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RESEARCH ARTICLE

Cross-Sectional Associations of Work Fatigue with Repetitive-Task Risk, Sleep Quality, and Body Mass Index among Informal Fish-Smoking Workers

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ABSTRACT

Introduction: Workers in informal industries are routinely exposed to physical, environmental, and ergonomic stressors that may be associated with fatigue and musculoskeletal strain. This study examined the cross-sectional associations of repetitive-task risk, sleep quality, body mass index, and selected individual characteristics with work fatigue among fish-smoking workers in Semarang, Indonesia.

Methods: Using a cross-sectional design, data were collected from 64 workers through structured questionnaires, observational assessments, and anthropometric measurements. Fatigue levels were measured using the Indonesian version of the Japanese Industrial Fatigue Research Committee (JIFRC) Fatigue Questionnaire, repetitive-task risk was assessed using the Assessment of Repetitive Tasks (ART) method, and sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI), which evaluates subjective sleep quality over the preceding month.

Results: Moderate fatigue was reported by 59.4% of participants. In the bivariate analysis, left-hand repetitive-task risk was associated with fatigue ($p = 0.037$), whereas right-hand repetitive-task risk and the dichotomised sleep-quality category were not associated with fatigue. In the adjusted linear regression model, the left-hand association was attenuated ($B = 0.028$, $p = 0.839$), while BMI remained associated with the coded fatigue outcome ($B = 0.181$, 95% CI 0.047 to 0.316, $p = 0.009$). The overall regression model explained 21.3% of the variation in fatigue ($R^2 = 0.213$; adjusted $R^2 = 0.115$) and did not reach the conventional threshold for statistical significance ($F(7, 56) = 2.166$, $p = 0.051$). These estimates should be interpreted cautiously because of the small sample and imbalanced categories.

Conclusion: Among workers in the participating fish-smoking centres, BMI was associated with the coded fatigue outcome after adjustment, while the unadjusted association involving left-hand repetitive-task risk was not retained in the adjusted model. Because the overall regression model was marginally non-significant, the individual adjusted associations should be interpreted cautiously. The findings identify anthropometric assessment, fatigue screening, and further task-specific ergonomic evaluation as priorities for future health-promotion research. Longitudinal and intervention studies are needed before conclusions can be drawn regarding causality, intervention effectiveness, or productivity.

Keywords: Body Mass Index; Informal Workers; Repetitive-Task Risk; Sleep Quality; Work Fatigue

INTRODUCTION

Occupational health in the informal sector remains an underexamined yet crucial component of public health, particularly in low- and middle-income countries such as Indonesia. The informal workforce, accounting for over half of total employment, plays a pivotal role in the socioeconomic fabric of communities, including the fish-smoking industry, a traditional and labour-intensive sector central to local food production and economic sustainability (1). Workers in these industries are routinely exposed to physical, environmental, and ergonomic stressors that have been associated with fatigue, musculoskeletal strain, and reduced productivity. Fatigue in this context represents a multifactorial phenomenon encompassing physiological, psychological, and environmental determinants, and its persistence poses serious implications for occupational health, safety, and performance (2).

Studies across various informal occupations have consistently demonstrated that excessive workload, repetitive manual activities, and suboptimal working conditions contribute significantly to fatigue and musculoskeletal disorders (3,4). Among furniture and seaweed workers, extended working hours and physically demanding tasks have been associated with higher levels of fatigue and decreased productivity (5,6). Age and work tenure have also been identified as potentially relevant factors, with older workers and those with longer occupational exposure reporting diminished endurance and greater fatigue symptoms (3). Additionally, exposure to poor lighting, heat, and repetitive postures has been associated with greater fatigue, underscoring the need for improved ergonomic and environmental management strategies in informal industries (7,8).

Despite the abundance of literature addressing fatigue in formal sectors, relatively limited attention has been given to informal labourers in fish-smoking operations. This type of work requires repetitive hand movements, prolonged standing, and exposure to heat and smoke, which may increase the likelihood of fatigue and musculoskeletal strain. Inadequate ergonomic design, prolonged working hours, and minimal access to health interventions may increase the likelihood of fatigue and musculoskeletal strain (9). Given that fish smoking is a major economic activity in coastal Indonesia, concurrent assessment of repetitive-task exposure, sleep quality, and individual characteristics may help identify locally relevant health-promotion needs.

Work fatigue, in ergonomic and physiological terms, is often described as the decline in an individual's ability to sustain a given workload due to cumulative stressors, both physical and mental (10). It can be acute, resulting from immediate overexertion, or chronic, when recovery periods are insufficient. Physiological explanations for fatigue proposed in previous research include energy depletion, accumulation of metabolic byproducts such as lactate, and neuroendocrine dysregulation following prolonged effort (2). Psychologically, the experience of fatigue is shaped by motivation, emotional strain, and poor sleep quality; previous studies have also described bidirectional associations between sleep problems and fatigue (11,12).

Poor sleep quality is an increasingly recognised factor associated with occupational fatigue. Empirical studies indicate that insufficient or poor-quality sleep impairs alertness, cognitive control, and recovery from physical exertion (13,14). Workers in physically demanding roles often report disrupted sleep due to environmental stressors, irregular schedules, or discomfort from musculoskeletal pain, and these conditions may coincide with greater fatigue and poorer work performance (15). Reported associations between sleep quality and fatigue support considering sleep-related recovery alongside ergonomic exposure when assessing worker well-being, without assuming a direct causal pathway.

