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The Effect of Sleep Quality, Hot Work Climate, and Age on Work Fatigue Through Work Duration as an Intervening Variable on Charcoal Workers in Batam City

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Abstract

Workers in the informal charcoal industry face the risk of physical exposure and high workloads. This study aims to analyze the effects of sleep quality, hot work climate, and age on work fatigue, with work duration as an intervening variable, among charcoal workers in Batam City. This study used a quantitative, observational-analytical design. The population was charcoal workers; a sample of 99 workers was selected using a total sampling technique. Data were collected using a questionnaire and analyzed using Smart-PLS SEM. The results showed that sleep quality had a significant direct effect on work duration (coefficient = 0.591, p = 0.000) and work fatigue (coefficient = 0.618, p = 0.000). A hot work climate has a significant effect on work duration (coefficient = 0.264, p = 0.002). However, it does not have a significant direct effect on work fatigue (coefficient = 0.027, p = 0.354). Age has a significant direct effect on work duration (coefficient = 0.0395, p = 0.003) and work fatigue (coefficient = 0.431, p = 0.000). Work duration is significantly associated with work fatigue (coefficient = 0.431, p = 0.000) and fully mediates the relationship between hot work climate and work fatigue. The value indicates that the combination of variables in the model explains 96.5% of the variation in work fatigue. Sleep quality and work duration are the main determinants of work fatigue among charcoal workers. Hot work climates do not directly cause fatigue, but rather must first lead to an increase in workers' work duration. It is recommended that charcoal business owners arrange adequate rest periods between burnings and that workers maintain sleep quality to reduce the risk of chronic work fatigue. While previous studies examined these factors separately, the mediating role of work duration among informal charcoal workers remains under-investigated, which constitutes the research gap addressed here. Ethical approval was obtained prior to data collection, and informed consent was secured from all respondents.

Keywords

Age, Charcoal workers, Hot work climate, Sleep quality, Work duration, Work fatigue

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I. BACKGROUND

Charcoal is a product of burning wood at high temperatures and can be used for household purposes, such as cooking, or in the combustion process for manufacturing materials. Carbon monoxide (CO) is a dangerous gas produced from incomplete combustion, including in the charcoal-making process. Exposure to CO can increase carboxyhemoglobin (COHb) levels in the bloodstream, thereby reducing the ability to transport oxygen. Carbon monoxide (CO) is a dangerous, colorless, odorless, and non-irritating gas, making it difficult to detect without specialized equipment. The incomplete combustion of organic materials such as wood, coal, and fossil fuels forms this gas. In the workplace, CO is classified as a toxic substance that can impact the respiratory and cardiovascular systems. This can endanger workers' health if proper Occupational Safety and Health (OHS) management is not implemented (Gatterer et al., 2024). The charcoal industry carries a high risk of carbon monoxide (CO) exposure because its manufacturing process involves burning large amounts of biomass, often with inadequate ventilation. The primary mechanism underlying CO toxicity is that when inhaled, CO enters the respiratory tract and then travels to the lungs, where it binds to hemoglobin in the blood to form carboxyhemoglobin (COHb), which can reduce the amount of oxygen carried by hemoglobin throughout the body. CO binds to hemoglobin (CO-Hb) 200 to 250 times more strongly than oxygen. This reduces hemoglobin's ability to bind oxygen and inhibits its release to body tissues. As a result, organs such as the brain, nervous system, and heart do not receive sufficient oxygen to function properly, leading to a decrease in the blood's oxygen-binding capacity. As a result, workers can experience hypoxia, with symptoms ranging from headaches and nausea to impaired consciousness, arrhythmia, and even death (Savioli et al., 2024; Susanti & Purnawan, 2025).

An estimated 2.4 billion people worldwide rely on solid fuels (such as wood, animal dung, crop residues, and charcoal) for cooking, heating, and other household needs, and this figure could be closer to 3 billion. Charcoal is produced by burning biomass (wood and various agricultural and forest residues) through incomplete combustion, controlled by the amount of oxygen present. Slow combustion produces a black, carbonaceous solid called charcoal, which produces relatively less smoke (compared to other solid fuels) when used (Derebe et al., 2025; Ezzati & Kammen, 2002; Wilkinson et al., 2007).

One informal sector facing ergonomic risks and extreme work environments is the charcoal industry. Charcoal workers are constantly exposed to hot working conditions caused by burning wood during the carbonization process. Exposure to ambient temperatures exceeding the Threshold Limit Value (TLV) stipulated in Minister of Manpower Regulation No. 5 of 2018 can trigger heat stress (Peraturan Menteri Ketenagaan Kerja No 5, 2018). This condition forces the body to work extra hard to thermoregulate through excessive sweating, which, if prolonged, can accelerate dehydration, increase heart rate, and lead to lactic acid accumulation, resulting in chronic work fatigue (Bridger, 2017). In addition to environmental factors, individual characteristics such as age and sleep quality play a crucial role in a person's work capacity. As we age, the body's functional capacity, muscle strength, and recovery ability naturally decline, which can lead to fatigue at work (Tord Kjellstrom et al., 2016). On the other hand, poor sleep quality due to sleep disorders or economic demands that force workers to sacrifice rest time results in the body not getting enough restorative phase.

This lack of quality sleep disrupts cognitive and motor functions, making workers more susceptible to fatigue at the start of work hours (Åkerstedt T, 2019). The relationship between these factors and work fatigue is not always direct. However, it can be exacerbated by adopted working hours, such as long hours or hours exceeding the standard 8 hours per day (Peraturan Pemerintah RI No. 35, 2021). Occupational fatigue is a significant occupational safety and health (OHS) issue, particularly for the working population at disproportionate risk of injury and illness, as they may be unable to avoid fatigue-causing working conditions. Over 43% of workers experience sleep deprivation (those at highest risk work nights, or long or irregular shifts), and productivity losses due to worker fatigue (National Safety Council (NSC), 2020).

It is common for charcoal workers to neglect rest periods in order to meet production targets. Long work hours have a significant impact on workers' health. Workers with poor sleep quality or older workers will experience significantly more fatigue if required to work extended periods in hot conditions. Long work hours reduce the body's tissue recovery time, compounding the cumulative effects of geothermal heat and age-related physical decline. The impact of long work hours and

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fatigue on workers at high risk remains poorly understood, largely because research specifically examining fatigue in this group is limited. Although some occupational safety and health issues have received increased attention for this group (e.g., exposure to physical and chemical hazards), further study is needed to improve understanding of the impact of long work hours and fatigue among workers at higher risk, as well as research to design effective interventions to address these occupational safety and health hazards (Cunningham et al., 2022a).

