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## Association Between Heat Stress Exposure, Physical Activity, and Nutritional Status with Occupational Fatigue: Pilot Study

**David Kusmawan[1,2,3]✉, Silvia M. Perdana[1], Putri Irwanti S.[4], Ira Gustina[5], Anom Bowolaksono[6,7], Ardi Firmansyah[8]**

[1]Department of Public Health, Faculty of Medicine and Health Science, Universitas Jambi, Indonesia
[2]Center of Excellent E-Medical, LPPM Universitas Jambi, Indonesia
[3]PT. School of Safety, Bintaro, Tangerang, Banten Province, Indonesia
[4]Department of Nursing, Faculty of Medicine and Health Science, Universitas Jambi, Indonesia
[5]Center of Health Administration and Policy Studies, Faculty of Public Health, Universitas Indonesia, Indonesia
[6]Affiliated Scientist, Reproductive Biology, Center for Global Field Study, University of Washington Seattle, USA
[7]Department of Biology, Faculty of Mathematics and Natural Science, Universitas Indonesia, Indonesia
[8]PT. Hok Tong, Jambi City, Indonesia

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### Abstract

Global economic losses from workplace heat and reduced labor productivity are projected to reach nearly US$2 trillion by 2030. The rubber processing industry is particularly vulnerable to heat exposure. This study aimed to describe worker sociodemographic characteristics and assess the relationship between perceived heat stress, nutritional status, physical activity, and occupational fatigue among employees at PT. X in Jambi Province. A cross-sectional design with purposive sampling involved 74 workers across three production areas. Fatigue was measured using the Swedish Occupational Fatigue Inventory (SOFI), while perceived heat stress was assessed with the Heat Stress Perception Index (HSSI). Data were analyzed with univariate and multivariate methods, including multiple linear regression. Participants had a mean age of 34.03 years, BMI of 25.88, and oxygen saturation of 98.01%. The mean heat stress perception score was 50.31, and occupational fatigue averaged 40.55. Lack of energy was the most reported fatigue dimension (mean = 49.23), whereas lack of motivation was the least (mean = 29.92). Regression analysis identified gender ($p = 0.003$), physical activity ($p = 0.031$), and perceived heat stress ($p = 0.035$) as significant predictors. These findings highlight the need for targeted occupational health interventions to mitigate fatigue in the rubber processing industry.

## INTRODUCTION

Global $CO_2$ concentrations have increased by about 290 ppm since 1880, reaching 405 ppm in 2016 and 406.55 ppm in August 2018 (IPCC, 2014b; Scripps Institution of Oceanography, 2018). Without effective climate change mitigation, concentrations are projected to rise to between 540 and 1300 ppm by 2030–2100. The global average temperature, which has already increased by 0.6 ± 0.2°C since the 1850s, is predicted to rise by 1.4–5.8°C by 2100 (IPCC, 2014c). Climate change interacts with demographic shifts such as population aging, urbanization, and socio-economic development, further exacerbating heat

✉ Correspondence Address:
E-mail: david.kusmawan@unja.ac.id

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hazards. Anthropogenic heat from transportation and waste heat from buildings also contribute to rising urban temperatures.

Hot environments and associated heat stress can increase mortality, morbidity, adverse pregnancy outcomes, and mental health problems. High heat exposure also reduces physical work capacity and cognitive-motor performance, leading to lower productivity and higher occupational health risks (O'Callaghan-Gordo et al., 2022). Increasing environmental heat due to climate change thus threatens worker health, wellbeing, and community sustainability. The risks range from direct clinical impacts of heat stress to indirect effects such as poor air quality, limited access to clean water, and inadequate nutrition (Hokmabadi et al., 2020).

The thermal environment is a critical determinant of human health (Zamanian et al., 2017). Numerous studies show that workplace heat exposure reduces physical work capacity, increases absenteeism, and lowers organizational productivity. Physiological, psychological, and economic consequences have been documented (Morrissey et al., 2021). Global economic losses from occupational heat stress are substantial, yet further research is needed to clarify its relationship with productivity loss, reduced efficiency, and healthcare costs across demographic groups (Kjellstrom et al., 2009). Losses from workplace heat stress are projected at around US$2 trillion globally by 2030 (O'Callaghan-Gordo et al., 2022).

