was balanced, with 41.5% on day shifts and 58.5% rotating through afternoon and night schedules. Collectively, these data (Table 1) describe a stable, well-qualified workforce operating under standard industrial work patterns.

Table 1. Demographic and Occupational Characteristics of the participant (n = 585).

Quantitative variable	Category	Mean ± SD
Age (years)		39.2 (6.62)
Work experience (years)		9.05 (6.36)
Daily work hours		7.48 (1.41)
Weekly work hours		42.11 (8.99)
Qualitative variable		No. (%)
Education Level	≤ Diploma	223 (38.1)
	Associate	115 (19.7)
	≥ Bachelor	247 (42.2)
Marital Status	Married	515 (88)
	Single	70 (12)
Employment Status	Permanent	446 (76.2)
	Contractual/ Temporary	139 (23.8)
Shift Type	Day	243 (41.5)
	Afternoon/ Night	342 (58.5)

Table 2. General Health Status, Occupational Fatigue Levels, and Productivity among Copper-Industry Employees.

Questionnaire		No. 585 (%)
GHQ-28	Healthy	454 (77.6)
	Possible disorder	131 (22.4)
SOFI-20	Low fatigue	282 (48.2)
	Moderate fatigue	252 (43.1)
	High fatigue	51 (8.7)
HRP-26	Poor	98 (16.8)
	Moderate	381 (65.1)
	Good	106 (18.1)

Table 2 presents the distribution of general health status, occupational fatigue levels, and productivity among employees of the copper industry. Most employees (77.6%) were classified as "Healthy" on the GHQ-28, while roughly one in five exhibited scores indicative of potential disorder. Fatigue levels were predominantly low to moderate, with only 8.7% of workers reporting high fatigue on the SOFI-20. On the HRP-26 scale, most participants rated their productivity as "Moderate" (65.1%). In contrast, smaller proportions fell into the "Good" and "Poor" categories. A notable subset still experiences elevated distress or fatigue and reduced productivity.

3.2. Prevalence of Musculoskeletal Symptoms

Table 3 illustrates that musculoskeletal symptoms were highly prevalent among the 585 copper-industry workers: 57.1% reported pain in at least one anatomical region over the past year (mean MSD_Count = 2.63 ± 2.35), and nearly 30% experienced discomfort in three or more sites. The lower back (43.3%), knees (41.2%), and neck (32.7%) were the most frequently affected regions, whereas elbow pain was the least common (11.9%). These findings highlight a substantial MSD burden in this workforce and underscore the importance of ergonomic interventions targeting spinal and lower-limb stressors.

Table 3. Point and 12-month Prevalence of Musculoskeletal Symptoms by Body Region (n = 585).

Region	Point prev No. (%)	12-mo prev No. (%)
Lower back	173 (29.6%)	254 (43.4%)
Knees	166 (28.4%)	242 (41.4%)
Neck	126 (21.5%)	188 (32.1%)
Shoulders	113 (19.3%)	168 (28.7%)
Wrists	121 (20.7%)	176 (30.1%)
Hands	116 (19.9%)	174 (29.8%)
Ankles	110 (18.9%)	160 (27.3%)
Upper back	98 (16.8%)	149 (25.4%)
Feet	101 (17.2%)	144 (24.6%)
Hips/thighs	89 (15.2%)	134 (22.9%)
Chest	70 (12.0%)	106 (18.2%)
Elbows	62 (10.6%)	92 (15.7%)
Overall MSD burden		
Mean number of affected regions		2.63 ± 2.35
Any MSD (MSD_Count ≥ 1)		334 (57.1)
Multiple MSDs (MSD_Count ≥ 3)		173 (29.6)

Table 4. Spearman correlations between MSD_Count and outcome scores (n = 585).

Outcome Variable	Spearman ρ	*p*-value
GHQ_Total	0.43	< 0.001
SOFI_Total	0.53	< 0.001
HRP_Total	–0.30	< 0.001

3.3. Correlation Between MSD Burden and Outcome Scores

Because MSD_Count and the outcome variables deviated from normality (Shapiro–Wilk $p < 0.001$ for all), we employed Spearman's rank correlation (ρ) to quantify their associations. Pearson's coefficients were also examined and differed by less than |0.03| from the values reported below, confirming that the substantive interpretation is insensitive to the correlation metric. Table 4 summarizes the results.

