Reaction Time-Based Fatigue Analysis in Construction Workers

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Abstract—Occupational fatigue in construction projects remains a critical safety issue, yet its assessment is commonly based on subjective questionnaires and interviews that may not accurately reflect real-time physiological performance. This study aimed to analyze the relationship between biological factors and work-related factors and the level of work fatigue among construction workers using Digital Reaction Timer measurement as an objective indicator. A cross-sectional study was conducted involving active construction workers, where fatigue was quantified using a digital reaction timer as an objective human performance indicator. Biological factors such as age, gender, sleep duration, and nutritional status, as well as work-related factors including working hours, shift patterns, workload, and work experience, were statistically analyzed against reaction time results. The findings show that reaction time measurement can differentiate fatigue levels and identify significant determinants affecting performance degradation. Several biological and occupational variables were associated with increased reaction time, indicating higher fatigue levels. The results demonstrate that an engineering-based digital measurement approach provides a more objective and quantifiable fatigue assessment compared to traditional self-reported methods, supporting data-driven safety management in high-risk construction environments.

Keywords—Biological factor, Construction workers, Digital Reaction Timer, Occupational factors, Work fatigue

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I. INTRODUCTION

Thermal Work fatigue has become a pervasive occupational health problem across various industrial sectors and reflects increasing physical and cognitive demands in contemporary work environments [1]. Fatigue is widely understood as a multidimensional condition that reduces physical capacity, impairs mental functioning, and lowers overall work performance [2]. Cognitive consequences of fatigue include decreased attention, slower reaction time, and impaired decision-making, which significantly elevate the probability of human error and occupational accidents [3]. Sustained exposure to high workload combined with insufficient recovery facilitates the accumulation of acute fatigue and its progression into chronic fatigue [4]. Chronic fati gue is strongly associated with long-term health impairment, reduced productivity, and deterioration of workers' quality of life [5].

Available quantitative evidence consistently demonstrates that work fatigue represents a substantial occupational health burden at global, national, and sectoral levels. Reports from the International Labour Organization indicate that approximately 2.78 million workers die annually due to occupational accidents and work-related diseases, while more than 374 million non-fatal occupational injuries occur each year, highlighting the large scale of work-related health problems closely linked to fatigue [6]. In Indonesia, occupational health surveillance data reveal that more than 65 percent of workers who visit occupational clinics report fatigue-related complaints, indicating fatigue as one of the most dominant occupational health problems [7].

Work fatigue is not a singular phenomenon but emerges from the interaction of multiple determinants that operate at both individual and occupational levels, indicating that fatigue should be understood as a multifactorial condition rather than an isolated outcome. Internal determinants, commonly referred to as biological factors, include age, gender, sleep quality, and nutritional status, all of which influence physiological capacity, recovery processes, and vulnerability to physical and mental exhaustion [8]. Increasing age is associated with reduced muscular endurance and slower physiological recovery, while gender differences reflect both biological characteristics and differential exposure to job demands [9]. Sleep quality plays a critical role in restoring cognitive and physical functions, where poor or insufficient sleep significantly accelerates fatigue accumulation [10]. Nutritional status further determines energy availability and metabolic efficiency, with abnormal nutritional conditions increasing susceptibility to fatigue during physically demanding tasks [11]. External determinants, or work-related factors, include shift work, long working hours, work experience, and workload, which directly shape exposure to physical strain and psychological stress [12]. Prolonged work experience in repetitive and monotonous tasks contributes to chronic fatigue, particularly when combined with heavy workload and limited rest [13]. Understanding the combined influence of biological and work-related factors is therefore essential, as fatigue arises from the dynamic interaction between individual physiological vulnerability and occupational exposure, making integrated assessment crucial for effective fatigue management and prevention strategies.