Heat stress not only causes physiological and psychological discomfort but also reduces performance and productivity and increases the risk of fatal accidents. Elevated thermoregulation demands, cardiovascular strain, irritability, and emotional distress can distract workers or lead them to ignore safety procedures (Nerbass et al., 2017). Heat exposure combined with metabolic heat from physical workloads further raises internal body temperature (Xiang et al., 2014), increasing risks of accidents (Anggraini et al., 2024). Other studies show that sleep quality strongly affects occupational fatigue (Kusmawan et al., 2023) and that risk perception influences safety behaviors (Kusmawan et al., 2021). Fatigue itself is a major factor contributing to workplace accidents and fatalities, especially when combined with poor sleep quality and high mental workload (Rini et al., 2022; Kusmawan et al., 2024).

Research in industrial settings has found a positive correlation between high temperatures and traumatic injuries, primarily through mechanisms of fatigue, reduced psychomotor performance, and decreased alertness. Rising temperatures and more frequent heat waves are expected to further increase heat-related morbidity and mortality among workers. High-risk groups include agricultural, construction, firefighting, mining, and manufacturing workers. Contributing factors include ambient temperature, use of personal protective equipment (PPE), work environment, physical activity, and heavy machinery. Workers in developing countries are especially vulnerable.

Preliminary surveys at PT. X, a rubber processing company in Jambi Province, showed heat exposure in dry and wet production areas exceeding the threshold limit. Workers reported dehydration, fatigue, and sleep disorders, while absenteeism and productivity losses were also noted. Therefore, this study aims to model the risk factors for occupational fatigue associated with heat exposure, physical activity, and nutritional status among rubber processing workers.

## METHOD

### Design, Research Instruments, and Data Analysis

This study employed an observational design using the Walkthrough Survey method. A cross-sectional design with purposive sampling was applied to workers at PT. X in Jambi Province. Research instruments included the Swedish Occupational Fatigue Inventory (SOFI) and the Heat Strain Score Index (HSSI). Thermal stress was measured using a WBGT Tenmars device, blood pressure with a digital Omron monitor, and oxygen saturation with a pulse oximeter.

### Subjects, Population, and Sample Size of the Research

The study population consisted of production workers at PT. X. The sample size was calculated using the Lemeshow formula (Lemeshow, 1991) with a 95% confidence interval, yielding a minimum requirement of 40 participants. In total, 74 workers were included as respondents in this study.

### Ethical Clearance

This study received ethical approval from the Research Ethics Committee, Faculty of Medicine and Health Sciences, Universitas Jambi (Approval No. 1896/UN21.8/PT.01.04/2024).

## RESULT AND DISCUSION

### Descriptive Analysis

As shown in Table 1, most workers were male (83.8%) with a mean age of 34.03 years (range: 18–55). The majority had completed

Figure 1. Research Location and Description of Wet and Dry Production Workers
Source: (Personal Documentation)

Table 1. Sociodemographic Characteristics

| Continuous Variable | | Mean ± SD |
|---|---|---|
| Age (years) | | 34.03 ± 9.29 |
| Number of children | | 1.51 ± 1.13 |
| Length of service (years) | | 9.29 ± 8.55 |
| Body Mass Index | | 25.81 ± 12.84 |
| Heart rate | | 79.08 ± 11.31 |
| $O_2$ Saturation (%) | | 98.03 ± 1.88 |
| Working hours (hours) | | 8.55 ± 0.95 |
| Heat exposure perception | | 49.97 ± 12.56 |
| SOFI (%) | | 39.96 ± 11.48 |
| Categorical Variables | Frequency | Presentation |
| Gender | | |
| Man | 62 | 83.8 |
| Women | 12 | 16.2 |
| Education Level | | |
| Elementary | 4 | 5.4 |
| Junior and Senior | 50 | 67.6 |
| High | 20 | 27.0 |
| Marital status | | |
| Married | 56 | 75.7 |
| Not married | 18 | 24.3 |
| Smoking Status | | |
| Smoking | 37 | 50.0 |
| Not Smoking | 37 | 50.0 |
| Work Area | | |
| Air-conditioned room | 27 | 36.5 |
| Wet Dry Production | 34 | 45.9 |
| Field | 4 | 5.4 |
| Laboratory | 9 | 12.2 |
| Physical Activity | | |
| Very easy | 5 | 6.8 |
| Easy | 22 | 29.7 |
| It's getting hard | 24 | 32.4 |
| Very difficult | 20 | 27.0 |
| It's very hard to feel like stopping | 3 | 12.2 |

Table 2. Mean scores of dimensions of SOFI among the participants

| Dimensions of Work Fatigue | Min | Max | Mean ± SD |
|---|---|---|---|
| Lack of energy | 14.29 | 82.86 | 49.23 ± 16.59 |
| Exerting physical strength | 14.29 | 68.57 | 35.33 ± 15.77 |
| Physical discomfort | 14.29 | 85.71 | 42.12 ± 19.21 |
| Lack of motivation | 14.29 | 74.29 | 29.92 ± 13.73 |
| Sleepy | 14.29 | 85.71 | 43.20 ± 17.56 |
| Total | 20.57 | 64.57 | 39.96 ± 11.48 |

secondary education (67.6%), and 75.7% were married, with an average of 1.51 children (range: 0–4). Participants were distributed across four work areas, with 45.9% employed in rubber production (dry and wet sections). On average, they worked 8.5 hours per day.