As illustrated in Table 4, each additional painful body region was moderately associated with higher distress and fatigue: MSD_Count correlated with GHQ_Total ($\rho = 0.43$) and SOFI_Total ($\rho = 0.53$), both highly significant ($p < 0.001$). Conversely, a greater MSD burden corresponded to lower productivity, as reflected in a negative correlation ($\rho = –0.30$) with HRP_Total ($p < 0.001$).

Table 5. Unadjusted Linear Regression of Outcomes on MSD_Count (n = 585).

Outcome	β	R^2	*p* (β)
GHQ_Total	1.84	0.164	< 0.001
SOFI_Total	8.68	0.296	< 0.001
HRP_Total	–1.59	0.106	< 0.001

3.4. Simple Linear Regression (Unadjusted Models)

Unadjusted linear regression models were fitted to quantify the direct relationship between musculoskeletal symptom burden (MSD_Count) and each outcome—general health distress (GHQ_Total), occupational fatigue (SOFI_Total), and productivity (HRP_Total). As displayed in Table 5, MSD_Count emerged as a significant predictor in all three models ($p < 0.001$).

A one-unit increase in MSD_Count was associated with a 1.84-point rise in GHQ_Total, accounting for 16% of its variance, and an 8.68-point increase in SOFI_Total, explaining nearly 30% of the variability in fatigue. In contrast, each additional symptomatic region was associated with a 1.59-point decrease in HRP_Total ($R^2 = 0.11$), indicating that greater musculoskeletal burden is linked to lower productivity. These findings, before any covariate adjustment, underscore the substantive impact of MSD_Count on general health, occupational fatigue, and worker productivity.

3.5 Multiple Linear Regression (Adjusted Models)

Multivariable linear regression analyses were conducted to assess the unique contribution of MSD_Count to each outcome after controlling for age, work experience, number of children, daily and weekly working hours, education level, marital status, shift type, and employment status. As

Table 6. Adjusted Linear Regression Models Predicting Outcomes from MSD_Count (n = 585).

Outcome	β	95% CI	Adj. R^2	*p* (β)
GHQ_Total	+1.85	[1.50, 2.20]	0.174	< 0.001
SOFI_Total	+8.44	[7.33, 9.55]	0.321	< 0.001
HRP_Total	−1.63	[−2.02, −1.24]	0.117	< 0.001

shown in Table 6, MSD_Count remained a significant predictor across all models (all p < 0.001). Specifically, each additional painful region was associated with a 1.85-unit increase in GHQ_Total (β = 1.85, 95% CI [1.44, 2.26], Adj. R^2 = 0.17), indicating that MSD burden independently contributes to poorer general health status. For occupational fatigue, the adjusted effect of MSD_Count was 8.44 units (95% CI [7.20, 9.68]), underscoring its substantial role in explaining fatigue variance. Finally, MSD_Count inversely predicted HRP_Total, with each additional site linked to a 1.63-unit decrease (β = −1.63, 95% CI [−2.04, −1.22], Adj. R^2 = 0.12), highlighting the detrimental impact of musculoskeletal complaints on productivity.

4. DISCUSSION

This cross-sectional investigation examined the independent relationship between multisite musculoskeletal symptom burden and three critical outcomes: general health status, occupational fatigue, and self-reported productivity among copper-industry workers. Consistent with our hypotheses, we found that an increasing number of painful body regions was significantly associated with poorer psychological and somatic health, elevated multidimensional fatigue, and reduced work productivity, even after adjustment for demographic, psychosocial, and ergonomic covariates. These findings underscore the pervasive impact of musculoskeletal disorders beyond localized pain, extending to broader health and performance domains in heavy-industry settings.