Ergonomic stressors, particularly repetitive movements, represent commonly investigated exposures in relation to fatigue and musculoskeletal strain in manual labour. Repetitive upper-limb tasks such as cutting, skewering, and lifting are pervasive in fish processing and smoking activities, producing repeated loading of the same muscle groups and joints. Studies of repetitive upper-limb work, including fish-processing activities, have documented muscular fatigue and musculoskeletal complaints associated with repetitive and forceful exertions (9,16,17). Studies among fish processing workers in Europe and Southeast Asia have reported high prevalence rates of upper-limb musculoskeletal complaints in work characterised by repetitive and forceful exertions (9,16). Over time, repetitive strain may reduce work tolerance, creating a cycle of fatigue and performance decline.

Ergonomic exposures and poor sleep quality may coexist among informal fish-smoking workers, who are also exposed to physical and environmental demands. Ergonomic discomfort may interfere with rest, while inadequate sleep may limit recovery and concentration; however, these pathways require direct testing rather than being inferred from cross-sectional associations (18). Environmental factors such as heat exposure, smoke, and noise may add to the overall work burden, but their independent or combined effects on fatigue cannot be assumed without specific measurement. Studies have noted that fatigue may involve physical, cognitive, and emotional dimensions relevant to decision-making and overall occupational safety (19,20). Considering these domains together can improve the descriptive assessment of worker needs, even when interaction or mediation effects are not analysed.

Individual characteristics, including age, sex, body mass index (BMI), and work tenure, may be associated with differences in reported fatigue. Older workers generally exhibit reduced physiological resilience due to decreased aerobic capacity and slower recovery rates, which may affect tolerance of sustained physical work (3,4). Likewise, sex-related differences may influence fatigue perception and endurance, as hormonal and body composition variations affect energy metabolism (21). BMI is an anthropometric indicator of weight status rather than a direct measure of dietary intake or nutritional quality. Higher BMI may be associated with greater biomechanical loading and comorbid conditions relevant to physical work capacity (22,23). Low and high BMI may have different relationships with fatigue; therefore, the form of the association should be examined rather than assumed.

Work tenure reflects the duration of employment and may indicate longer exposure to occupational demands, particularly in occupations characterised by repetitive and strenuous tasks (24). Long-term exposure to suboptimal ergonomic and environmental conditions has been associated with chronic fatigue, although the relationship may vary according to task and worker characteristics (25). Consequently, assessing fatigue in fish-smoking workers requires considering not only task-specific demands but also the duration of occupational exposure and individual health characteristics.

Previous studies in fish processing and comparable informal occupations have documented repetitive-task exposure, awkward postures, musculoskeletal symptoms, and fatigue, and some have examined ergonomic interventions (26–28). However, these bodies of evidence have generally assessed ergonomic, sleep-related, and individual factors separately or in different occupational contexts. Evidence remains limited on whether these measured factors are concurrently associated with fatigue among informal fish-smoking workers in Indonesia and how such information can support feasible local health-promotion priorities. Addressing this gap requires a cautious cross-sectional assessment rather than an assumption of interaction or causality.

This study therefore examined the cross-sectional associations of repetitive-task risk, sleep quality, BMI, age, sex, and work tenure with work fatigue among fish-smoking workers in Semarang, Indonesia. The primary research question was whether these measured factors were associated with fatigue in the sampled workers. The study was intended primarily as an occupational health-promotion needs assessment with an exploratory analytical component, not as a test of causal pathways, interactions, or intervention effectiveness. Its contribution lies in describing the co-occurrence of selected concerns and identifying priorities for more detailed assessment and future intervention research in similar informal work settings.

METHODS

Study Design and Setting

This study employed an observational analytic design using a cross-sectional approach to examine the associations of repetitive-task risk, sleep quality, body mass index, and selected individual characteristics with work fatigue among fish-smoking workers in Semarang, Indonesia. The cross-sectional method enabled the exposures and outcome to be assessed during the same study period (2,10). Data collection was conducted at Bandarharjo fish-smoking centres located in Semarang in August 2025. Participants generally worked 8–9 hours per day, from approximately 06:00 or 07:00 to 15:00, for 6 days per week. The ART assessment reported in the analysis was conducted on the fish-stabbing task for each worker. Fatigue was assessed during the shift. The participating centres were selected because they employed informal workers performing repetitive fish-processing tasks.

Population and Sampling

The source population comprised workers employed at the participating fish-smoking centres during the recruitment period. The sampling frame included 82 potentially eligible workers from the participating centres. A total-sampling approach was used, whereby all 82 workers in the sampling frame were approached for participation. Eighteen workers were not enrolled because they were absent from the study sites during the data-collection period, rather than because they failed the stated eligibility criteria; consequently, 64 workers were enrolled and analysed. Thus, “total sampling” refers to an attempt to recruit all eligible workers at the participating centres rather than all fish-smoking workers city-wide. No separate formal sample-size calculation was undertaken because the study attempted to recruit the complete sampling frame. In this informal-sector setting, all eligible workers at the selected study site were invited to participate. From an ethical and practical standpoint, selecting only a proportion of workers through sampling was considered inappropriate because the workforce constituted a small, clearly defined group within a single work location. Inclusion criteria required that participants be actively engaged in fish-smoking work for at least six months and provide informed consent. No participant-level data were missing among the 64 analysed workers.

Ethical Considerations

The study received ethical clearance from the Research Ethics Committee of the Faculty of Public Health, Universitas Diponegoro No. 113/EA/KEPK-FKM/2025. Written informed consent was obtained from all participants prior to data collection. Ethical procedures followed the principles of autonomy, confidentiality, and beneficence as stipulated by national research ethics standards.