This study is grounded in the Conservation of Resources (COR) theory and the Job Demands–Resources (JD-R) model. Within this framework, a hot work climate and prolonged work duration constitute job demands that deplete workers' physiological and psychological resources. In contrast, adequate sleep quality serves as a personal resource that buffers against this depletion. Age is treated as an individual characteristic that shapes the size of the available resource pool and the speed of recovery. Work fatigue is therefore conceptualized as the outcome of a resource-loss spiral that occurs when job demands persistently exceed the resources workers can mobilize and restore.

While previous studies have separately examined the effects of sleep quality, heat exposure, and age on work fatigue, limited research has investigated the mediating role of work duration in the relationships among these determinants and work fatigue, particularly among informal charcoal workers who operate outside formal occupational health protection. The novelty of this study lies in modeling work duration as an intervening variable using SEM-PLS, thereby clarifying whether environmental and individual factors influence fatigue directly or indirectly via exposure duration. Accordingly, this study aims to analyze the direct and mediated relationships among sleep quality, hot work climate, age, work duration, and work fatigue in charcoal workers in Batam City.

2. METHODS

The research is quantitative analytical with a cross-sectional design, and the research location is Batam City. The study population consisted of 99 charcoal workers, selected using the total sampling technique. The research variables consisted of three variables: the independent variables (sleep quality, work climate, and age), the dependent variable (work fatigue), and the intervening variable (work duration). The instrument used was a questionnaire. Data were analyzed using SEM-PLS. The variables were also tested for validity and reliability, with Cronbach's alpha values > 0.60 or > 0.70.

The sample size follows the guidelines for SEM-PLS analysis. Because a total sampling technique was applied, all 99 charcoal workers who met the inclusion criteria were included. This satisfies the minimum requirement proposed by Hair et al. (2021), namely at least ten times the largest number of structural paths directed at a single construct; with a maximum of three predictors pointing to work fatigue, the required minimum is 30 respondents, and a post-hoc power analysis using G*Power confirmed that N = 99 provides statistical power above 0.80 to detect medium effect sizes at $\alpha = 0.05$. The response rate was 100%, and no missing data were recorded because questionnaires were checked for completeness at the point of collection.

The questionnaire items were adapted from previously validated instruments in the occupational health and ergonomics literature and contextualized for the charcoal production setting. Content validity was assessed through expert judgment prior to data collection, followed by construct validity and reliability evaluation. All reflective indicators met the recommended thresholds (outer loading ≥ 0.70, Cronbach's alpha and composite reliability ≥ 0.70, and AVE ≥ 0.50), confirming that the instrument is both valid and reliable.

This study was conducted in accordance with research ethics principles. Written informed consent was obtained from all respondents, and participation was voluntary and anonymous.

3. RESULTS

In this study, the first step was to evaluate the measurement model. The measurement model in this study was reflective. In Hair et al. (2021), the evaluation of the reflective measurement model consisted of a loading factor ≥ 0.70, composite reliability ≥ 0.70, Cronbach's alpha, and average variance extracted (AVE ≥ 0.50), as well as an evaluation of discriminant validity, namely the Fornell and Lacker criteria, and a Heterotrait Monotrait Ratio (HTMT) below 0.90 cross-loading (Hair et al., 2021).

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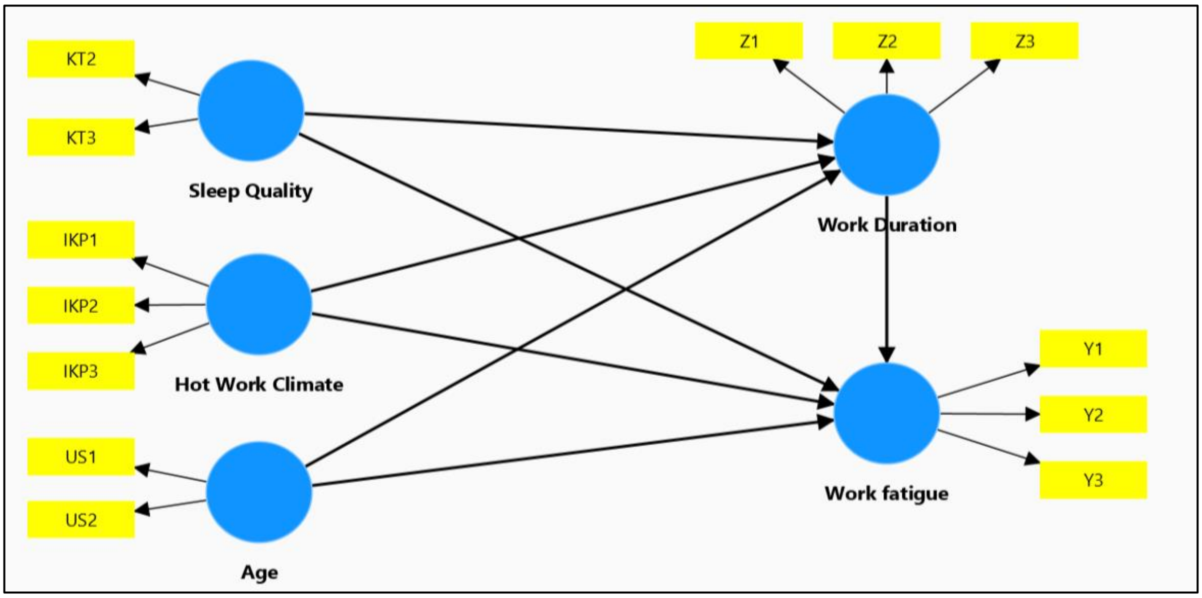

Figure 1. Research Model

Evaluation of Measurement Models

Table 1. Outer Loading, Composite Reliability and Average Variance Extracted

Variabel	Item Measurement	Indikator	Outer Loading	Cronbachs Alpha	Composite Reabilty	AVE
Sleep Quality	KT1	I find it difficult to get to sleep at night	0.877	0.747	0.887	0.797
	KT2	I often wake up in the middle of the night or early morning	0.909			
Hot Work Climate	IKP1	Light	0.782	0.701	0.821	0.605
	IKP2	Currently	0.752			
	IKP3	Heavy	0.798			
Age	US1	Early Worker Age (Young):> 15 - 24 Th	0.892	0.728	0.803	0.673
	US2	Middle-Aged / Adult Working Age: 25 - 64 years	0.742			
Work Duration	Z1	I often work more than 8 hours a day	0.973	0.919	0.950	0.863
	Z2	The rest time given is not sufficient compared to the length of working time.	0.840			
	Z3	I often work overtime to complete the charcoal production target.	0.968			
Work Fatigue	Y1	I feel weak or lacking energy after finishing work.	0.838	0.851	0.899	0.691
	Y2	I find it difficult to concentrate when doing repetitive work.	0.897			
	Y3	Shoulder, back or waist pain after work	0.795			
	Y4	I feel sleepy while doing work activities	0.792			

Based on the table above, the Sleep Quality variable is measured by 2 (two) valid measurement items with outer loadings between 0.877 and 0.909, which means that the two measurement items are valid in reflecting the measurement of Sleep Quality. The variable's reliability is acceptable, as indicated by Cronbach's Alpha and Composite reliability above 0.70 (reliable), or by its internal consistency. Convergent validity is indicated by an AVE of 0.797, which exceeds 0.50 and meets the requirements for good convergent validity. Overall, the variation in measurement items within the variable was 79.7%. Among the two measurement items, KT2 has the highest outer loading (0.909), indicating that the measurement items related to Work Duration and managing work fatigue have been implemented. Sleep quality strongly influences work duration and work fatigue.

