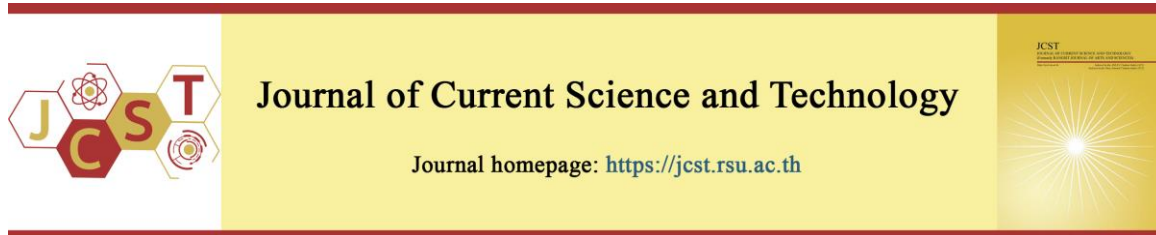


Cite this article: Kristanto, A., Ma'ruf, F., & Bariyah, C. (2026). Work fatigue and associated factors among wood-cutting workers: An ergonomic assessment using the fatigue assessment scale. *Journal of Current Science and Technology*, 16(4), Article 217. <https://doi.org/10.59796/jcst.V16N4.2026.217>



Work Fatigue and Associated Factors among Wood-Cutting Workers: An Ergonomic Assessment Using the Fatigue Assessment Scale

Agung Kristanto^{1, 2, *} 

Farid Ma'ruf^{1, 2} 

Choirul Bariyah^{1, 2} 

¹Department of Industrial Engineering, Faculty of Industrial Technology, Universitas Ahmad Dahlan, Yogyakarta 55166, Indonesia

²Research Center in Ergonomics and Occupational Safety and Health, Universitas Ahmad Dahlan, Yogyakarta 55166, Indonesia

*Corresponding author; agung.kristanto@ie.uad.ac.id

Received 14 March 2026; Revised 22 May 2026; Accepted 16 June 2026; Published 15 September 2026

Abstract

Work fatigue is a common occupational health problem in labor-intensive industries, particularly among wood-cutting workers exposed to repetitive physical demands and prolonged standing. However, studies integrating subjective fatigue assessment and physiological monitoring in woodworking settings remain limited. Therefore, this study aimed to examine the relationship between individual characteristics and work fatigue among wood-cutting workers in Indonesia. A total of 60 participants, comprising 41 males and 19 females aged 19.17–58.67 years, were included in this cross-sectional study. Data were collected using the Standardized Nordic Questionnaire (SNQ) to screen for musculoskeletal complaints; the Fatigue Assessment Scale (FAS) was applied to measure fatigue levels; and a wearable heart rate monitor recorded physiological responses before, during, and after work. Spearman correlation analysis examined associations between individual characteristics (age, working hours, daily recovery duration, overtime, coffee consumption, exercise frequency, commuting distance, and heart rate) and fatigue scores. The results showed that 40.00%, 48.33%, and 11.67% of workers experienced severe, moderate, and no fatigue, respectively. Significant correlations were found between fatigue levels and age ($p = 0.267$, $p = 0.039$), daily recovery duration ($p = -0.265$, $p = 0.041$), and heart rate ($p = 0.305$, $p = 0.018$). Heart rate showed the strongest association with fatigue, suggesting that cardiovascular strain may be associated with perceived fatigue during wood-cutting activities. Other variables, including working hours, overtime duration, coffee consumption, exercise frequency, and commuting distance, were not significantly associated with fatigue. These findings indicated that physiological workload, worker age, and insufficient recovery periods were important factors associated with work fatigue among wood-cutting workers. The study supported the use of combined subjective and physiological approaches for ergonomic fatigue assessment and workplace fatigue management.