4.1. Impact on General Health Status

Our results demonstrate that as the number of painful anatomical regions increases, so too does the burden of psychological and somatic symptoms. While earlier studies showed that workers reporting pain in multiple sites experienced greater anxiety and body complaints than those with single-site pain [31, 32], they stopped short of estimating how each additional pain site contributes to overall distress. In contrast, our data reveal a consistent incremental effect. Each new pain region was associated with a 1.85-point increase in the total general health score, accounting for approximately 18% of the variance in general health distress. This pattern underscores that musculoskeletal complaints should not be viewed in isolation; relatively, pain across the body exerts a cumulative toll on mental and physical well-being [33]. Importantly, copper-industry workers perform strenuous manual tasks, including lifting and repetitive motions, exposure to vibration, and environmental challenges such as heat and airborne irritants. These factors likely exacerbate the psychological impact of multisite pain [4, 34]. Our findings therefore reinforce the need for comprehensive health surveillance that captures the breadth of musculoskeletal symptoms alongside traditional mental-health assessments in industrial workforces.

4.2. Effects on Occupational Fatigue

The present study extends the understanding of how widespread musculoskeletal discomfort drains workers' energy reserves. Previous field research in automotive and light manufacturing contexts reported that pain at two or more sites moderately predicted self-reported exhaustion [35, 36]. Here, we find that each additional painful site was associated with an 8.44-point increase in the SOFI-20 total fatigue score, accounting for 32% of the overall variability in fatigue levels. Under the unique conditions of copper processing, long shifts, rotating schedules, high ambient temperatures, and fine particulate exposures, workers enduring multisite pain not only perceive their tasks as more physically demanding but also report greater difficulty recovering between bouts of work [37]. In practical terms, this manifests as heightened sensations of heaviness, reduced willingness to initiate or sustain activity, and frequent reliance on brief pauses or task modifications [38]. These fatigue experiences can accumulate over days, leading to a persistent low-energy state that undermines safety, increases error risk, and erodes overall quality of life [39]. Our findings suggest that fatigue-management strategies in heavy-industry settings must account for the pervasive influence of multisite pain by integrating ergonomic adjustments with targeted rest-break scheduling and education rather than focusing solely on single-region injuries.

4.3. Consequences for Work Productivity

Beyond health and fatigue, multisite musculoskeletal pain appears to influence how workers engage with their tasks and the work environment. Our analysis indicates that each additional painful region corresponded to a 1.63-point reduction in total productivity score, explaining about 12% of the variance in self-reported work performance. Prior investigations into presenteeism have highlighted that chronic discomfort can distract from task goals and diminish workers' sense of control and satisfaction [40, 41]. By quantifying the effect of each new pain site on the overall productivity metric, we show that as pain spreads to additional body regions, employees increasingly struggle to maintain focus, adapt to changing work demands, and interact positively with colleagues and supervisors. This is not simply a matter of taking longer to complete a job; instead, pain across multiple sites alters cognitive and emotional engagement, leading to more frequent errors, hesitancy in decision-making, and reduced willingness to volunteer for extra tasks or collaborate on complex operations [42]. In heavy-industry environments where precision and coordination are critical, these declines in engagement can cascade into slower production lines, higher rework rates, and greater reliance on supervisory oversight [43]. Addressing multisite pain, therefore, is not only a matter of individual health but also a strategic priority for maintaining workforce motivation, adaptability, and sustained productivity in demanding operational contexts.

4.4. Implications for Practice

Our findings highlight the urgent need for comprehensive ergonomic and psychosocial interventions in copper-processing facilities. Engineering controls such as adjustable workstations, mechanical material-handling aids, and task rotation can mitigate spinal loading and lower-limb strain, directly reducing MSD prevalence. Concurrently, organizational policies promoting regular rest breaks, fatigue management training, and access to on-site physiotherapy or exercise programs may attenuate the pain–fatigue feedback loop. Moreover, integrating mental health support, including stress-reduction workshops and peer-support networks, can address the psychosocial dimensions of MSDs, thereby enhancing overall well-being and sustained productivity.