Meanwhile, KT1 needs to be improved and accelerated. Workers should pay attention to factors that maintain stable sleep quality. This can be done by managing workloads/tasks to avoid stress, providing education on sleep hygiene, or establishing ergonomic work shift patterns, as sleep quality has been proven to be a solid indicator of workers' physical and mental well-being.

The Hot Work Climate variable is measured by 3 (three) valid items, with loadings ranging from 0.752 to 0.798, indicating that the items are valid in reflecting the Hot Work Climate. The level of variable reliability is acceptable, as indicated by Cronbach's Alpha and Composite reliability above 0.70 (reliable), or by internal consistency. The level of convergent validity is indicated by an AVE of 0.605, which exceeds 0.50 and meets the criteria for good convergent validity. Overall, the variation in the measurement items comprising the variable is 60.5%. Among the three measurement items, IKP1 and IKP3 have the highest outer loadings (0.782 and 0.798), indicating that the two measurement items, namely those related to work duration and managing work fatigue, have been implemented. The Work Climate is reflected in Work Duration and worker fatigue, while IKP2 needs to be improved and accelerated. Improve the ventilation system in the combustion furnace area, or add a heat-insulating shielding wall around the furnace. This is important to minimize direct heat radiation striking the worker's body and to provide a special rest area isolated from the charcoal furnace's heat radiation. This area should be equipped with a hanging fan or a mist fan to help reduce the worker's body temperature more quickly.

The Age variable is measured by 2 (two) valid measurement items with outer loadings between 0.892 and 0.742, which means that both measurement items are valid and reflect the measurement of Work Duration. The variable's reliability level is acceptable, indicated by Cronbach's Alpha and Composite reliability above 0.70 (reliable), or by its internal consistency. The convergent validity is indicated by an AVE of 0.605 > 0.50, which meets the requirements for good convergent validity. Overall, the variation in the measurement items comprising the variable is 60.5%. Among the two measurement items,

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measurement item US1 has the highest outer loading (0.892), indicating that it is related to Work Duration and that managing the impact of Work Fatigue has been implemented. Age has a strong impact on Work Fatigue, while US2 needs to be improved and accelerated. Evaluate and improve the K3 program. It is necessary to identify whether the current fatigue management program is not yet adaptive to certain age groups (for example, older workers or workers who are too young), so that policy adjustments (acceleration) are needed, such as the development of a workplace wellness program based on the age category of workers.

The Work Duration variable is measured by 3 (three) valid measurement items with outer loading between 0.840 and 0.973, which means that the three measurement items are valid in reflecting the measurement of Work Duration. The variable's reliability level is acceptable, as indicated by Cronbach's Alpha and Composite reliability above 0.70 (reliable), or by its internal consistency. Convergent validity is indicated by an AVE of 0.863, which exceeds 0.50 and meets the requirements for good convergent validity. Overall, the variation in the measurement items comprising the variable is 86.3%. Among the three measurement items, measurement items Z1 and Z3 have the highest outer loading (0.973) and (0.968), which indicates that both measurement items, namely related to Work Duration and in managing the impact of Work Fatigue, have been implemented. Work Duration has a significant impact on Work Fatigue, while Z2 needs to be improved and accelerated. When workers perform heavy physical work (such as lifting wood, stirring coconut shells, or harvesting charcoal) for a long time (e.g., 8 hours a day), the muscles experience physiological fatigue due to the accumulation of lactic acid. Mentally, long work durations reduce the capacity for focus and concentration, which is the main trigger for work accidents (human error).

The Work Fatigue variable is measured by 4 (four) valid measurement items with outer loading between 0.792 and 0.897, which means that the four measurement items are valid in reflecting the measurement of Work Fatigue. The level of variable reliability is acceptable, as indicated by Cronbach's Alpha and Composite reliability above 0.70 (reliable), or by internal consistency. The level of convergent validity is indicated by an AVE of 0.691, which exceeds 0.50 and meets the criteria for good convergent validity. Overall, the variation among the measurement items in the variable is 69.1%. Among the four measurement items,

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measurement items Y1 and Y2 have the highest outer loading (0.838) and (0.897), which indicates that the measurement items related to work fatigue have been implemented. Work fatigue can significantly disrupt workers' lives, while Y3 and Y4 need to be improved and accelerated. When workers are tired, their respiratory rate tends to become faster and shallower. This increases the volume of charcoal dust (carbon) inhaled into the respiratory tract, thereby accelerating the risk of ISPA (Acute Respiratory Tract Infection) or pneumococcal infection in the long term.

Discriminant Validity

1. Fornell Lacker criterion

Evaluation of discriminant validity should be conducted using the Fornell and Lacker criteria. Discriminant validity is a form of evaluation to ensure that variables are theoretically distinct and have been empirically tested. The Fornell and Lacker criteria is that the root of the AVE of a variable is smaller than the correlation between the variables (Hair et al., 2021; Yamin, 2023).

Table 2. Fornell Lacker

	Work Duration	Hot Work Climate	Work Fatigue	Sleep Quality	Age
Work Duration	0.929				
Hot Work Climate	0.512	0.778			
Work Fatigue	0.889	0.496	0.831		
Sleep Quality	0.698	0.402	0.913	0.893	
Age	0.743	0.570	0.848	0.830	0.820

Based on Table 2, the Fornell-Lacker value criteria show that the Work Duration variable has a root AVE (0.929) with a greater correlation with Hot Work Climate (0.512), Work Fatigue (0.889), Sleep Quality (0.697), and Age (0.743). These results indicate that, overall, the research variables exhibit good discriminant validity according to the Fornell-Lacker method (root AVE > correlations).

2. Heterotrait-Monotrait Ratio of Correlations (HTMT)

According to Hair et al. and Henseler et al (2021), if the HTMT value is ≤ 0.85 (Very Good), this is a strict limit. If the HTMT value between two variables is below, then the discriminant validity is met. The two variables are proven to be conceptually different. If the HTMT value is ≤ 0.90 (Still Acceptable): This is a loose limit for variables that theoretically have similar concepts (for example, measuring job satisfaction and work commitment). If the value is below 0.90, the discriminant

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validity is still declared met. If the HTMT value is≥ 0.90 or 1.00 (Problematic/Failed), this indicates severe multicollinearity (Hair et al., 2021; Yamin, 2023).