In terms of physical activity, responses were relatively balanced: 29.7% described their tasks as easy, 32.4% as moderate, and 27.0% as difficult. Descriptive statistics from the Swedish Occupational Fatigue Inventory (SOFI) revealed variations in fatigue levels (Table 2). Among the five dimensions, *Lack of Energy* had the highest mean score (49.23 ± 16.59), making it the most commonly reported symptom, while *Lack of Motivation* had the lowest mean score (29.92 ± 13.73), indicating relatively lower mental disengagement. Overall, SOFI scores ranged from 20.57 to 64.57, with a mean of 39.96 ± 11.48, suggesting a moderate level of work-related fatigue among the workers.

Before conducting multiple linear regression, classical assumptions were tested to ensure the validity and reliability of the model (Field, 2024). Table 3 summarizes the results of four diagnostic tests. First, error normality was assessed using the Kolmogorov–Smirnov test, which produced a significance value of 0.05, the residuals can be considered normally distributed. This finding is further illustrated in Figure 1, which shows a relatively symmetrical distribution. Second, homoscedasticity was tested using the Breusch–Pagan method, yielding a value of 0.9, indicating homogeneous error variance. Third, the Durbin–Watson statistic of 2.126 fell within the acceptable range, confirming no autocorrelation. Finally, multicollinearity was examined using the Variance Inflation Factor (VIF), with all values below 10, suggesting no significant correlation among independent variables. Overall, these results confirm that all classical assumptions for multiple linear regression were met, allowing further analysis to proceed appropriately.

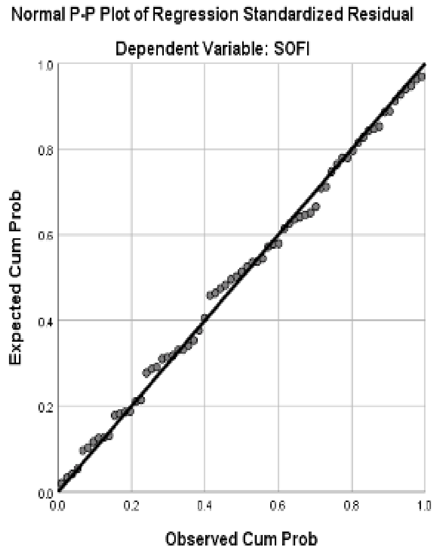


Figure 2. Normality Test Graph

Following confirmation that all classical assumptions were met, multiple linear regression analysis was conducted to identify risk factors associated with the dependent variable. Table 4 presents the results, including coefficients (B), standard errors, t-values, and p-values. Gender (B = –15.459, p = 0.003), physical activity (B = 3.361, p = 0.031), and perceived heat stress (B = 0.311, p = 0.035) were significant predictors at the 5% level. Gender showed a negative coefficient, suggesting differences in fatigue by sex, while higher physical activity and greater perceived heat stress were positively associated with fatigue. These results emphasize the role of behavioral and perceptual factors in shaping health outcomes.

The rubber processing industry, including PT. X in Jambi Province, faces notable fatigue risks due to high environmental temperatures. Jambi City, located near the Batang Hari River and an industrial cluster, is the ninth-hottest city in Indonesia, with temperatures reaching 33°C (BMKG data). Workers absorb heat both from the environment and from physical activity, making occupational fatigue a major concern. Studies link heat exposure with fatigue via increased

Table 3. Multiple Linear Regression Analysis Assumption Test

| Assumption Test | Test | Test Value | Conclution |
|---|---|---|---|
| Error Normality | Kolmogorov-Smirnov | 0.05 | Error is normally distributed |
| Homogeneity | Breusch-Pagan | 0.9 | Homogeneous Error |
| Autocorrelation | Durbin Watson | 2.126 | No autocorrelation |
| Multicollinearity | Variance Inflation Factor (VIF) | < 10 | There is no correlation between independent variables |