Variables and Operational Definitions

Work fatigue was defined as the perceived level of physical and mental exhaustion following work activities, measured using the Indonesian version of the Japanese Industrial Fatigue Research Committee (JIFRC) Fatigue Questionnaire (29,30). The instrument contained 30 items, each scored from 1 to 4, producing a total score ranging from 30 to 120. The Indonesian JIFRC has demonstrated satisfactory validity and reliability in an Indonesian worker population (30). Missing items were addressed through a prevention protocol. In this procedure, respondents were always instructed to review forms prior to submission to ensure all 30 items covering activity reduction, motivational decline, and physical symptoms were fully answered. For descriptive analysis, scores were classified as low, moderate, or high fatigue using the prespecified Indonesian scoring criteria: 30–52 = low/light fatigue, 53–75 = moderate fatigue, 76–98 = high/heavy fatigue, and 99–120 = very high fatigue (31). These instrument-based cut-offs, rather than the sample median or mean, were used to categorise fatigue, with codes 1, 2, 3, and 4 corresponding respectively to low, moderate, high, and very-high fatigue. The high and very-high categories were combined in the study dataset for descriptive presentation.

Repetitive-task exposure was assessed separately for the right and left upper limbs using the Assessment of Repetitive Tasks (ART) method (17,32). Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI), a self-administered questionnaire assessing sleep quality and sleep disturbances during the previous month. The PSQI contains 19 self-rated items that generate seven component scores: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. The seven component scores are summed to produce a global score ranging from 0 to 21, with higher scores indicating poorer sleep quality. A global PSQI score >5 was classified as poor sleep quality, whereas a score ≤5 was classified as good sleep quality (33).

Individual characteristics included age (years), sex (male/female), work tenure (years), and weight status assessed using body mass index (BMI) calculated as weight (kg)/height (m^2). BMI categories used for descriptive presentation were underweight (<18.5), normal (18.5–25.0), overweight (25.1–27.0), and obese (>27.0). In the regression model, BMI was entered as an ordinal variable rather than as a continuous BMI measure. The numerical coding used in the regression dataset was sex: 1 = male and 2 = female; age: 1 = <30 years and 2 = ≥30 years; work tenure: 1 = <5 years, 2 = 5–10 years, and 3 = >10 years; and BMI: 1 = underweight, 2 = normal, 3 = overweight, and 4 = obese. Ergonomic risk levels for repetitive motion were classified using ART total-score thresholds of low, moderate, and high risk, with the right- and left-hand ART variables each coded as 1 = low, 2 = moderate, and 3 = high risk (9).

Data Collection Procedures

Data collection combined self-reported and observational methods. Workers completed a structured questionnaire assessing demographic information, sleep quality, and perceived fatigue. Questionnaires were administered during the work shift under standardised conditions. Ergonomic observations were conducted by trained field researchers during the production stage. For each worker, the task selected for formal ART assessment was the fish-stabbing task. Repetitions of the right and left hands were counted over five minutes using a manual counter. The ART assessment included repetition frequency, force, arm posture, wrist posture, hand or finger grip, breaks, task duration, work pace, and other relevant factors. These component scores were combined to produce a total ART score for each worker and were classified using the prespecified category thresholds (34). Weight and height were measured using calibrated digital scales and a microtoise to ensure accuracy in BMI calculation.

The Pittsburgh Sleep Quality Index (PSQI) was used to assess subjective sleep quality during the preceding month. The instrument comprises 19 self-rated items that form seven component scores, each scored from 0 to 3. These component scores are summed to obtain a global PSQI score ranging from 0 to 21. Based on the original PSQI scoring criterion, participants with a global score ≤5 were classified as having good sleep quality, whereas those with a score >5 were classified as having poor sleep quality. The Indonesian-language PSQI has previously demonstrated acceptable psychometric properties; however, the published Indonesian validation study was conducted among adolescents, and this population difference should be considered when interpreting its use among adult informal workers (33,35,36). The JIFRC Fatigue Questionnaire was applied to assess perceived physical and mental fatigue in the local occupational context (30). The JIFRC was administered using its Indonesian version (37).

Data Analysis

The study employed both descriptive and inferential statistical analyses. Descriptive statistics summarised participant characteristics and distributions of exposure and outcome variables. Continuous variables were summarised using means and standard deviations or medians and interquartile ranges, as appropriate, while categorical variables were presented as frequencies and percentages. Inferential analyses examined unadjusted and adjusted associations between the measured factors and fatigue.

For bivariate analysis, complete cross-tabulations were constructed for each exposure category by fatigue category. Fisher's exact test was used for 2 × 2 tables, and Fisher's exact test was used for larger contingency tables because several expected cell counts were small (38). The choice of an exact test was based on sparse cell counts rather than non-normality. Cramér's V was reported to describe the magnitude of association for the contingency-table analyses. A two-sided p-value < 0.05 was considered statistically significant, but interpretation also considered effect magnitude and precision.

The primary adjusted analysis used multiple linear regression to examine adjusted associations with the coded fatigue outcome. The regression dataset retained the instrument-based fatigue category coding, in which 1 = low, 2 = moderate, 3 = high, and 4 = very-high fatigue. The fitted outcome was therefore the ordinal category code, not the continuous 30–120 JIFRC total score. The category code was treated numerically in the fitted linear regression; coefficients should therefore be interpreted as changes in the coded fatigue outcome rather than changes in the questionnaire total score. Predictor coding was specified as follows: sex (1 = male, 2 = female); age (1 = <30 years, 2 = ≥30 years); work tenure (1 = <5 years, 2 = 5–10 years, 3 = >10 years); BMI (1 = underweight, 2 = normal, 3 = overweight, 4 = obese); and right- and left-hand repetitive-task exposure (1 = low, 2 = moderate, 3 = high). Sleep quality was entered as a dichotomous predictor coded as 1 = good sleep quality (PSQI global score ≤5) and 2 = poor sleep quality (PSQI global score >5) (33). Covariates were selected a priori on the basis of their plausible relationships with fatigue and the measured exposures rather than through significance-based selection.