Table 3. Value HTMT

	Work Duration	Hot Work Climate	Work Fatigue	Sleep Quality	Age
Work Duration					
Hot Work Climate	0.600				
Work Fatigue	0.878	0.618			
Sleep Quality	0.832	0.544	0.155		
Age	0.062	0.833	0.207	0.220	

Based on Table 3, the test results show that the HTMT value is below 0.90 for the discriminant variable pair. The variable dividing the variation of the measurement item against the item that measures it is stronger than dividing the other variables.

3. Cross Loading

The correlation value of an indicator with its latent variable (construct) must be greater than the correlation value of the indicator with other latent variables.

Table 4 Cross Loading

	Work Duration	Hot Work Climate	Work Fatigue	Sleep Quality	Age
IKP1	0.308	0.782	0.353	0.318	0.359
IKP2	0.522	0.752	0.452	0.334	0.577
IKP3	0.284	0.798	0.305	0.265	0.307
KT1	0.577	0.398	0.792	0.877	0.592
KT2	0.664	0.326	0.838	0.909	0.872
US1	0.672	0.343	0.846	0.903	0.892
US2	0.538	0.669	0.496	0.374	0.742
Y1	0.664	0.326	0.838	0.909	0.872
Y2	0.973	0.444	0.897	0.708	0.705
Y3	0.681	0.496	0.795	0.569	0.631
Y4	0.577	0.398	0.792	0.877	0.592
Z1	0.973	0.444	0.897	0.708	0.705
Z2	0.840	0.577	0.671	0.501	0.686
Z3	0.968	0.428	0.891	0.717	0.687

From Table 4, the cross-loadings indicate that each variable shows both high and low correlations with the variable it measures.

Structural Model

1) Inner VIF Multicollinear Test

Before testing the structural model hypothesis, we check for multicollinearity among the variables using the VIF statistic. The estimation results show an internal VIF < 5, indicating low multicollinearity among the variables. This result confirms that the parameter estimates from SEM-PLS are robust (unbiased).

Table 5. Inner VIF

	Work Duration	Hot Work Climate	Work Fatigue	Sleep Quality
Work Duration			2.198	
Hot Work Climate	1.195		1.349	
Work Fatigue				
Sleep Quality	1.195		1.962	
Age	1.195		1.438	

Based on Table 5, the VIF value < 5 means that the Multicollinearity Test is fulfilled for all research variables.

Table 6. Direct Effect

Hipotesis	Path Coefficient	P-Value	95% Interval Lower Limit	95% Interval Upper Limit	F Square
H1= Sleep Quality → Work Duration	0.591	0.000	0.425	0.725	0.642
H2= Sleep Quality → Work Fatigue	0.618	0.000	0.560	0.673	5.598
H3= Hot Work Climate → Work Duration	0.264	0.002	0.110	0.449	0.129
H4= Hot Work Climate → Work Fatigue	0.027	0.354	-0.036	0.077	0.015
H5= Age → Work Duration	0.395	0.043	0.112	0.812	0.097
H6= Age → Work Fatigue	0.217	0.003	0.343	0.580	0.607
H7= Work Duration → Work Fatigue	0.431	0.000	0.358	0.504	2.427

Table 7. Indirect Effect

Hipotesis	Path Coefficient	p-value	Effect size	Description
H8 = Sleep Quality → Work Duration → Work Fatigue	0.254	0.000	0.064	Effect Towards Moderate
H9 = Hot Work Climate → Work Duration → Work Fatigue	0.114	0.005	0.012	Low Effect
H10 = Age → Work Duration → Work Fatigue	0.221	0.058	0.097	High Effect

3) Evaluation of the goodness and suitability of the model

R-Square and Q-Square

R-square describes the magnitude of the variation of endogenous variables that can be explained by other exogenous/endogenous variables in the model. According to Chin (1998), the qualitative interpretation of R-square is 0.19 (low influence), 0.33 (moderate influence), and 0.66 (high influence). Q-square is a measure of predictive accuracy, namely how well changes in exogenous/and endogenous variables predict endogenous variables. This measure is a form of validation in PLS to state the suitability of model predictions (predictive relevance). A Q-square value

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greater than 0 indicates that the model is predictive. Still, according to Hair et al. (2021), the qualitative interpretation of Q-square is 0 (low influence), 0.25 (moderate influence), or 0.50 (high influence).

Table 8. Value R-Square and Q-Square

	R-square	Q-square
Work Duration (Z)	0.545	0.536
Work Fatigue (Y)	0.965	0.964

Based on Table 8, the R-square value indicates that the joint influence of Sleep Quality and Hot Work Climate on Work Duration is 54.5% (high). The influence of Sleep Quality, Hot Work Climate, and Age on Work Fatigue is 96.5% (high influence).

2. Table SRMR

SRMR is the Standardized Root Square Residual. In Yamin (2022), this value is a measure of model fit, namely the difference between the data correlation matrix and the estimated model correlation matrix. In Hair et al. (2021), an SRMR value below 0.08 indicates a model fit. However, in Karin Schmelleh et al. (2003), an SRMR value between 0.08 and 0.10 indicates an acceptable model fit. The model estimation result is 0.012, indicating a good fit. Empirical data can explain the influence between variables in the model.

Table 9. Value SRMR

	Model Estimates
SRMR	0.012

Based on Table 9, the model's estimated value is 0.012, indicating a good fit. Empirical data can explain the influence between variables in the model.

3. Model Fit

The fixed model is assessed based on the Goodness of Fit (GoF) index, which is an evaluation of the overall model, including the measurement model and the structural model. According to Wetzels et al. (2009) and Yamin (2022), the GoF index value is interpreted as: 0.1 = low GoF; 0.25 = medium GoF; and 0.36 = high GoF.

Table 10. Goodness of Fit Index (GoF)

Average Communality	Average R-square	GoF Index
0.729	0.750	0.739

Based on Table 10, the calculation results show that the GoF value is 0.739, which is well above the threshold of 0.36 for high GoF. This indicates that the combined performance of the outer (measurement) and inner (structural) models in this study is excellent and can be classified as a good model fit. The high average communality (0.729) demonstrates strong convergent validity, while the high average R-square (0.750) indicates that the model explains 75% of the variance in the endogenous constructs.

4. Linearity Test

The linearity test is used to ensure that the relationship between latent variables (independent variables to dependent variables) is indeed linear, not quadratic, U-shaped, or other non-linear forms. The significance level used is p > 0.05 to confirm linearity.