Keywords: ergonomics, Fatigue Assessment Scale (FAS), heart rate, occupational health, work fatigue, wood-cutting industry

1. Introduction

Work fatigue is widely recognized as a critical occupational health and safety issue in labor-intensive settings because of its ability to degrade attention, slow reaction time, and increase error and incident

risks. These outcomes directly influence operational performance and reliability. Contemporary reviews have characterized fatigue as a multidimensional phenomenon comprising physical, mental, and motivational aspects that span occupations and health

conditions. This complexity underscores the need for valid instruments and multi-facet assessments in workplace ergonomics (Billones et al., 2021). In woodworking operations, particularly during wood-cutting tasks, workers often contend with repetitive exertions and prolonged standing due to machine operation, dust, and noise exposure, which collectively contribute to musculoskeletal strain and cumulative load. Recent field studies in wood processing confirmed the high ergonomic risk in the sector, with infrared thermography during real work cycles showing localized musculoskeletal overload (Soranso et al., 2022).

Currently, the state of the art has shown rapid methodological advancement toward an integrated fatigue assessment framework that combines subjective self-reports with physiological markers. On the subjective side, the Fatigue Assessment Scale (FAS) remains a widely adopted and reliable instrument for capturing both physical and mental fatigue dimensions. Scoping reviews further recommend the use of FAS in broader and multi-instrument strategies to cover multidimensionality of fatigue (Billones et al., 2021). Regarding the physiological aspect, there is a growing emphasis on cardiovascular load and heart-rate-based monitoring using wearable devices to index internal workload and recovery. A recent systematic review has synthesized evidence and provided recommendations for assessing cardiovascular stress at work. Related studies also showed how heart rate and heart rate variability could index physical fatigue and workload during manual operations (Ni et al., 2022; Darbandy et al., 2020). Beyond measurement, previous intervention studies reported that work–rest scheduling and micro-breaks could reduce muscle fatigue without harming productivity. This suggests an actionable, organizational-level intervention once risk factors have been identified (Tsao et al., 2021; Xu & Hall, 2021). In line with previous reports, large-scale occupational cohorts have also documented the high prevalence of work-related musculoskeletal disorders (WMSDs) linked to work demands. The results are particularly relevant for woodworking, where repetitive upper-limb activity and constrained posture are inherent to task execution (Greggi et al., 2024).

Despite recent advances in occupational fatigue assessment, several important gaps remain. First, most fatigue studies have focused on construction, healthcare, or general manufacturing sectors, while ergonomic investigations specifically involving wood-cutting workers remain limited. Recent

thermography studies mainly report distinct overload patterns in the woodworking sector (Soranso et al., 2022). Second, previous studies commonly examined only isolated factors such as age or working hours (Dias et al., 2023), without integrating demographic, work-related, lifestyle, and physiological variables within a single analytical framework. Third, although subjective fatigue instruments such as the Fatigue Assessment Scale (FAS) are widely used, studies combining validated subjective fatigue assessment with objective physiological monitoring, particularly heart rate responses during real woodworking activities, are still scarce. This methodological limitation constrains the ecological validity of ergonomic recommendations for wood-cutting workflows (Dias et al., 2023).

Therefore, the present study addresses these gaps by investigating the relationship between demographic, work-related, lifestyle, and physiological factors and work fatigue among wood-cutting workers using an integrated ergonomic assessment approach combining FAS and wearable heart rate monitoring. This study also aims to provide sector-specific evidence for fatigue management and ergonomic intervention in labor-intensive woodworking operations.

2. Objectives

This study aimed to examine the relationship between individual and work-related factors and work fatigue among wood-cutting workers in Indonesia using subjective and physiological fatigue assessments. Specifically, this study aimed to evaluate fatigue levels among wood-cutting workers using the Fatigue Assessment Scale (FAS), measure workers' physiological responses through heart rate monitoring during wood-cutting activity, and analyze the correlation between demographic, work-related, lifestyle, and physiological factors and perceived fatigue levels.

3. Materials and Methods

This study employed a cross-sectional design to examine the relationship between demographic, work-related, lifestyle, and physiological factors and work fatigue among wood-cutting workers.