Multicollinearity was assessed using tolerance and variance inflation factors (37, 38). The retained regression output showed tolerance values of 0.712–0.934 and VIF values of 1.070–1.405. Numerical results for linearity, homoscedasticity, residual normality, leverage, studentised residuals, and Cook's distance are not available in the materials supplied for final reporting and are therefore not reported. Missing data were handled using complete-case analysis, resulting in an adjusted-model sample of 64 participants. Model fit was summarised using the intercept, R^2, adjusted R^2, and overall F test.

Reliability and Validity

The measurement instruments used in this study have previously demonstrated psychometric utility in relevant populations. The original PSQI demonstrated acceptable internal consistency, test–retest reliability, and validity for distinguishing good and poor sleepers. Subsequent psychometric studies have supported its reliability and validity in other populations. An Indonesian-language version has also demonstrated reliability and validity, although the published Indonesian validation was conducted among adolescents rather than adult informal workers (33,35,36). Similarly, the JIFRC Fatigue Questionnaire has been locally validated in an Indonesian worker population (30). Observational procedures for repetitive motion were standardised across observers through pre-study assessor training, calibration sessions, and consensus scoring, following recommendations for ergonomic risk assessments (39). Disagreements were resolved through discussion after the independent ratings had been recorded. No independent duplicate ratings were retained for formal reliability analysis; therefore, assessor calibration and consensus scoring were used as quality-control procedures, and no inter-rater reliability statistic is reported (40).

Limitations and Bias Control

Given the cross-sectional design, causal inferences could not be drawn between the measured factors and fatigue outcomes. Multivariable adjustment addressed only the covariates included in the model and could not eliminate residual or unmeasured confounding. Covariates were selected according to a prespecified conceptual rationale; however, potentially relevant factors such as specific task type, working hours, physical workload, heat and smoke exposure, hydration, dietary intake, comorbidities, medication use, and shift timing were not fully measured or included. Observation bias was reduced through standardised observer training and standardisation of observation sequences. Self-report bias in sleep and fatigue assessments was reduced, but not eliminated, through anonymous questionnaire administration and standardised explanations by the research team. Non-enrolment of workers who were absent during the data-collection period may have introduced selection bias; because the reason for absence was not established in the manuscript, absence should not be attributed specifically to illness or injury unless documented. The adjusted model treated the ordinal fatigue category code as a numeric outcome; this modelling choice should be considered when interpreting coefficient magnitudes.

Summary of Analytical Framework

The study assessed selected ergonomic, anthropometric, sleep-related, and individual factors concurrently to describe their associations with work fatigue among fish-smoking workers. By combining questionnaires, anthropometric measurements, and direct task observation, the study provided an exploratory health-promotion needs assessment for the participating centres. The analytical approach estimated unadjusted and adjusted associations but did not test causal pathways, interaction effects, intervention effectiveness, or the relative dominance of one domain over another. The findings were therefore intended to identify priorities for further assessment and future evaluation rather than to justify specific interventions or policy effects.

RESULTS

Table 1 shows the frequency distribution of variables in this study. A total of 64 fish-smoking workers were included in the study. Most participants were female (67.2%), while 32.8% were male. The workforce was predominantly aged 30 years or older (96.9%), with only 3.1% of participants younger than 30 years. Most workers had substantial occupational experience, as 71.9% had worked for more than 10 years, 15.6% had worked for 5–10 years, and 12.5% had worked for fewer than 5 years.

Regarding body mass index, 39.1% of participants were classified as having normal BMI, followed by 35.9% who were obese, 15.6% who were overweight, and 9.4% who were underweight. These findings indicate that slightly more than half of the workers were classified as either overweight or obese.

Table 1. Frequency Distribution of Variables (n = 64)

Variables	Category	Frequency (f)	Percentage (%)
Sex	Male	21	32.8
	Female	43	67.2
Age	<30 years	2	3.1
	≥30 years	62	96.9
Work tenure	<5 years	8	12.5
	5–10 years	10	15.6
	>10 years	46	71.9
BMI category	Underweight	6	9.4
	Normal	25	39.1
	Overweight	10	15.6
	Obese	23	35.9
Repetitive-task risk (right hand)	Low	1	1.6
	Moderate	40	62.5
	High	23	35.9
Repetitive-task risk (left hand)	Low	9	14.1
	Moderate	44	68.8
	High	11	17.2
Sleep quality	Good (PSQI ≤5)	12	18.8
	Poor (PSQI >5)	52	81.3

Variables	Category	Frequency (f)	Percentage (%)
Fatigue Level	Low	24	37.5
	Moderate	38	59.4
	High	2	3.1

In Table 1, assessment of repetitive motion showed that moderate risk was the most common category for both hands. For the right hand, 62.5% of workers had moderate repetitive-task risk, 35.9% had high risk, and 1.6% had low risk. For the left hand, 68.8% were classified as having moderate risk, 17.2% had high risk, and 14.1% had low risk. Poor sleep quality was observed in 81.3% of participants, whereas 18.8% were classified as having good sleep quality. With regard to work fatigue, moderate fatigue was the most frequently reported level, affecting 59.4% of workers. Low fatigue was reported by 37.5%, while high fatigue was observed in 3.1% of participants.