Table 11. Linearity Test Results

Hypothesis Path	Path Coefficient	P-value	Description
Work Duration → Work Fatigue	0.038	0.286	Linearity Fulfilled
Sleep Quality → Work Duration	0.039	0.633	Linearity Fulfilled
Sleep Quality → Work Fatigue	0.022	0.277	Linearity Fulfilled
Hot Work Climate → Work Duration	0.045	0.696	Linearity Fulfilled
Hot Work Climate → Work Fatigue	-0.007	0.834	Linearity Fulfilled
Age → Work Duration	-0.032	0.781	Linearity Fulfilled
Age → Work Fatigue	0.011	0.729	Linearity Fulfilled

Based on Table 11, it can be seen that the linearity test requirements are met for all variable relationships, as all p-values are greater than 0.05 (ranging from 0.276 to 0.834). This confirms that all relationships between the latent variables in this study are linear, not quadratic, U-shaped, or other non-linear forms. Therefore, the assumption of linearity is satisfied, supporting the appropriateness of using PLS-SEM for this analysis.

4. DISCUSSION

1. Direct Effect

1) Direct Effect of Sleep Quality Variables on Work Duration.

The results of the study show that the first hypothesis (H1) is accepted, namely there is a significant influence of Sleep Quality on Work Duration with a path coefficient (0.591) and p-value (0.000 <0.05) directly. Any change in Sleep Quality will affect Work Duration. Within the 95% confidence interval, the influence of Sleep Quality on Work Duration lies between 0.425 and 0.725. However, Sleep Quality on Work Duration has a strong influence at the structural level (f-square = 0.642). The need for companies or business owners to evaluate their current Sleep Quality. Good Sleep Quality Evaluation is considered very important in overcoming Occupational Diseases (PAK).

Many studies have examined sleep using various sleep elements. Elements such as sleep quality and sleep duration are essentially separate components of sleep. The differences between factors related to sleep quality and sleep duration (such as health status, fatigue level, and sleepiness) are important (Kohyama, 2021; van Elk et al., 2024).

Scientifically, sleep is regulated by the circadian rhythm, a 24-hour biological clock monitored by the Suprachiasmatic Nucleus in the hypothalamus and influenced by chemicals such as GABA, serotonin, and the hormone melatonin. During sleep, the brain experiences changes in electrical waves that are divided into two main stages: NREM (Non-Rapid Eye Movement): Has an important role in physical recovery, reducing metabolism, cleaning metabolic waste products from the brain, and cell repair, and REM (Rapid Eye Movement): The stage where the brain functions very actively (dream phase) which is important for memory consolidation, the ability to think clearly, and the ability to think clearly cognitive and mental health. Sleep acts as a way to "restart" or repair physical conditions. During sleep, the body repairs muscle tissue, produces proteins, releases growth hormones, and restores the balance of the central nervous system after a day of activity (Guyton & Hall, 2016).

From an OHS perspective, sleep is a crucial element in fatigue management. Poor-quality sleep, less than 7–8 hours per day for adults, can directly impact thinking skills, slow response times, reduce focus, and increase the likelihood of workplace accidents. Sleep is defined as an active, repetitive physiological process characterized by reversible changes in consciousness and decreased responsiveness to the environment (Guyton & Hall, 2016). Research on sleep and work duration, which impacts health (Bergman et al., 2022; Suharmawati et al., 2025; Yoshida et al., 2024). When workers get quality sleep, their cognitive functions, such as concentration, alertness, and reaction time, are at optimal levels. This optimal physical and mental state allows workers to allocate their work time effectively and productively throughout the standard working hours.

Biologically fresh workers can complete their workloads quickly and accurately, thereby minimizing wasted time due to negligence or low levels of focus. Conversely, poor sleep quality will trigger fatigue. In the OHS domain, fatigue from sleep disturbances reduces work capacity and triggers presenteeism, in which workers are physically present for the entire work period but unable to function optimally. Decreased cognitive function due to sleep deprivation slows down the thinking process, so that tasks

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that should be completed quickly become bloated. This disrupts employees' effective time management and work duration (Ishibashi & Shimura, 2024).

Overall, the results of this study confirm that interventions to improve workers' sleep quality, whether through sleep hygiene education or ergonomic work shift arrangements, are strategic steps that have a significant impact on companies' ability to maintain productive work durations while simultaneously reducing the risk of work accidents.

2). Direct Effect of Sleep Quality Variables on Work Fatigue.

The results of the study show that the second hypothesis (H2) is accepted, namely there is a significant influence of Sleep Quality on Work Fatigue with a path coefficient (0.618) and p-value ($0.000 < 0.05$) directly and positively. Any change in Sleep Quality will affect Work Fatigue; in a 95% confidence interval, the influence of Sleep Quality on Work Fatigue lies between 0.560 and 0.673. However, the existence of Sleep Quality on Work Fatigue has a strong influence at the structural level (f-square = 5.598). Sleep quality plays a very strong role. Higher sleep quality scores were associated with increased work duration (0.591) and increased work fatigue (0.618). This suggests that any change in sleep quality significantly affects fluctuations in workers' work fatigue. The poorer a worker's sleep quality, the more likely it is that their workplace fatigue will increase linearly.

Sleep quality makes a dominant contribution and is the main structural factor in explaining variation in the occurrence of Work Fatigue among workers, making it one of the determinants that cannot be ignored in OHS risk management. Theoretically and from an occupational health perspective, work fatigue is a physiological and psychological response of the body to an imbalance between available energy and the workload. Sleep is the single most effective biological restorative mechanism for restoring body functions (Guyton & Hall, 2016). The significant influence of sleep quality on work fatigue aligns with the theory of fatigue-related accidents. Workers with high levels of fatigue due to poor sleep quality will experience decreased alertness, delayed reaction times, and increased carelessness or human error. This state of fatigue is dangerous because it can trigger workplace accidents and reduce organizational productivity at a large scale (Sadeghniiat-Haghighi & Yazdi, 2015). The research conducted found a significant association between sleep quality and fatigue (Alameri et al., 2024; Zhao et al., 2024; Suharmawati et al., 2025; Ayas & Özcebe, 2025). Charcoal workers who are constantly on guard to ensure the fire does not go out or remains burning can experience restless sleep and insomnia. Workers say they do not sleep soundly because they are afraid that if they sleep soundly and fall asleep, the charcoal will be of poor quality or not burn properly, will not sell well, and no one will buy it even if they do buy it at a high price will be very low, so that for very little sleep time people tend to become tired from lack of sleep.

3). Direct Effect of Hot Work Climate Variables on Work Duration.