3.1 Participants

This study included 60 wood-cutting workers employed in the center of the small-scale woodworking industry located in Klaten Regency, Central Java Province, Indonesia. Therefore, a total population sampling approach was applied. Among participants,

there were 41 males and 19 females, with ages ranging from 19.17 to 58.67 years. All participants had at least one year of work experience in wood-cutting activities and were actively engaged in manual and machine-based cutting tasks. Inclusion criteria required participants to be in good general health and free from a previous diagnosis of musculoskeletal disorders (MSDs), as confirmed through self-reports using the Standardized Nordic Questionnaire (SNQ). Ethical approval was obtained from the Human Ethics Committee of Universitas Ahmad Dahlan, with approval number REC-UAD/01/01/02-2025/026. Participation was voluntary, and written informed consent was obtained from all individuals before data collection.

3.2 Description of the Activity

Wood-cutting activities in the selected small and medium-sized enterprises (SMEs) involved several physically demanding tasks, including manual material handling, wood positioning, machine operation, manual cutting, and stacking of processed wood materials. Workers manually transported raw wood to cutting stations, which required repetitive lifting and carrying activities that imposed substantial physical loads on the lower back and shoulders. During machine preparation and operation, workers maintained prolonged standing postures while applying repetitive upper-limb movements to guide and stabilize wood materials. These activities exposed workers to repetitive strain, sustained muscular effort, and awkward postures, particularly in the shoulders, arms, wrists, and lower back. In addition, manual cutting tasks required continuous gripping force and precision movements, increasing localized muscular fatigue in the hand and wrist regions. The work environment also involved continuous exposure to occupational risk factors such as wood dust, machine vibration, noise, and heat. Combined with repetitive physical activity and limited recovery time, these conditions potentially contributed to cumulative physical fatigue and musculoskeletal strain among workers.

3.3 Data Acquisition

3.3.1 MSDs Pain History

All participants were wood-cutting workers in good health and without a history of MSDs. The SNQ, translated into Indonesian (Ramdan et al., 2019), was administered before data collection to confirm health status by identifying any pain, discomfort, or movement limitations in body regions such as the neck, shoulders, back, arms, wrists, hips, knees, and ankles.

The Indonesian version of the SNQ used in this study has previously demonstrated acceptable validity and reliability for assessing musculoskeletal symptoms among Indonesian workers. The questionnaire covered symptoms experienced in the 12 months and the 7 days before participation. Since only workers without significant complaints participated, the data obtained reflected work-related fatigue rather than pre-existing conditions.

3.3.2 Fatigue Level

The fatigue level of workers was assessed using the FAS, a concise and robust self-report instrument widely used across clinical and occupational studies to measure physical and mental fatigue. This instrument comprised 10 items, each rated on a five-point Likert scale ranging from “never” to “always”, with higher scores denoting greater fatigue. The FAS has demonstrated strong psychometric properties, including high internal consistency and test-retest reliability across occupational and clinical populations (Horisberger et al., 2019). Specifically, it has shown excellent internal consistency (Cronbach’s $\alpha \approx 0.93$), solid test-retest reliability (intraclass correlation coefficient (ICC) ≈ 0.90), and unidimensionality. Furthermore, it distinguished fatigue from depression or anxiety symptoms (Michielsen et al., 2003).

In this study, the FAS was administered at the end of each work shift to capture participants’ perceived fatigue after wood-cutting tasks. Participants were asked to complete the questionnaire independently, following clear instructions from the study team. The item responses were summed to obtain a total fatigue score ranging from 10 to 50, with higher scores indicating greater fatigue. Based on established cut-off values, a total score of 10–21, 22–34, and 35–50 indicated no, moderate, and severe fatigue, respectively (Michielsen et al., 2003). These thresholds were used to classify workers’ fatigue levels, which enabled more precise analysis of the relationship between individual characteristics and physiological indicators, such as heart rate, and fatigue outcomes.