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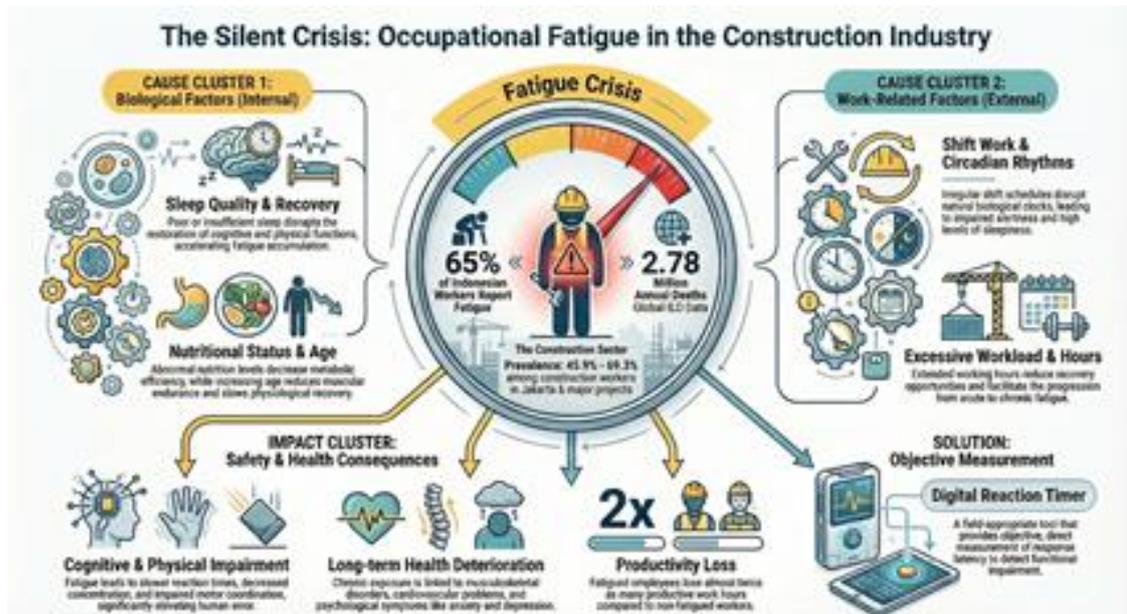
International Journal of Marine Engineering Innovation and Research, Vol. 11(1), Mar. 2026. 223-232
(pISSN: 2541-5972, eISSN: 2548-1479)

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Figure 1. Occupational Fatigue in Construction Industry

The Digital Reaction Timer provides a practical solution by enabling direct measurement of workers' response latency to visual stimuli, offering an objective, simple, and field-appropriate method for detecting fatigue-related functional impairment, making it particularly suitable for construction environments where rapid assessment and minimal operational disruption are essential. However, empirical evidence integrating objective reaction-time-based fatigue assessment with the analysis of both biological and work-related determinants among construction workers remains limited, particularly within the Indonesian construction context. Therefore, this study aims to examine the relationship between biological factors and work-related factors and the level of work fatigue among construction workers using Digital Reaction Timer measurement as an objective indicator.

1. Literature Review
1.1 Grand Theory: Fatigue Model Theory and Human Performance Theory in Occupational Fatigue Assessment

This study is grounded in two major theoretical frameworks that explain the emergence of work fatigue, namely Fatigue Model Theory and Human Performance Theory. Fatigue Model Theory conceptualizes fatigue because of an imbalance between workload demands and the body's recovery capacity, where prolonged exposure to physical and cognitive load without adequate rest leads to progressive decline in physiological and psychological functioning [17]. This theory directly supports the role of work-related factors such as shift work, working hours, work experience, and workload in influencing fatigue levels, as these factors determine the intensity and duration of occupational demands. Human Performance Theory further explains that fatigue reduces the efficiency of human information processing systems, leading to slower reaction time, impaired attention, and

decreased motor coordination, which collectively degrade work performance and safety [1],[2]. Within this framework, biological factors such as age, gender, sleep quality, and nutritional status are viewed as individual capacity modifiers that shape how workers respond to job demands and recover from fatigue [18]. The integration of both theories provides a comprehensive conceptual foundation for this study, where work fatigue is understood as a dynamic outcome of interaction between individual physiological vulnerability and occupational exposure, and objectively manifested through reaction time performance measured using Digital Reaction Timer.