The third hypothesis (H3) is accepted, namely there is a significant influence of Hot Work Climate on Work Duration with a path coefficient (0.264) and p-value ($0.002 < 0.05$), directly positive. Any change in Hot Work Climate will affect Work Duration. In the 95% confidence interval, the influence of Hot Work Climate on Work Duration is between 0.110 and 0.449. An increase will follow any increase in Hot Work Climate exposure in the work environment, as well as any increase in the Work Duration required by workers to complete their tasks (or an extension of the time required to complete tasks due to decreased efficiency). However, the existence of Hot Work Climate has a moderate or moderate influence in the structural level between (f square = 0.129), This means that even though Hot Work Climate is not the only single factor determining employee work duration (because there are other factors such as workload, work period, or individual physical condition), this physical environment variable still provides a proportional contribution that should not be ignored in the overall work system. Even though its influence is moderate, technical improvements are still needed to minimize work duration.

In theory, Corporate Hygiene and Occupational Health (Suma'mur, 2023), Exposure to hot work environments (heat stress) above the Threshold Limit Value (TLV) forces workers' bodies to make physiological compensations to lower their body temperature. This process triggers premature fatigue (heat exhaustion), decreased concentration, and reduced motor speed. Consequently, work efficiency decreases, requiring workers to complete the same task for longer than at a comfortable temperature. The global climate has been altered by human activity. As a direct consequence of global climate change, extreme heat conditions can increase the risk of death and morbidity from all causes or specific diseases, such as

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acute cardiovascular events, kidney disorders, and mental illness, based on well-documented epidemiological findings of daily high temperatures or heat waves (A et al., 2020; He et al., 2022; Masson-Delmotte, V., Zhai, P., Pirani, A., Connors et al., 2021; X et al., 2016; Y-H et al., 2018). According to workers, the work climate has a significant influence, as they work in a hot environment with long working hours; although there are rest periods, they still have to remain alert.

4). Direct Effect of Hot Work Climate Variables on Work Fatigue.

The fourth hypothesis (H4) is accepted, namely, there is an influence, but not a significant Hot Work Climate, on Work Fatigue, with a path coefficient of 0.027 and a p-value of 0.354 (> 0.05). Any change in the Hot Work Climate will increase Work Fatigue within the 95% confidence interval. The influence of the Chimney Furnace Design above on increasing Heat Exposure is between 0.036 and 0.077. However, the existence of a Hot Work Climate in increasing Work Fatigue has a low influence at the structural level (f square = 0.015. Hot temperatures not necessarily cause fatigue unless they alter a person's work duration. When workers are exposed to environments with high ISBB, their bodies experience heat stress. According to the theory, the human body naturally regulates its temperature to maintain core body temperature through sweating and increased heart rate.

If this heat exposure continues unchecked, workers will experience premature fatigue (heat exhaustion), dehydration, and even decreased cognitive function and motor skills. As a result of this reduced physical capacity and focus, the work pace significantly decreases. To complete the same volume of work, workers require more time than when working under ergonomic, comfortable conditions (neutral temperature). This is in line with the global physical risk mitigation document released by Masson-Delmotte et al. (2021) through the IPCC report, which emphasizes that increasing environmental temperature anomalies and heat waves in workplaces globally are directly proportional to a decrease in effective working hours and a loss of labor productivity in physical-based sectors (Masson-Delmotte, V., Zhai, P., Pirani, A., Connors et al., 2021). Charcoal workers said they work in hot climates but do not experience significant fatigue because they wait for the charcoal to cook by building huts near the stoves, which provide drinking and rest facilities. Researchers found that the work climate and fatigue variables were not significantly related.

5). Direct Effect of Age Variable on Duration of Work.

The results of the study show that the fifth hypothesis (H5) is accepted, namely there is a significant influence of age on the duration of work with a path coefficient (0.395) and p-value (0.043 < 0.05), directly positive. Each additional year of age influences the Duration of Work; within the 95% confidence interval, the effect lies between 0.112 and 0.812. However, the effect of age on the Duration of Work is moderate at the structural level (f-square = 0.097). These results provide clear confirmation that age is a significant factor in determining the duration of work assigned to a worker. As an individual ages, their work duration increases linearly. Theoretically, this positive relationship can be understood in terms of emotional maturity and career adaptation. Workers of a more mature (older) age have generally passed the phase of searching for a work identity and have a higher level of emotional stability, professional loyalty, and organizational commitment than younger workers, who tend to be more dynamic and adaptive to changes in the external environment (Staudinger et al., 2022). These psychological characteristics of senior workers make them more consistent and able to maintain long work durations in their daily routines (Charness & Burner, 2024).

However, the results of the effect size test indicate a medium effect size (Hair et al., 2021). This implies that although age significantly influences work duration, its contribution is not absolute or solely dominant in the structural model. This moderate relationship indicates that other variables beyond age, such as physical fitness level, health condition, work motivation, or family economic demands, simultaneously contribute to or interact in determining a person's total work duration in the field. The results of this study reinforce previous research findings that, as workers age, they develop better time management and self-regulation, thereby optimizing sustainable, productive work hours. According to the WHO, the working age is the duration of a worker's life measured sequentially from birth. WHO categorizes the human lifespan into several stages of development, both biological and social, from childhood to old age.

The working age range is Young/Early Workers (15-24 Years) and Adult Workers (25-64 Years) (Peng & Chan, 2022; Sgarbossa et al., 2024). Workers begin to experience a decline in physical capacity (such as decreased muscle strength and sensory acuity) and an

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increased risk of degenerative diseases that can affect OHS performance in the workplace. If workers work long hours while their age is categorized as mature, their age affects their ability to complete tasks, both in terms of physical strength and mental resilience. Physically, older workers are often weaker and tire easily, while younger workers are usually more energetic and active. Age-related changes in body tissues can reduce a person's strength and resilience, increasing the risk to their health (Fatmasari & Astuti, 2025; Fitriana, 2023). According to charcoal workers, the average age of the workers is adult, with no elderly members, and they are all still energetic. Researchers have observed that the average charcoal worker is between 23 and 50 years old.

6). Direct Effect of Age Variable on Work Fatigue.

The results of the study show that the sixth hypothesis (H6) is accepted, namely there is a significant influence of Age on Work Fatigue with a path coefficient (0.217) and p-value ($0.003 < 0.05$) directly and positively. As workers' age increases, the level of work fatigue experienced will also increase. In the 95% confidence interval, the magnitude of the influence of Age on Work Fatigue lies between 0.343 and 0.580. However, the Age on Work Fatigue variable has a strong influence at the structural level (f-square = 0.607). Age plays a very strong role. Theoretically and empirically, this study's results align with several studies that show that increasing age is often accompanied by a decline in physical and functional capacity (chronological aging), making older workers more susceptible to burnout when faced with the same workload as younger workers. However, psychologically, this could also be related to the accumulation of burnout that has persisted over many years in the same work environment (Ahola et al., 2012; Wijaya, A. & Saputra, 2022).