3.3.3 Heart Rate (HR)

Heart rate monitoring was conducted following the manufacturer’s recommended sensor placement procedure to improve measurement consistency during work activities. Heart rate measurements were recorded under three conditions: initial resting condition before work activities, active working condition during wood-cutting tasks, and final resting condition after

completion of work activities. Measurements were conducted using the same wearable device and standardized placement procedure for all participants to maintain measurement consistency. The Suunto Vertical All Black wristband (Suunto Oy, Finland) was attached to participants' wrists, specifically positioned approximately two finger-widths above the wrist bone, to measure heart rate and energy consumption. Personal data, including gender, weight, height, and normalized maximum heart rate, were entered into the smartwatch for each participant. The normalized maximum heart rate was estimated by subtracting each participant's age from 220 beats per minute (bpm) (Kristanto et al., 2025). For optimal sensor performance, the skin at the sensor site was cleaned with alcohol to minimize impedance.

3.4 Statistical Analysis

Data were analyzed using IBM SPSS Statistics version 26, and individual characteristics were summarized through descriptive statistics, with continuous variables presented as mean $\pm$ standard deviation (SD). The independent variables were grouped into demographic factors (age, sex), work-related factors (working hours, daily recovery duration, overtime frequency), lifestyle-related factors (coffee consumption, exercise frequency, commuting distance), and physiological response (heart rate). Daily recovery duration referred to the amount of off-work recovery time obtained by workers within a 24-hour period, including sleep, relaxation time at home, and other non-work resting activities outside working hours. This variable did not refer to formal work breaks during the work shift. The dependent variable comprised the level of work fatigue, which was measured using the FAS.

Spearman's rank-order correlation (ρ) was applied to examine the associations between individual factors and fatigue scores because several variables were ordinal and the analysis used a non-

parametric approach. Given the exploratory nature of this study and the relatively modest sample size ($N = 60$), the analysis focused on bivariate associations using Spearman's rank-order correlation rather than multivariable regression modelling. Consequently, potential confounding effects among variables could not be fully controlled and should be considered when interpreting the observed associations. Correlation strength was interpreted as weak ($\rho < 0.30$), moderate ($\rho = 0.30\text{--}0.49$), and strong ($\rho \geq 0.50$). Statistical significance was set at $p < 0.05$.

3.5 Hypothesis

This study hypothesized that demographic, work-related, lifestyle, and physiological factors were associated with work fatigue among wood-cutting workers. Specifically, greater age, shorter daily recovery duration, and higher working heart rate were expected to be associated with higher fatigue levels.

4. Results

4.1 Participants

The demographic characteristics of participants and the summary statistics are presented in Table 1.

Table 1 shows that the participant group consisted of 60 healthy wood-cutting workers, comprising 68% male and 32% female, with an average age of 31.8 years and body mass index (BMI) of 21.7 kg/m², without previous MSDs. Participants worked 7.2 hours per day on average with an average overtime of 2.44 hours/day, indicating irregular work-rest patterns. The average daily recovery duration was 5.90 ± 2.42 hours/day, indicating variations in workers' off-work recovery opportunities, including sleep and non-work rest periods outside working hours. Most participants consumed little coffee and had low exercise frequency, with 35% reporting no exercise. The average commute was 16 km, although some traveled approximately 60 km daily, increasing cumulative fatigue risk.

Table 1 The demographic characteristics and descriptive statistics of participants (N = 60)

Individual characteristics	N(%)	Mean $\pm$ SD	Range
Sex			
Male	41(68)		
Female	19(32)		
Age (years)		31.78 $\pm$ 7.10	19.17 – 58.67
Weight (kg)		60.52 $\pm$ 11.53	42.00 – 87.00
Height (m)		1.67 $\pm$ 0.07	1.50 – 1.82
BMI (kg/m ²)		21.68 $\pm$ 4.13	14.53 – 30.85
Working hours (hours/day)		7.20 $\pm$ 0.16	7.02 – 7.83
Daily recovery duration (hours/day)		5.90 $\pm$ 2.42	2.00 – 9.13
Overtime working duration (hours/day)		2.44 $\pm$ 1.37	1.00 – 6.50
Coffee consumption			
• Never	38(63)		
• 1 times/day	11(18)		
• 2 times/day	10(17)		
• >3 times/day	1(2)		
Exercise frequency			
• Never	21(35)		
• 1 times/week	21(35)		
• 2 times/week	13(22)		
• >3 times/week	5(8)		
Commuting distance (km)		16.02 $\pm$ 7.74	8.00 – 60.00
Pain history			
• Have a history	0(0)		
• No prior history	60(100)		