Overall, the descriptive findings showed that the study population was predominantly female, aged 30 years or older, and had long work tenure. Moderate repetitive-task risk, poor sleep quality, and moderate work fatigue were the most common categories observed among the participants.

Table 2. Participant Characteristics and Occupational Factors by Work Fatigue Level

Variable	Category	Low fatigue n (%)	Moderate fatigue n (%)	High fatigue n (%)	Total n (%)	Exact p	Cramér's V
Sex	Male	10 (47.6%)	11 (52.4%)	0 (0.0%)	21 (100.0%)	0.408	0.181
	Female	14 (32.6%)	27 (62.8%)	2 (4.7%)	43 (100.0%)		
Age	<30 years	0 (0.0%)	2 (100.0%)	0 (0.0%)	2 (100.0%)	0.548	0.149
	≥30 years	24 (38.7%)	36 (58.1%)	2 (3.2%)	62 (100.0%)		
Work tenure	<5 years	5 (62.5%)	3 (37.5%)	0 (0.0%)	8 (100.0%)	0.315	0.182
	5–10 years	3 (30.0%)	6 (60.0%)	1 (10.0%)	10 (100.0%)		
	>10 years	16 (34.8%)	29 (63.0%)	1 (2.2%)	46 (100.0%)		
BMI (4 categories)	Underweight	4 (66.7%)	2 (33.3%)	0 (0.0%)	6 (100.0%)	0.010	0.335
	Normal	13 (52.0%)	12 (48.0%)	0 (0.0%)	25 (100.0%)		
	Overweight	0 (0.0%)	10 (100.0%)	0 (0.0%)	10 (100.0%)		
	Obese	7 (30.4%)	14 (60.9%)	2 (8.7%)	23 (100.0%)		
Right-hand repetitive-task risk	Low risk	0 (0.0%)	1 (100.0%)	0 (0.0%)	1 (100.0%)	0.834	0.104
	Moderate risk	14 (35.0%)	25 (62.5%)	1 (2.5%)	40 (100.0%)		
	High risk	10 (43.5%)	12 (52.2%)	1 (4.3%)	23 (100.0%)		
Left-hand repetitive-task risk	Low risk	5 (55.6%)	4 (44.4%)	0 (0.0%)	9 (100.0%)	0.037	0.262
	Moderate risk	12 (27.3%)	31 (70.5%)	1 (2.3%)	44 (100.0%)		
	High risk	7 (63.6%)	3 (27.3%)	1 (9.1%)	11 (100.0%)		
Sleep quality	Good (PSQI ≤5)	5 (41.7%)	7 (58.3%)	0 (0.0%)	12 (100.0%)	1.000	0.091
	Poor (PSQI >5)	19 (36.5%)	31 (59.6%)	2 (3.8%)	52 (100.0%)		
Total		24 (37.5%)	38 (59.4%)	2 (3.1%)	64 (100.0%)		

Table 2 presents the cross-tabulation of participant characteristics and occupational factors by work fatigue level. Overall, 24 workers (37.5%) reported low fatigue, 38 (59.4%) reported moderate fatigue, and 2 (3.1%) reported high fatigue. Because several contingency-table cells had expected counts below five, exact-test p-values were used as the primary measures of statistical significance.

Moderate fatigue was more common among both male and female workers, affecting 52.4% and 62.8%, respectively. High fatigue was observed only among female workers (4.7%). However, sex was not significantly associated with work fatigue (exact p = 0.408), and the magnitude of association was weak (Cramér's V = 0.181). Similarly, age was not significantly associated with fatigue (exact p = 0.548; Cramér's V = 0.149). Both workers younger than 30 years experienced moderate fatigue, whereas among workers aged 30 years or older, 38.7% reported low fatigue, 58.1% moderate fatigue, and 3.2% high fatigue.

Work fatigue also did not differ significantly across work-tenure categories (exact p = 0.315; Cramér's V = 0.182). Among workers with less than five years of tenure, low fatigue was most common (62.5%). In contrast, moderate fatigue predominated among those with 5–10 years of tenure (60.0%) and those with more than 10 years of tenure (63.0%). High fatigue was reported by 10.0% of workers with 5–10 years of tenure and 2.2% of those with more than 10 years of tenure.

BMI category was significantly associated with work fatigue (exact p = 0.010), with a moderate association magnitude (Cramér's V = 0.335). Low fatigue was most frequent among underweight workers (66.7%) and workers with normal BMI (52.0%). All overweight workers were classified as having moderate fatigue. Among workers with obesity, 30.4% reported low fatigue, 60.9% moderate fatigue, and 8.7% high fatigue. These findings indicate that the distribution of fatigue levels differed across the four BMI categories, although the bivariate design does not establish a causal relationship.

For right-hand repetitive-task risk, moderate fatigue was the most frequent category among workers with moderate risk (62.5%) and high risk (52.2%). The single worker classified as low risk also reported moderate fatigue. No statistically significant association was found between right-hand repetitive-task risk and fatigue (exact p = 0.834), and the association strength was weak (Cramér's V = 0.104).

In contrast, left-hand repetitive-task risk was significantly associated with fatigue level (exact p = 0.037), although the magnitude of association was weak (Cramér's V = 0.262). Moderate fatigue occurred in 70.5% of workers with moderate left-hand risk, compared with 44.4% of those with low risk and 27.3% of those with high risk. High fatigue was observed in 2.3% of workers with moderate risk and 9.1% of those with high risk. This pattern should be interpreted cautiously because of the small number of workers in some cells and because the association was assessed only at the bivariate level.