Work-related fatigue can also arise from psychological factors within the workplace. When fatigue reaches a certain level, it can lead to health problems for workers, such as work-related stress. Both workers and their organizations are at risk when workers experience fatigue, which can increase the likelihood of workplace accidents. An imbalance between task demands and the number of available workers can also lead to fatigue. Symptoms of work-related fatigue include muscle pain, tension, stiffness in various parts of the body, mental disturbances, and reduced attention or concentration at work. Fatigue is the body's way of protecting itself from further damage and

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allowing it to recover after rest. The brain deeply regulates fatigue through the central nervous system. While the effects of fatigue can vary from person to person, it can lead to decreased effectiveness, work capacity, and physical endurance (Cunningham et al., 2022b; Frasie et al., 2024; Pu et al., 2024; Rochmania et al., 2024).

According to research, work in the charcoal industry is labor-intensive and relies on manual muscle strength (lifting coconut shell sacks, moving raw materials, briquette molding, and packaging). Physiologically, aerobic capacity, muscle strength, and flexibility of the human body peak at 25–30 years and gradually decline thereafter (due to decreased muscle mass, or sarcopenia). Older workers must expend more energy to complete the same physical load as younger workers do. This decline in physical capacity is directly proportional to the accumulation of muscle fatigue, which can lead to occupational diseases.

7). Direct Effect of Hot Work Duration Variables on Work Fatigue.

The Seventh Hypothesis (H7) is accepted, namely there is a significant influence of work duration on work fatigue with a path coefficient (0.431) and p-value (0.000 < 0.05) directly. Any change in work duration will increase the impact of work fatigue. In the 95% confidence interval, the influence of work duration on work fatigue lies between 0.358 and 0.504. However, work duration on work fatigue has a strong influence at the structural level (f-square = 2.427). The need for companies or business owners to evaluate the current work duration. A good evaluation of work duration is considered very important in overcoming occupational diseases (PAK).

The Relationship between Work Duration and Work Fatigue: Work duration plays a crucial role in causing fatigue. If a worker works beyond the stipulated time, they will experience decreased work efficiency, increased work fatigue, workplace accidents, and occupational diseases. This is because the hours they work are in accordance with applicable regulations, which are not more than 8 hours per day (Peraturan Menteri Ketenagaan Kerja No. 5, 2018).

Worker fatigue can also be caused by insufficient rest time, as work duration approaches rest periods. Preventing fatigue is crucial because there is a relationship between the time spent working and fatigue levels. This is because work duration directly correlates with the quantity of workplace hazard exposure (exposure duration). The longer workers are in the production area, the longer they

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are exposed to the furnace's heat and dense carbon dust. Long work durations, due to forced, monotonous physical activity, trigger lactic acid buildup and shorten workers' recovery time. As a result, the body experiences chronic fatigue, manifested as decreased stamina and concentration at work.

One of the most effective ways to maintain or increase productivity in the workplace is to ensure that employees do not experience excessive fatigue so they can perform at their best. Workplace fatigue can be minimized in various ways, such as adjusting the workload to an individual's physical and mental abilities, choosing a more natural way of working, increasing mobility and variety in work, rethinking the design and arrangement of the workspace, and consuming nutritious food (Shiri et al., 2022; Sunaryo & Ratriwardhani, 2022; Wang et al., 2023).

According to researchers, charcoal workers must take regular breaks and change their working habits. If the working hours are too long, charcoal workers will experience acute muscle fatigue. Muscles forced to work for hours without sufficient rest will experience tremors, pain, and a drastic decrease in strength. The longer the working hours, the longer the worker's lungs are exposed to carbon dust (soot) and smoke from burning charcoal. Long working hours also prolong the body's exposure to heat stress from the charcoal kiln.

2. Indirect Effect

1). Indirect Effect of Sleep Quality Variables Through Work Duration on Work Fatigue.

The eighth hypothesis (H8) is accepted, where Work Duration acts as an Intervening variable that mediates the indirect influence of Sleep Quality through Work Duration on Work Fatigue, with a path coefficient (0.254) and p-value ($0.000 < 0.05$), where Sleep Quality and Work Duration together have a positive indirect effect on Work Fatigue. However, at the structural level, the mediating role of Work Duration is still relatively low (upsilon v = 0.064) (Ogbeibu et al., 2020). Within a 95% confidence interval, improvements in sleep quality consistently impact health through the Job Fatigue pathway. However, due to its small effect size (0.064), these improvements in sleep quality account for only 6.4% of the variance in sleep quality reduction through the Work Duration pathway.

This study empirically demonstrates that sleep quality and work duration jointly influence job fatigue, both positively and indirectly. This relationship suggests a psychophysiological domino effect in the

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workplace. When an employee experiences decreased sleep quality (restless sleep, frequent awakenings, or insomnia), their physical condition and cognitive function in the morning are impaired (Akerstedt & Wright, 2009). This decrease in concentration and stamina reduces work efficiency. To complete the same volume or target of work, sleep-deprived workers require longer than usual. This condition forces extended work hours (for example, through overtime or delayed start times). This long work time allocation, exceeding the normal threshold, ultimately drains workers' remaining energy and results in massive accumulation of job fatigue, both physical and emotional (Barnes, 2012).

Work duration is not the only pathway through which poor sleep quality triggers fatigue. Poor sleep quality is thought to have a much more direct and powerful pathway to damaging workers' psychological well-being (such as triggering work stress, anxiety, and decreased motivation) without necessarily requiring extended work duration. In the agency/company where this research was conducted, rules regarding working hours (e.g., 9-to-5 system or maximum overtime limit rules) are strictly enforced (Undang-Undang RI, 1970). These structural constraints severely limit the variation in workers' work duration. Even if workers' sleep quality is poor and their workload is slow, they cannot increase their work hours at will due to the restrictions imposed by the company's official attendance system (Suma'mur, 2023). Even if employees experience sleep disturbances, they tend to engage in active compensatory strategies at work to maintain performance, such as increasing caffeine intake, taking short breaks, or focusing more on critical tasks (Maharani & Nugroho, 2022; Nurmayanti & Hermiyanti, 2024; Sari et al., 2025). This compensation successfully prevents the work duration from increasing too much, thereby suppressing the effect size value of this mediator variable.

2). Indirect Effect of Hot Work Climate Variables Through Work Duration on Work Fatigue.