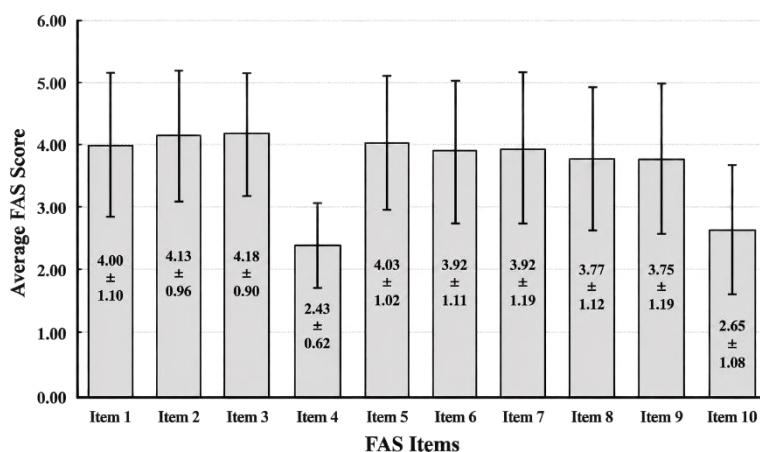


Figure 1 The average score of the 10-item FAS for all participants

4.2 Fatigue Level Analysis

4.2.1 FAS

Figure 1 shows the average score of the 10-item FAS based on Michielsen et al. (2003) for all participants. According to Figure 1, the 10-item FAS indicated higher physical than mental fatigue. The highest scores were on physical exhaustion items such as “*I didn’t do much during the day* (item 3)” and “*I*

got tired very quickly (item 2).” In comparison, reverse-scored items such as “*I had enough energy for everyday life* (item 4)” and “*I could concentrate well* (item 10)” had the lowest scores, suggesting limited energy and clarity. However, cognitive-related items such as “*I had problems thinking clearly* (item 7)” scored high, showing mental fatigue accompanied by physical strain in wood-cutting. This dual impact

reflected the multidimensional nature of fatigue in this context.

The predominance of physical exhaustion-related items compared with cognitive items suggests that fatigue among wood-cutting workers was primarily driven by sustained physical workload and repetitive muscular activity. This finding supports the study objective of examining the relationship between physiological workload and perceived fatigue using combined subjective and objective ergonomic assessment approaches.

4.2.2 Fatigue Level Distribution

The average total fatigue score for all participants was 36.78 ± 7.48 , which fell within the severe category, as presented in Figure 2.

As shown in Figure 2, the distribution of fatigue scores had a mean of 36.78 ± 7.48 , indicating

severe fatigue. Based on the analysis, 40% of workers had high fatigue, while only 11.67% were classified as having no fatigue, indicating that a greater proportion of workers experienced elevated fatigue despite similar working hours. This pattern may indicate that work-related and recovery-related factors were associated with fatigue among wood-cutting workers.

The high proportion of workers classified in the moderate and high fatigue categories indicates that fatigue was not limited to isolated individuals but represented a substantial occupational issue within the studied woodworking environment. This distribution further supports the importance of identifying contributing demographic and physiological factors associated with work fatigue.