4.5. Strengths and Limitations

Despite the strengths of this study, including a large stratified sample, validated measurement tools, and multivariable modeling controlling for key confounders, several limitations should be acknowledged. The cross-sectional design precludes causal inference, and reliance on self-reported instruments may introduce recall or perception biases. Furthermore, although sampling was stratified by department, no department-specific biomechanical or environmental exposure data (such as workload, heat, noise, or chemical agents) were collected, preventing examination of inter-departmental differences and leaving the possibility of residual confounding. The GHQ-28 assesses general psychological distress without distinguishing between work-related and non-work-related origins, limiting the interpretation of its association with occupational factors. Finally, as the study population consisted exclusively of male workers, the findings may not extend to female populations. Future longitudinal studies incorporating objective ergonomic assessments, physiological markers, and wearable fatigue-monitoring technologies are recommended to clarify causal pathways and better characterize exposure–response relationships.

4.6. Future Directions

Building on our results, randomized controlled trials of multifaceted intervention packages combining ergonomic redesign, fatigue-mitigation strategies, and mental health support are warranted to determine the most effective approaches for reducing MSD burden and enhancing productivity. Additionally, cost-effectiveness analyses could guide resource allocation by comparing the economic benefits of reduced absenteeism and improved performance against intervention costs. Finally, examining the role of organizational culture, safety climate, and worker engagement may reveal further levers for optimizing health and performance in high-risk industrial settings.

5. Conclusion

In conclusion, our study demonstrates a clear dose-response relationship between the number of painful musculoskeletal sites and overall health outcomes among copper-industry workers: as the count of affected regions increases, employees report significantly elevated psychological distress, greater occupational fatigue, and pronounced declines in work productivity. These findings highlight multisite symptom burden as a pervasive, rather than isolated, occupational health risk that undermines both well-being and performance. Practically, this means that interventions must move beyond targeting single anatomical areas to adopt system-wide strategies such as redesigning workstations for flexibility, implementing proactive task rotation and rest schedules, and offering integrated health-promotion services including physiotherapy and fatigue-management training. By addressing the cumulative impact of musculoskeletal pain through multidisciplinary ergonomic and organizational measures, industry stakeholders can more effectively mitigate distress and fatigue, safeguard worker health, and sustain productivity in demanding industrial environments.

Institutional Review Boar Statement: The study was reviewed and approved by the Ethics Committee of Shiraz University of Medical Sciences under the approval code IR.SUMS.SCHEANUT.REC.1404.064. All procedures were conducted in accordance with the relevant ethical standards, and written informed consent was obtained from all participants prior to data collection.

Acknowledgments: We extend our sincere gratitude to all employees of the copper company for their cooperation and support throughout this project. We are deeply thankful to the workers who volunteered to participate in the study and generously shared their time and experiences.

Declaration of Interest: The authors have no competing interests to declare relevant to this article's content.

Author Contribution Statement: AC contributed to the study conception, overall supervision, and critical revision of the manuscript. MK, YS, MRF, FGM, FA, SHN, AA, and MS contributed to data collection and field implementation. RT contributed to study design, data analysis, interpretation of results, and drafting of the manuscript. All authors reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

References

1. Ajstrup M, Budtz CR, Nielsen KJ, Andersen DR, Andersen JH, Christiansen DH. Musculoskeletal Health Climate Is a Prognostic Determinant of Sickness Absence Among Female Eldercare Workers: A Prospective Cohort Study. *J Occup Environ Med.* 2023;65(1):e4-e9. Doi: 10.1097/JOM.0000000000002729
2. Mishra S, Avinash G, Kundu MG, Verma J, Sheth A, Dutta A. Work-related musculoskeletal disorders among various occupational workers in India: a systematic review and meta-analysis. *J Occup Health.* 2024;67(1):uiae077. Doi: 10.1093/joccuh/uiae077
3. Choobineh A, Daneshmandi H, Saraj Zadeh Fard SK, Tabatabaee SH. Prevalence of Work-related Musculoskeletal Symptoms among the Iranian Workforce and Job Groups. *Int J Prev Med.* 2016;7:130. Doi:10.4103/2008-7802.195851
4. 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. Doi: 10.18502/ijph.v50i4.5992. PMID: 34183917; PMCID: PMC8219631.
5. Upadhyay R, Jaiswal V, Bhattacherjee A, Patra AK. Role of whole-body vibration exposure and posture of dumper operators in musculoskeletal disorders: a case study in metalliferous mines. *Int J Occup Saf Ergon.* 2022;28(3):1711-1721. Doi: 10.1080/10803548.2021.1932111
6. Nejad NH, Choobineh A, Rahimifard H, Haidari HR, Tabatabaei SH. Musculoskeletal risk assessment in small furniture manufacturing workshops. *Int J*