The ninth hypothesis (H9) is accepted, where work duration acts as an intervening variable that mediates the indirect effect of Hot Work Climate through Work Duration on Work Fatigue, with a path coefficient (0.114) and p-value ($0.005 < 0.05$). where Hot Work Climate and Work Duration jointly affect Work Fatigue. Theoretically, these results explain the existence of a physical adaptation mechanism for workers that

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impacts their time management. Exposure to a hot work environment above the threshold value (NAB) can increase heat strain on the worker's body, leading to decreased stamina, dehydration, and reduced physical and mental work capacity (Suma'mur, 2023). When workers are fatigued by extreme temperatures, their speed and effectiveness in completing daily tasks will slow. However, at the structural level, the mediating role of Work Duration is still relatively low (upsilon v = 0.012) (Ogbeibu et al., 2020). Within the 95% confidence interval, it was found that if improvements were made to the Work Climate, the contribution to reducing work fatigue through the Work Duration channel would be only 2.3%.

This suggests that the duration of the work is not the dominant factor in the intervention. Therefore, occupational health strategies should not focus solely on work duration, but rather on other, more potent risk factors arising directly from the work environment. As a result of this decline in productivity, workers are forced to allocate longer hours to complete the same targets or volume of work. This condition triggers an increase in work duration (for example, through extended overtime or delayed leave times due to unfinished tasks) (Tarwaka, 2022). Work fatigue can be caused by the accumulation of physical environmental loads that are not balanced with recovery time (Suma'mur, 2023). Longer working hours, coupled with continuous exposure to hot environmental temperatures without adequate recovery time, cumulatively accelerate the onset of severe job fatigue.

A hot physical environment generally directly attacks human physiology instantly (such as increased heart rate, excessive sweating, and dizziness) which immediately triggers physical fatigue, without having to wait for the worker's work duration to become long first, in other words, a Hot Work Climate has a much more dominant direct influence on Work Fatigue compared to its indirect influence through Work Duration (Salanova & Llorens, 2021). According to researchers, working in a hot environment will affect workers' health, leading to fatigue that, if not managed properly, can further impact workers' health, cause dehydration, and even lead to other occupational diseases. Charcoal workers also said that their work is long because they have to keep the fire from going out, so they use a strategy: changing the wood to keep it burning and always consuming plenty of water.

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3). Indirect Effect of Age Variable Through Work Duration on Work Fatigue.

The tenth hypothesis (H10) is rejected, as the duration of work serves as an intervening variable that mediates the indirect effect of age on work fatigue, with the path coefficient on the indirect effect equal to 0.221. However, the significance value (p-value) is 0.058, which is greater than the significance threshold of 0.05. Thus, in purely structural statistics, the hypothesis stating that work duration mediates the indirect effect of age on work fatigue is rejected or is not significant. However, when viewed from the effect size approach, mediation (Ogbeibu et al., 2020). The resulting Upsilon value is 0.097. This figure indicates that Work Duration has low to moderate explanatory power (effect size) in explaining the relationship between age and work fatigue. The p-value approaching the critical limit (0.058 > 0.05) indicates a marginal effect or a tendency toward mediation that is not yet strong enough to be declared statistically significant in this study sample

The research confirms that changes in worker age do not automatically create a significant linear pattern in work duration, leading to worker fatigue. Theoretically, increasing worker age is generally accompanied by a natural decline in physical capacity (biological aging), decreased resistance to heavy workloads, and an increased need for biological recovery (Suma'mur, 2023). On the other hand, older workers typically have advantages in terms of work experience and emotional maturity. This greater experience enables senior workers to develop more effective coping mechanisms for completing tasks efficiently (Tarwaka, 2022). According to researchers, the insignificant difference was due to the rigidity of the work-hour policy. At the research location, the work duration (start time, end time, and overtime allowance) was not regulated, regardless of employee age. Both young and older workers were required to adhere to the same work duration standards.

The lack of variation in the allocation of working time across age groups means the Work Duration fails to serve as a statistically significant bridge (mediator). Next is Work Experience Compensation: Although older workers are more susceptible to fatigue, the work efficiency gained from years of experience enables them to complete tasks on time without the need for extended working hours (overtime). Conversely, younger workers who are physically stronger may need the same or even longer working duration because they are still in the technical

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adaptation phase. This breaks the chain of theoretical reasoning that increasing age will linearly increase working duration. This lack of significance is likely due to the limited number of samples or the lack of distribution of senior workers in this study, so that the effect of mediation cannot be detected robustly using statistical tests (Lachowicz et al., 2023).

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the cross-sectional design captures relationships at a single point in time. It therefore does not permit firm causal inference regarding the effects of sleep quality, hot work climate, age, and work duration on work fatigue. Second, data were collected from charcoal workers at a single location in Batam City using total sampling, which limits the generalisability of the results to other regions and industries. Third, the key variables were measured using self-reported questionnaires, which may introduce recall and social-desirability bias; objective measures, such as WBGT for heat exposure or actigraphy for sleep, were not used. Finally, the relatively small sample and the limited representation of older workers may have reduced the statistical power to detect the mediating effect of work duration in the age–fatigue relationship (H10). Future research should employ longitudinal or multi-site designs, incorporate objective measurements, and use larger, more age-diverse samples to strengthen causal interpretation.

5. CONCLUSION

This study demonstrates that sleep quality, hot work climate, age, and work duration significantly influence work fatigue among charcoal workers. Sleep quality emerged as the strongest predictor of work fatigue ($\beta = 0.618$, $p < 0.001$), followed by work duration ($\beta = 0.431$, $p < 0.001$). Hot work climate significantly affected work duration ($\beta = 0.264$, $p = 0.002$) but showed no direct effect on work fatigue ($\beta = 0.027$, $p = 0.354$).

Importantly, work duration functions as a full mediator between hot work climate and work fatigue ($\beta = 0.114$, $p = 0.005$), indicating that environmental heat exposure increases fatigue primarily through prolonged work time. Conversely, work duration did not significantly mediate the age–fatigue relationship ($\beta = 0.221$, $p = 0.058$), suggesting age affects fatigue through direct physiological pathways rather than work duration.

This study extends the Conservation of Resources (COR) and Job Demands–

Resources (JD-R) theories to the under-researched context of informal charcoal workers. We provide empirical evidence that: (1) environmental stressors (heat) operate through temporal mechanisms (extended work duration) to deplete workers' resources, and (2) personal resources (sleep quality) serve as the primary buffer against fatigue, outweighing demographic factors. These findings clarify the distinct pathways through which environmental and individual factors influence occupational health outcomes in extreme working conditions.

AUTHOR CONTRIBUTIONS

N contributed to the development of research concepts, data collection, data processing and analysis, interpretation of research results, preparation and revision of the article manuscript. RDRP, RW, CPAPA & SCA, contributed to research supervision. LU & N, preparation of research methodology, validation of data analysis. UA & J contributed to revision and refinement of the article manuscript

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest in this research.

DATA AVAILABILITY STATEMENT

The data the findings of this research are available from the corresponding author upon reasonable request.

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