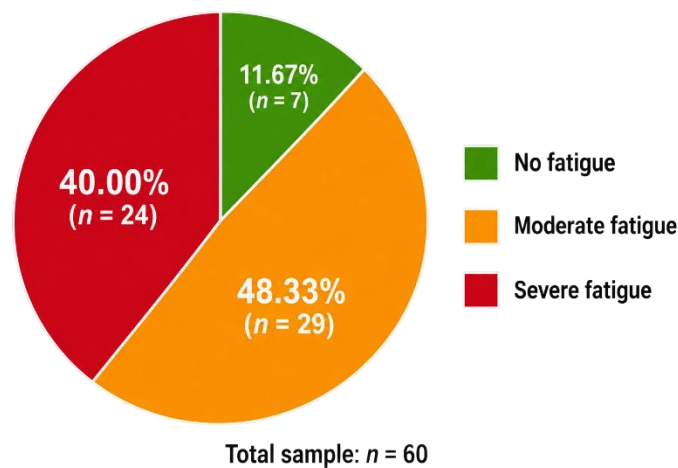


Figure 2 The distribution of fatigue score across all participants

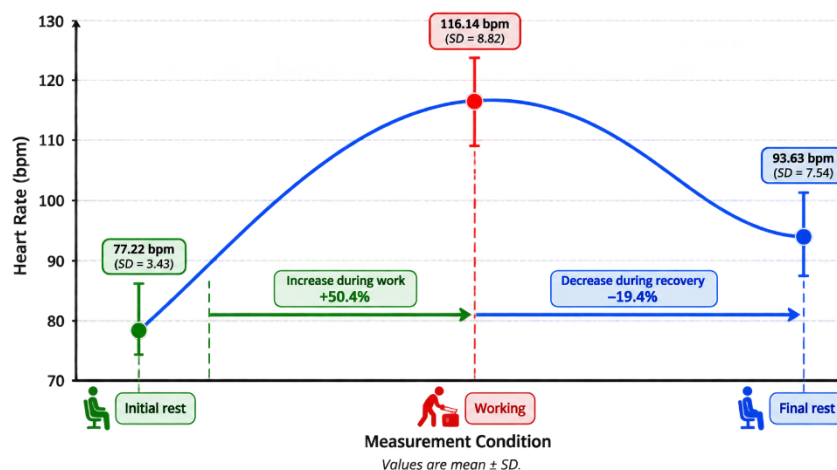


Figure 3 The average heart rate, including initial rest, working, and final rest conditions

Table 2 The correlation between individual characteristics and perceived fatigue by workers during wood-cutting activities

Individual characteristics	Fatigue	Spearman coefficient (<i>p</i> -value)
Sex†	Perceived fatigue	0.500 (0.310)
Age		0.267 (0.039)*
Working hours		0.013 (0.920)
Daily recovery duration		−0.265 (0.041)*
Overtime working duration		0.017 (0.896)
Coffee consumption		−0.048 (0.716)
Exercise frequency		0.042 (0.750)
Commuting distance		0.240 (0.064)
Heart rate		0.305 (0.018)*

*Significantly correlated ($p < 0.05$).

†Sex was analyzed using the Mann–Whitney U test; the reported value is the test statistic (U), not a Spearman correlation coefficient

4.3 Heart Rate Analysis

Figure 3 shows the average heart rate across the initial rest, working, and final rest conditions, for workers during wood-cutting activities.

According to Figure 3, heart rate increased from 77.22 bpm at rest to 116.14 bpm during active wood-cutting, indicating the substantial cardiovascular load imposed by the task. The heart rate decreased to 93.63 bpm during final rest but stayed above baseline, suggesting incomplete recovery even after the rest period. The pattern emphasized the high physical demand of wood-cutting and the potential cumulative strain on workers' cardiovascular systems.

The incomplete return of heart rate to baseline values during the final resting condition suggests insufficient short-term physiological recovery following wood-cutting activities. This pattern supports the observed association between cardiovascular strain and perceived fatigue levels identified in the correlation analysis.

4.4 Correlation between Individual Characteristics and Perceived Fatigue

Table 2 shows the correlations between individual characteristics and perceived fatigue among workers during wood-cutting activities in this study.

As shown in Table 2, the correlation analysis revealed three significant relationships, emphasizing that physiological factors and recovery patterns, such as heart rate, age, and daily recovery duration, played a more dominant role in influencing fatigue than lifestyle variables. Sex was additionally analyzed using the Mann–Whitney U test because it was a dichotomous categorical variable. The analysis showed no significant difference in fatigue scores between male and female workers ($p = 0.310$). Age was positively correlated with perceived fatigue ($p =$

0.267, $p = 0.039$), indicating that older workers experienced higher fatigue levels. Daily recovery duration showed a negative correlation ($p = -0.265$, $p = 0.041$), suggesting that shorter rest periods were associated with greater fatigue. Heart rate had the strongest positive correlation ($p = 0.305$, $p = 0.018$), suggesting cardiovascular strain was associated with perceived fatigue. However, other factors such as working hours, overtime, coffee consumption, exercise frequency, and commuting distance did not show significant associations.