The PSQI-classified sleep-quality category was also not significantly associated with work fatigue (exact p = 1.000), with a very weak association magnitude (Cramér's V = 0.091). Among workers with good sleep quality, 41.7% reported low fatigue and 58.3% moderate fatigue. Among those with poor sleep quality, 36.5% reported low fatigue, 59.6% moderate fatigue, and 3.8% high fatigue. The lack of statistical significance should be interpreted in light of the unequal distribution of workers between the two sleep-quality categories.

In summary, BMI category and left-hand repetitive-task risk were significantly associated with work fatigue in the bivariate analysis. BMI showed a moderate association, whereas the association involving left-hand repetitive-task risk was weak. Sex, age, work tenure, right-hand repetitive-task risk, and the PSQI-classified sleep-quality category were not significantly associated with fatigue. These findings describe unadjusted relationships and should not be interpreted as evidence of causality.

Multivariable Associations with Work Fatigue

Multiple linear regression analysis (Table 3) was performed to examine adjusted associations with fatigue, incorporating demographic variables, ART repetitive-task risk, and sleep quality. The adjusted analysis included all 64 participants. The regression model had an intercept of 2.217 and explained 21.3% of the variation in fatigue ($R^2 = 0.213$; adjusted $R^2 = 0.115$). The overall model did not reach the conventional 0.05 level of statistical significance, F (7, 56) = 2.166, p = 0.051.

Table 3. Multivariable Linear Regression Analysis of Factors Associated with Fatigue

Variable	B	SE	Beta	95% CI for B	t	p
Constant	2.217	0.795	—	0.624 to 3.810	2.788	0.007
Sex	0.135	0.148	0.118	−0.161 to 0.432	0.914	0.365
Age	−0.729	0.399	−0.236	−1.527 to 0.070	−1.829	0.073
Work tenure	0.149	0.098	0.195	−0.046 to 0.345	1.531	0.131
Body mass index (BMI)	0.181	0.067	0.350	0.047 to 0.316	2.701	0.009*
Repetitive-task risk (right hand)	−0.241	0.150	−0.226	−0.542 to 0.060	−1.605	0.114
Repetitive-task risk (left hand)	0.028	0.138	0.029	−0.247 to 0.304	0.205	0.839
Sleep quality	0.144	0.169	0.105	−0.194 to 0.482	0.856	0.396

Note: N = 64; $R^2 = 0.213$; adjusted $R^2 = 0.115$; F(7, 56) = 2.166; overall model p = 0.051.
*p < 0.05 indicates statistical significance.

The multicollinearity assessment indicated that all independent variables had tolerance values above 0.10 and VIF values well below 10, with tolerance ranging from 0.712 to 0.934 and VIF ranging from 1.070 to 1.405. Although the highest condition index was 45.793, there was no evidence of substantial variance concentration across multiple predictors in the same dimension. Therefore, no serious multicollinearity was detected, indicating that the independent variables could be included simultaneously in the multiple linear regression model.

The multivariable linear regression analysis showed that BMI was the only variable significantly associated with work fatigue after adjustment for the other variables included in the model. BMI had a positive regression coefficient (B = 0.181; 95% CI 0.047 to 0.316; t = 2.701; p = 0.009). Because BMI was entered as an ordinal variable, this coefficient should be interpreted according to the category coding used rather than as a per-kg/m² effect. BMI was coded in ascending categories as 1 = underweight, 2 = normal, 3 = overweight, and 4 = obese; thus, the coefficient represents the fitted change in the coded fatigue outcome associated with a one-category increase in the ordinal BMI code.

No statistically significant adjusted associations were observed for sex (B = 0.135; 95% CI −0.161 to 0.432; p = 0.365), age (B = −0.729; 95% CI −1.527 to 0.070; p = 0.073), work tenure (B = 0.149; 95% CI −0.046 to 0.345; p = 0.131), right-hand repetitive-task risk (B = −0.241; 95% CI −0.542 to 0.060; p = 0.114), left-hand repetitive-task risk (B = 0.028; 95% CI −0.247 to 0.304; p = 0.839), or the sleep-quality predictor entered in the model (B = 0.144; 95% CI −0.194 to 0.482; p = 0.396). Notably, the association between left-hand repetitive-task risk and fatigue observed in the bivariate analysis was no longer statistically significant after adjustment for the other variables.

The adjusted model suggests that BMI remained associated with work fatigue after adjustment in this sample, whereas the other demographic, ergonomic, and sleep-related variables were not. The overall model explained 21.3% of the observed variation, with an adjusted R^2 of 0.115, but the overall F test was marginally non-significant (p = 0.051). Therefore, the statistically significant BMI coefficient should be regarded as an exploratory within-model association and interpreted cautiously. Because the analysis was cross-sectional, these findings should be interpreted as adjusted associations rather than evidence of causal effects or temporal prediction.

Summary of Key Findings

Among the 64 workers, moderate fatigue was the most frequent category. Left-hand repetitive-task risk was associated with fatigue category in the unadjusted analysis, but this association was not retained in the adjusted model. BMI remained associated with the coded fatigue outcome after adjustment, when entered using the ordinal coding 1 = underweight, 2 = normal, 3 = overweight, and 4 = obese. The regression model explained 21.3% of fatigue variation but did not reach the conventional level of overall statistical significance ($p = 0.051$). The PSQI-classified sleep-quality category was not associated with fatigue in the bivariate analysis, although restricted variability limited interpretation. These results identify BMI assessment, fatigue screening, and more detailed task-level ergonomic and sleep-quality evaluation as priorities for future research; they do not demonstrate causal dominance, interaction effects, or intervention effectiveness.