Occup Saf Ergon. 2013;19(2):275-284. Doi: 10.1080/10803548.2013.11076985

7. Tompa E, Mofidi A, van den Heuvel S, et al. Economic burden of work injuries and diseases: a framework and application in five European Union countries. *BMC Public Health.* 2021;21(1):49. Doi: 10.1186/s12889-020-10050-7
8. Gorasso V, Van der Heyden J, De Pauw R, et al. The health and economic burden of musculoskeletal disorders in Belgium from 2013 to 2018. *Popul Health Metr.* 2023;21(1):4. Doi: 10.1186/s12963-023-00303-z
9. Marcuzzi A, Skarpsno ES, Nilsen TIL, Mork PJ. The interplay between multisite pain and insomnia on the risk of anxiety and depression: the HUNT study. *BMC Psychiatry.* 2022;22(1):124. Doi: 10.1186/s12888-022-03762-0
10. Zhao H, Dou H, Yong X, et al. Construction and validation of a musculoskeletal disease risk prediction model for underground coal miners. *Front Public Health.* 2023;11:1099175. Doi: 10.3389/fpubh.2023.1099175
11. Momeni Z, Choobineh A, Razeghi M, Ghaem H, Azadian F, Daneshmandi H. Work-related Musculoskeletal Symptoms among Agricultural Workers: A Cross-sectional Study in Iran. *J Agromedicine.* 2020;25(3):339-348. Doi: 10.1080/1059924X.2020.1713273.
12. Miró E, Sánchez AI, Raya A, Martínez MP. Central Sensitization Syndromes and Trauma: Mediating Role of Sleep Quality, Pain Catastrophizing, and Emotional Dysregulation Between Post-Traumatic Stress Disorder and Pain. *Healthcare.* 2025; 13(17):2221. Doi: https://doi.org/10.3390/healthcare13172221
13. Belgasm H, Alzubi A, Iyiola K, Khadem A. Interpersonal Conflict and Employee Behavior in the Public Sector: Investigating the Role of Workplace Ostracism and Supervisors' Active Empathic Listening. *Behav Sci (Basel).* 2025;15(2):194. Doi: 10.3390/bs15020194.
14. Das D, Singh AK. Interactions between work-related factors, perceived fatigue and musculoskeletal disorders among handicraft artisans: structural equation model analysis. *Ergonomics*. 2025;68(1):95-111. Doi: 10.1080/00140139.2023.2300952
15. Choobineh A, Tabatabaei SH, Tozihian M, Ghadami F. Musculoskeletal problems among workers of an Iranian communication company. *Indian J Occup Environ Med.* 2007;11(1):32-36. Doi: 10.4103/0019-5278.32462
16. Stefanik JJ, Frey-Law L, Segal NA, et al. The relation of peripheral and central sensitization to muscle co-contraction: the MOST study. *Osteoarthritis Cartilage*. 2020;28(9):1214-1219. Doi: 10.1016/j.joca.2020.06.002
17. Choobineh AR, Daneshmandi H, Aghabeigi M, Haghayegh A. Prevalence of musculoskeletal symptoms among employees of Iranian petrochemical industries: October 2009 to December 2012. *Int J Occup Environ Med*. 2013;4(4):195-204.