Table 4. Multiple Linear Regression Analysis Results

| **Risk Factors** | **Coefficient B** | **Std. Error** | **t** | **P** |
|---|---|---|---|---|
| Age | 0.016 | 0.249 | 0.066 | 0.948 |
| **Gender** | **-15.459** | **5.018** | **-3.081** | **0.003*** |
| Level of education | -0.940 | 3.248 | -0.289 | 0.773 |
| Work Area | -1.010 | 1.687 | -0.599 | 0.552 |
| Body Mass Index | 0.022 | 0.102 | 0.212 | 0.833 |
| Heart Rate | -0.118 | 0.139 | -0.850 | 0.399 |
| $O_2$ Saturation (%) | 0.583 | 0.729 | 0.799 | 0.427 |
| **Physical Activity** | **3.361** | **1.515** | **2.219** | **0.031*** |
| Smoking status | 0.628 | 3.164 | 0.199 | 0.843 |
| **Perception of heat stress exposure** | **0.311** | **0.144** | **2.159** | **0.035*** |
| Number of children | 0.398 | 2.270 | 0.175 | 0.862 |

Note: *) significant

muscle temperature and accelerated adenosine triphosphate (ATP) turnover, which reduce endurance and impair neuromuscular performance (Ball, 2020).

At PT. X, work is divided into wet and dry production areas, offices, and laboratories. The wet and dry areas recorded the highest heat exposure (31°C near the furnace, Walkthrough survey). Univariate analysis showed most workers were male (83.8%), with a mean age of 34.03 years, BMI of 25.88, heart rate of 79.36 bpm, oxygen saturation of 98.01%, mean perceived heat stress of 50.31, and mean fatigue score of 40.55.

Multivariate analysis confirmed that age, education, work area, BMI, heart rate, oxygen saturation, smoking, and number of children were not significantly associated with fatigue. Significant predictors remained gender, physical activity, and perceived heat stress. Female workers were 15.4 times more likely to experience fatigue than males. High physical activity and elevated heat stress perception increased fatigue risk 3.36-fold and 0.3-fold, respectively. SOFI results showed *Lack of Energy* as the most prevalent fatigue dimension (49.23 ± 16.59), followed by *Sleepiness* and *Physical Discomfort*. *Lack of Motivation* was the least reported (29.92 ± 13.73), consistent with Ramos (2020).

Job fatigue includes tiredness, drowsiness, reduced energy, and greater effort to maintain performance (National Safety Council). These indicators can guide workplace fatigue control programs. Gender differences in thermoregulation may explain part of the disparity: women's lower aerobic capacity and smaller blood volume increase cardiovascular strain, while differences in heat-loss mechanisms affect tolerance in dry versus humid environments (Avellini et al., 1980; Ashley et al., 2008). Additional household responsibilities may also contribute to higher fatigue levels among women (Ramos et al., 2020).

Perception of heat stress itself is another risk factor. Extreme heat has been linked to cardiovascular, respiratory, and kidney morbidity (Grundstein & Williams, 2018). Physiologically, the hypothalamus regulates vasodilation and sweating to maintain homeostasis. Ineffective evaporation under high humidity can impair cooling, increase accident risk, and lead to energy loss (NIOSH, 2016).

Physical activity was also inversely related to recovery. Workers with physically demanding jobs often reported exhaustion and reduced participation in leisure-time exercise (Bláfoss et al., 2019). Barriers included lack of time (70.2%) and fatigue (43.9%) (Balatoni et al., 2023). These findings highlight the complexity of occupational fatigue, influenced not only by environmental heat but also by workload, gender, and behavioral factors.

Finally, workplace conditions in factories and workshops, where employees spend long hours indoors, strongly influence health and work ability. Prior studies indicate that age, exercise duration, physiological strain, and employment status significantly correlate with work ability (Kazemi et al., 2019). While this study met the minimum sample size requirement, confounding factors and the cross-sectional design limit causal interpretation.

## CONCLUSION

Key variables requiring attention are gender, physical activity, and perceived heat stress exposure. Effective interventions should include managing heat exposure, regulating working hours, and preventing fatigue through ergonomic education. Equally important are initiatives to improve workers' nutritional health and the development of industry regulations tailored to the needs of female employees. These strategies are essential to identify underlying problems and implement effective solutions. Future studies should investigate the physiological and urinary profiles of workers exposed to heat stress, with particular emphasis on urine specific gravity (USG). In addition, both targeted and untargeted omics-based approaches may help identify biomarkers related to heat-induced reproductive health problems and chronic kidney disease (CKD).

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