DISCUSSION

Ergonomic and Sleep-Related Factors Associated with Fatigue

The present study provides an exploratory assessment of the associations of repetitive-task exposure, sleep quality, BMI, and selected individual characteristics with work fatigue among fish-smoking workers at the participating centres in Semarang, Indonesia. The findings showed an unadjusted association between left-hand repetitive-task risk and fatigue, which was not retained after adjustment, while BMI remained associated with the coded fatigue outcome in the adjusted model. However, the overall regression model was marginally non-significant (F (7, 56) = 2.166, $p = 0.051$), with $R^2 = 0.213$ and adjusted $R^2 = 0.115$. The absence of statistically significant adjusted associations for the other measured factors should not be interpreted as evidence that they were unimportant or that BMI was a dominant determinant. Rather, the results should be considered in light of the small sample, imbalanced categories, measurement choices, modest model explanatory capacity, and limited precision. This pattern is consistent with viewing fatigue as a multidimensional outcome, while recognising that the present study did not test interactions among physiological, psychosocial, and environmental factors (40,41).

Ergonomic risks, including awkward postures and repetitive motions, have been well documented as factors associated with fatigue and musculoskeletal discomfort (9,17). In this study, 62.5% of workers were classified as having moderate right-hand repetitive-task risk, and 68.8% were classified as having moderate left-hand repetitive-task risk, consistent with repetitive manual tasks typical of fish processing. Similar findings have been observed in agricultural and manufacturing sectors, where repetitive exertions have been associated with increased muscle strain and reduced endurance (42). Nevertheless, the association observed for the left hand in the unadjusted analysis was attenuated after adjustment. Hand dominance, task-specific asymmetry, muscle recruitment, and limb-specific physiological fatigue were not measured; therefore, the difference between the right- and left-hand results cannot be attributed to dominant–nondominant limb mechanisms (43,44). The isolated unadjusted finding instead indicates a need for more detailed task-level assessment, including hand dominance, force, posture, work pace, task duration, and bilateral task distribution.

Poor sleep quality was prevalent among participants, with 81.3% classified as having poor sleep quality according to the PSQI cut-off used in this study. Although no significant relationship was found between PSQI-classified sleep quality and fatigue, this does not negate the relevance of sleep-related recovery. Previous occupational research has reported associations between sleep problems and work fatigue. In the present study, most participants were classified as having poor sleep quality, resulting in an imbalanced distribution that may have reduced the ability to detect an association. Dichotomising the PSQI global score into good and poor sleep-quality categories may also have reduced information compared with analysis of the continuous global score (45).

Association between Body Mass Index and Fatigue

The finding that BMI remained associated with the coded fatigue outcome in the adjusted model ($B = 0.181$, 95% CI 0.047 to 0.316, $p = 0.009$) is broadly consistent with previous studies reporting relationships between body size, physical workload, and fatigue-related outcomes (22,46). BMI was entered using ordinal coding of 1 = underweight, 2 = normal, 3 = overweight, and 4 = obese. Accordingly, the coefficient reflects a one-category increase in this ordinal coding and should not be interpreted as a per-kg/m² effect. Higher BMI may be accompanied by greater biomechanical loading during physically demanding work (47). However, BMI is an anthropometric indicator rather than a direct measure of dietary intake, nutritional adequacy, body composition, metabolic health, or physical fitness. Moreover, the single coefficient does not demonstrate that both low and high BMI were associated with fatigue. A bidirectional or U-shaped relationship should not be inferred unless non-linearity or separate BMI categories were explicitly examined (48).

The adjusted estimates for the other ergonomic and demographic variables included the null value; however, this does not establish that fatigue arose from cumulative rather than isolated stressors or that an exposure threshold existed. The study did not test whether BMI modified ergonomic associations or caused workers to reach a fatigue threshold earlier (49). Additionally, more than 70% of participants had worked for over ten years, resulting in limited variation in work tenure. Although adaptation among experienced workers is theoretically possible, physiological or perceptual adaptation was not measured and cannot explain the observed results (50). The null findings may instead reflect limited statistical power, imbalanced exposure categories, residual confounding, measurement error, or genuine weak associations in the sampled population.

Implications for Future Ergonomic and Health-Promotion Evaluation

The present findings do not establish the effectiveness of an integrated intervention package. They do, however, identify several priorities for further assessment in informal fish-smoking work. First, the high frequency of moderate repetitive-task risk supports more detailed task-level ergonomic evaluation before selecting specific modifications. The present data do not identify which specific workstation or work-organisation modification would be effective; candidate modifications should therefore be selected only after direct task assessment and worker consultation. Because hand dominance and physiological left-hand strain were not measured, workstation redesign should not be justified specifically as a means of correcting left-hand asymmetry. Any modification should be based on direct observation of posture, force, repetition, task duration, and worker feedback.

Educational initiatives promoting ergonomic awareness could be considered for feasibility testing rather than assumed to reduce fatigue in this setting. Because the present study did not evaluate ergonomic training or recovery interventions, their effectiveness cannot be inferred from these results. For fish-smoking workers, a small-scale participatory programme could examine whether practical instruction on posture, tool use, task alternation, and candidate recovery strategies is acceptable and feasible. Its effects on fatigue, musculoskeletal symptoms, work processes, and productivity would need to be evaluated prospectively. Integrating these strategies into informal settings requires low-cost and culturally tailored solutions that align with workers' daily routines.