18. Minhas D. Pain mechanisms for the practicing rheumatologist. *Best Pract Res Clin Rheumatol.* 2024;38(1):101942. Doi: 10.1016/j.berh.2024.101942
19. Chmielewski G, Majewski MS, Kuna J, Mikiewicz M, Krajewska-Włodarczyk M. Fatigue in Inflammatory Joint Diseases. *Int J Mol Sci.* 2023;24(15):12040. Doi: 10.3390/ijms241512040.
20. Papaconstantinou E, Cancelliere C, Verville L, et al. Effectiveness of non-pharmacological interventions on sleep characteristics among adults with musculoskeletal pain and a comorbid sleep problem: a systematic review. *Chiropr Man Therap*. 2021;29(1):23. Doi: 10.1186/s12998-021-00381-6
21. Javdani-Mallak A, Salahshoori I. Environmental pollutants and exosomes: A new paradigm in environmental health and disease. *Sci Total Environ.* 2024;925:171774. Doi: 10.1016/j.scitotenv.2024.171774
22. Tota M, Karska J, Kowalski S, et al. Environmental pollution and extreme weather conditions: insights into the effect on mental health. *Front Psychiatry.* 2024;15:1389051. Doi: 10.3389/fpsyt.2024.1389051
23. Varma P, Shen L, Postnova S, et al. Understanding sleep health challenges of defence shift workers to design a digital, sleep and circadian management tool. *Sci Rep.* 2025;15(1):10483. Doi: 10.1038/s41598-025-93597-y
24. Choobineh A, Soltanzadeh A, Tabatabaee H, Jahangiri M, Khavaji S. Health effects associated with shift work in 12-hour shift schedule among Iranian petrochemical employees. *Int J Occup Saf Ergon.* 2012;18(3):419-427. Doi: 10.1080/10803548.2012.11076937
25. An H, Gu X, Obrenovic B, Godinic D. The Role of Job Insecurity, Social Media Exposure, and Job Stress in Predicting Anxiety Among White-Collar Employees. *Psychol Res Behav Manag.* 2023;16:3303-3318. Doi: 10.2147/PRBM.S416100. PMID: 37614323; PMCID: PMC10443693.
26. Evans M, Fisher EB. Social Isolation and Mental Health: The Role of Nondirective and Directive Social Support. *Community Ment Health J.* 2022;58(1):20-40. doi:10.1007/s10597-021-00787-9.
27. Mokhtarinia HR, Hosseini ZSJ, Shokouhyan SM, Gabel CP. Translation, cultural adaptation and assessment of psychometric properties of the Extended Version of the Nordic Musculoskeletal Questionnaire (NMQ-E) in Persian language speaking people. *BMC Musculoskelet Disord.* 2024;25(1):89. Doi: 10.1186/s12891-024-07192-9
28. Malakouti SK, Fatollahi P, Mirabzadeh A, Zandi T. Reliability, validity and factor structure of the GHQ-28 used among elderly Iranians. *Int Psychogeriatr.* 2007; 19(4):623-634. Doi: 10.1017/S1041610206004522
29. Ahmadi M, Choobineh A, Mousavizadeh A, Daneshmandi H. Physical and psychological workloads and their association with occupational fatigue among hospital service personnel. *BMC Health Serv Res.* 2022;22(1):1150. Doi: 10.1186/s12913-022-08530-0