5. Discussion

This study found that wood-cutting workers had an average FAS score of 36.78 ± 7.48 , indicating severe fatigue. Based on the analysis, 40% of workers experienced severe fatigue, and only 11.67% reported having no fatigue, indicating that fatigue was common in this occupation. Similarly, previous studies have reported that repetitive motion, awkward postures, and sustained exertion in manual labor increased fatigue risk in woodworking and related industries (Das et al., 2020; Tran et al., 2023).

Item-level analysis of the FAS showed that physical fatigue symptoms were more prominent than mental fatigue symptoms. Specifically, items such as “*I didn’t do much during the day*” (mean = 4.18), “*I got tired very quickly*” (mean = 4.13), and “*Physically, I felt exhausted*” (mean = 4.03) recorded the highest mean scores. These results reflected severe physical strain, which correlated with high cardiovascular workload observed during cutting activities. The average working heart rate was 116.14 bpm, representing considerable physiological demand compared to resting levels (77.22 bpm). Previous studies confirmed that high heart rate during manual tasks strongly predicted increased physical fatigue (Rahman et al., 2018; Zinoubi et al., 2018).

Correlation analysis using Spearman's rank-order test showed significant associations between fatigue level and age ($\rho = 0.267, p = 0.039$), daily recovery duration ($\rho = -0.265, p = 0.041$), and heart rate ($\rho = 0.305, p = 0.018$). The positive correlation between age and fatigue level suggested that older workers tended to experience greater fatigue than younger workers. This relationship may be attributable to age-related physiological changes, including reduced cardiovascular efficiency, slower recovery from exertion, and diminished musculoskeletal resilience (Costa & Sartori, 2007). In line with previous studies, the results showed that aging workers had lower work capacity and were more prone to fatigue under physically demanding conditions (Aitken & MacMahon, 2019; Mehta, 2016; Xing et al., 2020).

Shorter daily recovery duration was associated with higher fatigue levels, emphasizing the importance of sufficient off-work recovery time, including sleep and relaxation, in reducing cumulative physical fatigue. Previous studies reported that sufficient and well-structured rest significantly reduced fatigue and lowered the risk of MSDs (Luger et al., 2019; Radwan et al., 2022). Therefore, optimizing work-rest schedules is essential for managing fatigue and protecting workers' health (Martinez et al., 2023; Xu & Hall, 2021). The positive correlation between heart rate and fatigue level indicated that higher cardiovascular strain was associated with higher perceived fatigue. Sustained muscle activity and repetitive upper-limb movements in wood-cutting increased metabolic demand, triggering higher cardiac output and heart rate (Moshawrab et al., 2022; Reimers et al., 2018; Umer et al., 2022). When the load persisted without adequate recovery, fatigue accumulated, as indicated by higher FAS scores. Studies in industrial settings also showed that heart rate was an objective biomarker of physical workload and fatigue (Albulescu et al., 2022; Darbandy et al., 2020). Heart rate showed the strongest association with fatigue among the variables examined, indicating that cardiovascular workload may be associated with perceived fatigue during wood-cutting activities. Although the observed correlations were statistically significant, the effect sizes were generally weak to moderate, suggesting that fatigue among wood-cutting workers was likely influenced by multiple interacting occupational and individual factors beyond the variables examined in this study. Therefore, while the statistically significant associations observed in this study provide useful

ergonomic insights, their practical significance should be interpreted within the context of the relatively weak correlation strengths and the multifactorial nature of occupational fatigue. However, there were no significant relationships observed between fatigue level and other factors such as working hours, overtime, coffee consumption, exercise frequency, or commuting distance. This differed from some previous studies, where lifestyle factors influenced fatigue risk (Whitehead, 2009). In this context, job-related and physiological factors could exert a stronger effect than personal habits. From a practical perspective, the findings suggest that ergonomic interventions focusing on adequate work-rest scheduling and recovery management may help reduce fatigue among wood-cutting workers. In addition, wearable heart rate monitoring may provide a practical approach for early identification of excessive physiological workload and fatigue risk in labor-intensive woodworking environments. Evidence-based methods, such as micro-breaks and physical conditioning programs, have been reported to help reduce fatigue and enhance overall worker health without diminishing productivity (Coleman Wood et al., 2018; Ding et al., 2020).