Because BMI was associated with fatigue in the adjusted analysis, basic anthropometric and general health assessment may be a reasonable component of future occupational health-promotion activities. However, the study did not measure dietary intake, hydration, physical activity, metabolic status, or body composition and cannot determine which intervention, if any, would alter the observed association. Consequently, the present findings do not provide a basis for recommending a specific nutritional, hydration, or weight-management programme. Such interventions, if considered in future studies, should first be supported by appropriate assessment of the relevant nutritional and health determinants and evaluated prospectively.

Psychosocial factors may be relevant to occupational fatigue, and previous studies have linked work–life balance with physical and mental health outcomes (51). Nevertheless, psychosocial stress, economic insecurity, social support, and mental health were not measured in this study. Therefore, the present findings do not provide evidence for recommending specific counselling, peer-support, or psychosocial interventions. Future needs assessments could include validated psychosocial measures to determine whether such support is warranted in this workforce.

Local Occupational Health and Policy Implications

The study's results have primarily local implications for occupational health promotion among workers in the participating informal fish-smoking centres. Informal labourers often fall outside formal occupational health and safety frameworks, leaving them vulnerable to unregulated ergonomic risks and inadequate access to health services (1). The findings support consideration of accessible local services that can assess fatigue, anthropometric status, sleep quality, and work tasks. Existing community-based occupational health mechanisms may provide an appropriate setting for such assessment. However, the study was not designed to evaluate national labour policy or to demonstrate that a comprehensive programme would improve well-being (41).

A proportionate initial response would be to strengthen access to basic occupational health assessment and participatory ergonomic review at the local level. Future feasibility studies could involve local health services, worker groups, centre owners, and relevant community organisations in identifying and evaluating context-appropriate task assessments and workplace modifications. Any education or redesign programme should include baseline assessment, worker participation, and prospective evaluation of fatigue and musculoskeletal outcomes. Broader psychosocial-support services should be considered only after local needs have been assessed because psychosocial distress was not measured in this study (52).

Wearable monitoring and integration into national surveillance systems were not examined in this study and may not represent proportionate priorities for the resource-constrained informal settings studied. A more immediate research priority is to improve the reproducibility of fatigue, sleep quality, and ergonomic assessments using feasible methods that can be applied by local occupational health personnel. Preventive and participatory approaches remain relevant, but their feasibility and added value should be evaluated within the fish-smoking work context rather than assumed from evidence in dissimilar occupational settings.

Work schedules, shift timing, circadian disruption, recovery facilities, and productivity were not measured in the present study. Consequently, the findings cannot support claims that schedule adjustment or recovery facilities would substantially reduce chronic fatigue, injuries, or productivity losses. Future studies should first document working hours, break patterns, timing of fatigue assessment, and perceived recovery before prospectively evaluating whether any structured work–rest intervention is warranted or effective in this workforce.

Overall, the findings from this study indicate that moderate fatigue, repetitive-task exposure, a high prevalence of poor sleep quality, and variation in BMI coexist among workers in the participating fish-smoking centres. BMI was associated with the coded fatigue outcome after adjustment, whereas the unadjusted left-hand repetitive-task association was not retained. Because the overall regression model was marginally non-significant and explained a modest proportion of the variation in fatigue, the individual adjusted estimates should be interpreted as exploratory. These observations support further assessment of anthropometric health, task-level ergonomic exposure, fatigue, and sleep quality. They do not establish interaction among these domains or demonstrate that an integrated, multilevel programme will reduce fatigue. Future longitudinal and intervention studies are required to determine causal pathways, feasible intervention components, effectiveness, and implications for occupational health policy.

CONCLUSION

This study indicates that BMI was associated with the coded fatigue outcome in the adjusted analysis among workers at the participating fish-smoking centres, while adjusted associations were not detected for the measured repetitive-task variables or the sleep-quality predictor. The predominance of moderate fatigue among workers was a descriptive finding and should not be interpreted as evidence of cumulative physical or metabolic strain. Although repetitive motion, particularly involving the left hand, was associated with fatigue at the bivariate level, its association was attenuated after adjustment for the variables included in the model. These findings do not establish that BMI was a dominant physiological determinant; rather, they identify an adjusted association that should be interpreted cautiously because the overall regression model did not reach conventional statistical significance ($F(7, 56) = 2.166$, $p = 0.051$) and explained 21.3% of the observed variation in fatigue (adjusted $R^2 = 0.115$), in view of the cross-sectional design, small sample, imbalanced categories, possible residual confounding, and measurement and coding limitations. Generalisation should be limited to workers in the participating fish-smoking centres.

From a practical perspective, the findings support fatigue and anthropometric screening and more detailed task-level ergonomic and sleep-quality assessment as priorities for future evaluation. Specific ergonomic, work–rest, nutritional, or other health-promotion interventions should be selected and tested prospectively rather than recommended on the basis of the present cross-sectional associations. From a theoretical perspective, this research contributes a context-specific cross-sectional assessment of selected anthropometric, ergonomic, and sleep-related factors associated with fatigue in informal fish-smoking work, without demonstrating interactions or causal pathways among these domains. Future studies should use longitudinal designs, validated continuous measures, adequately powered and parsimonious analyses, and intervention research to clarify temporality and evaluate the feasibility and effectiveness of proportionate health-promotion measures in similar occupational settings.

DECLARATIONS

Author contributions: Conceptualization and methodology: EK, SJ; Investigation: EK, SJ, SRT; Formal analysis: EK, SJ; Visualization and writing – original draft: EK, SRT; Writing – review and editing: EK, SJ, SRT. All authors have read and agreed to the published version of the manuscript.

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