30. Ziapour A, Khatony A, Kianipour N, Jafary F. Identification and analysis of labor productivity components based on ACHIEVE model (case study: staff of Kermanshah University of Medical Sciences). *Glob J Health Sci.* 2014;7(1):315-321. Doi: 10.5539/gjhs.v7n1p315
31. Fagerlund P, Shiri R, Suur-Uski J, Kaartinen S, Rahkonen O, Lallukka T. Separate and joint associations of chronic pain, multisite pain and mental health with sickness absence among younger employees: a register based longitudinal study. *Arch Public Health*. 2023;81(1):97. Doi: 10.1186/s13690-023-01115-1
32. Vieira LMSMA, Mininel VA, Sato TO. Sleep Quality as a Mediator of Burnout, Stress and Multisite Musculoskeletal Pain in Healthcare Workers: A Longitudinal Study. *Healthcare (Basel).* 2023;11(18):2476. Doi: 10.3390/healthcare11182476
33. Bezzina A, Austin E, Nguyen H, James C. Workplace Psychosocial Factors and Their Association With Musculoskeletal Disorders: A Systematic Review of Longitudinal Studies. *Workplace Health Saf.* 2023;71(12):578-588. Doi: 10.1177/21650799231193578
34. Florez-Acevedo S, Blancas MT, Spector JT. Occupational Heat Exposure & Mental Health Outcomes: A Review and Framework Incorporating Social Determinants of Health to Guide Future Research. *Curr Environ Health Rep.* 2025;12(1):15. Doi: 10.1007/s40572-025-00479-6
35. Asadi N, Sadeghi-Yarandi M. Investigating the relationship between environmental and cognitive ergonomics with work-related musculoskeletal disorders: A case study in an automobile industry. *Work*. 2025;80(2):514-527. Doi: 10.3233/WOR-240275
36. Fan J, Tan X, Smith AP, Wang J. Work-related musculoskeletal disorders, fatigue and stress among gas station workers in China: a cross-sectional study. *BMJ Open.* 2024;14(7):e081853. Doi: 10.1136/bmjopen-2023-081853
37. García-Pérez-de-Sevilla G, Franco AB, Trinidad A, Gasque-Celma P, Del-Blanco-Muñiz JÁ. Stress, pain intensity, and work productivity in individuals with chronic pain: a cross-sectional observational study. *BMC Public Health.* 2025;25(1):3805. Doi: 10.1186/s12889-025-23547-w
38. Dos Santos IN, de Oliveira AS, Viscardi LGA, Suassuna JAS, Santos ADC, Brasileiro-Santos MDS. Occupational risks and musculoskeletal complaints among industrial workers: a cross-sectional study. *Rev Bras Med Trab.* 2023;21(2):e2022878. Doi: 10.47626/1679-4435-2022-878
39. Chang YF, Yeh CM, Huang SL, et al. Work Ability and Quality of Life in Patients with Work-Related Musculoskeletal Disorders. *Int J Environ Res Public Health.* 2020;17(9):3310. Doi: 10.3390/ijerph17093310
40. Jalali M, Esmaeili R, Habibi E, Alizadeh M, Karimi A. Mental workload profile and its relationship with presenteeism, absenteeism and job performance among surgeons: The mediating role of occupational fatigue. *Heliyon.* 2023;9(9):e19258. Doi: 10.1016/j.heliyon.2023.e19258
41. García-Pérez-de-Sevilla G, Franco AB, Trinidad A, Gasque-Celma P, Del-Blanco-Muñiz JÁ. Stress, pain intensity, and work productivity in individuals with chronic pain: a cross-sectional observational study. *BMC Public Health.* 2025;25(1):3805. Doi: 10.1186/s12889-025-23547-w
42. Patel M, Hasoon J, Diez Tafur R, Lo Bianco G, Abd-Elsayed A. The Impact of Chronic Pain on Cognitive Function. *Brain Sci.* 2025;15(6):559. Doi: 10.3390/brainsci15060559
43. Susihono W, Adiatmika IPG. The effects of ergonomic intervention on the musculoskeletal complaints and fatigue experienced by workers in the traditional metal casting industry. *Heliyon*. 2021;7(2):e06171. Doi: 10.1016/j.heliyon.2021.e06171

Mattioli 1885

© Copyright: the Author(s), 2026. Licensee Mattioli 1885, Fidenza, Italy. This is an open-access article distributed under the terms of the Creative Commons Attribution NonCommercial License (CC BY-NC-4.0).

Disclaimer/Publisher's Note: The statements, opinions and data contained in this article are solely those of the author(s) and contributor(s) and do not necessarily reflect those of their affiliated organizations, the publisher, the editors or the reviewers. The publisher and the editors disclaim any responsibility for injury to people or property resulting from any ideas, methods, instructions or products mentioned in the content. Any product that may be evaluated in this article, or claim made by its manufacturer, is not guaranteed or endorsed by the publisher.