In contrast, several variables, including working hours, overtime duration, coffee consumption, exercise frequency, and commuting distance, were not significantly associated with fatigue levels in this study. These findings should be interpreted cautiously because the relatively homogeneous working conditions and limited variability among workers may have reduced the ability to detect stronger associations. In addition, the moderate sample size and narrow range of some occupational variables may have contributed to limited statistical sensitivity. Occupational fatigue is recognized as a multifactorial phenomenon influenced by interacting physical, physiological, environmental, and individual factors rather than by single variables alone (Techera et al., 2016). Similar findings have also been reported in field-based ergonomic studies where some occupational variables did not demonstrate statistically significant associations because of real-world work variability and complex exposure conditions (Simon et al., 2024; Nurjaman et al., 2025).

Despite its contributions, this study had several limitations. First, the cross-sectional design precluded the establishment of causal relationships between individual characteristics and fatigue levels, highlighting the need for longitudinal studies to clarify the temporal dynamics and fatigue

progression. In addition, the use of bivariate correlation analysis did not allow adjustment for potential confounding variables. Therefore, the observed associations should be interpreted as exploratory rather than independent predictive effects. Future studies with larger samples should apply multivariable regression models to evaluate independent determinants of work fatigue. Second, reliance on self-reported fatigue data through the validated FAS introduced the potential for response bias and limited real-time tracking of fatigue during work. Therefore, future investigations should use continuous physiological monitoring, such as real-time heart rate variability, and recruit larger, more diverse samples to better generalize results and advance understanding of fatigue mechanisms in wood-cutting tasks. In addition, the wrist-worn optical heart rate monitor used in this study may have been affected by motion artefacts during vibration-intensive wood-cutting activities, although standardized sensor placement procedures were applied to improve measurement consistency.

6. Conclusion

In conclusion, this study showed that work fatigue was common among wood-cutting workers, with the majority in the moderate to severe fatigue categories. The analysis found that age, rest time, and heart rate were key indicators of fatigue, while other factors such as working hours, overtime, coffee, exercise, and commuting were not significantly associated with fatigue levels in this study. The observed association between heart rate and fatigue may reflect the physical demands of wood-cutting tasks as well as the benefit of using objective measurements in risk management. The negative relationship with rest time indicated that workers needed sufficient and regular daily recovery duration. These results provided important insights for developing practical solutions, such as better work-rest schedules, adjusting workloads for age, and the use of heart rate monitoring as an indicator for identifying workers who may experience elevated physiological workload. Moreover, future investigations should follow workers over time and use real-time health monitoring to inform appropriate strategies for addressing fatigue in woodworking and other physically demanding occupations.

7. Acknowledgements

The authors are grateful to all participants in this study for dedicating their time.

8. Abbreviations

Abbreviations	Full Term
BMI	Body Mass Index
bpm	Beats per minute
FAS	Fatigue Assessment Scale
HR	Heart Rate
ICC	Intraclass Correlation Coefficient
MSDs	Musculoskeletal Disorders
SD	Standard Deviation
SMEs	Small and Medium-Sized Enterprises
SNQ	Standardized Nordic Questionnaire
WMSDs	Work-Related Musculoskeletal Disorders

9. CRediT Statement

Agung Kristanto: Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft, Writing - review & editing, Supervision, Project administration.

Farid Ma'ruf: Data curation, Methodology, Validation, Writing - review & editing.

Choirul Bariyah: Investigation, Formal analysis, Validation, Writing - review & editing.

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