1.2 Variable Framework within Occupational Fatigue Theory

This study conceptualizes work fatigue as a multidimensional condition involving a decline in physical and cognitive functioning resulting from prolonged workload and insufficient recovery, which manifests in decreased psychomotor performance such as slower reaction time and impaired attention [1],[2]. Work fatigue is influenced by both biological and occupational determinants. Biological factors reflect individual physiological capacity and recovery potential, including age, gender, sleep quality, and nutritional status, which shape vulnerability to fatigue accumulation. Work-related factors represent external occupational exposures such as shift work, working hours, work experience, and workload, which determine the intensity and duration of physical and cognitive demands placed on workers. Within this framework, work fatigue is operationalized as an objective performance outcome measured through reaction time using a Digital Reaction Timer, which captures psychomotor slowing as a direct indicator of functional impairment [19].
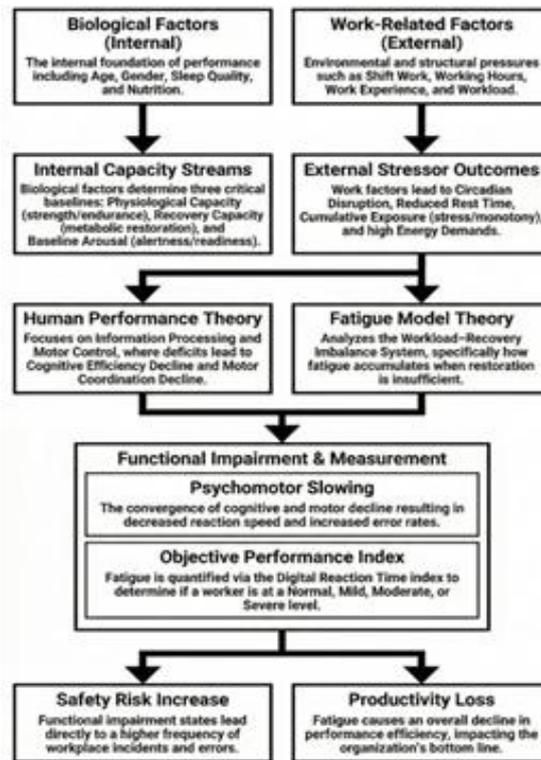
International Journal of Marine Engineering Innovation and Research, Vol. 11(1), Mar. 2026. 223-232
(pISSN: 2541-5972, eISSN: 2548-1479)

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Figure 2. Theoretical Framework

1.3 Research Hypotheses

This study is developed based on the theoretical framework and empirical evidence that suggest work fatigue is influenced by both biological and occupational determinants. Biological factors are assumed to shape individual physiological capacity and recovery ability, while work-related factors determine exposure to physical and cognitive workload. Therefore, the hypotheses in this study are formulated to examine the direct effects of each independent variable on the level of work fatigue among construction workers.
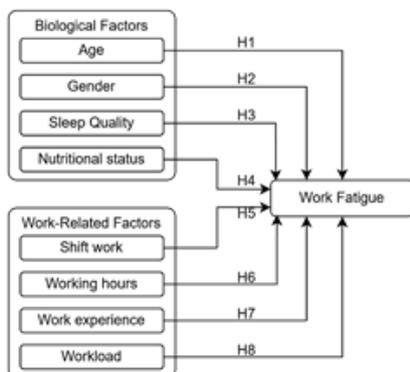

Figure 3. Hypothesis Framework

Hypotheses:

H1: Age is significantly associated with the level of work fatigue among construction workers.

H2: Gender is significantly associated with the level of work fatigue among construction workers.

H3: Sleep quality is significantly associated with the level of work fatigue among construction workers.

H4: Nutritional status is significantly associated with the level of work fatigue among construction workers.

H5: Shift work is significantly associated with the level of work fatigue among construction workers.

H6: Working hours are significantly associated with the level of work fatigue among construction workers.

H7: Work experience is significantly associated with the level of work fatigue among construction workers.

H8: Workload is significantly associated with the level of work fatigue among construction workers.

II. METHOD

A. Research Design

This study employed a quantitative cross-sectional research design to analyze the relationship between biological factors, work-related factors, and the level of work fatigue among construction workers. The study aimed to identify determinants that influence fatigue by using reaction time as an objective indicator of worker performance. A cross-sectional approach was considered appropriate because the variables were observed and measured at a single point in time among active workers at the project site. *Population, Sample, and Sampling Technique*

The population of this study consisted of all construction workers involved in the project at PT PP Rumah Sakit Jantung Harapan Kita. The sampling technique used was total sampling, in which all workers who met the inclusion criteria were selected as research participants. Data collection was conducted across two work shifts, namely the day shift and the night shift, with 23 workers measured during the day shift and 16 workers measured during the night shift. The total number of respondents included in the analysis was 39 workers. Total sampling was applied to ensure

comprehensive representation of the target population and to minimize sampling bias, given the relatively limited number of available workers at the project site.

B. Data, Data Collection Techniques, and Research Instrument

This study utilized primary data collected directly from respondents through objective measurement and structured questionnaires. Data collection aimed to obtain information on biological factors, work-related factors, and work fatigue levels. Biological and work-related variables were collected using a standardized questionnaire administered to all participants, while work fatigue was measured using a Digital Reaction Timer as an objective performance-based instrument. The data collection instruments used in this study are presented in Table 3.1.

TABLE 3. 1
RESEARCH VARIABLES, INSTRUMENT, AND MEASUREMENT METHODS

Variable	Instrument	Data Type	Measurement Method
Age	Questionnaire	Numerical	Years
Gender	Questionnaire	Categorical	Male/Female
Sleep Quality	Questionnaire	Ordinal	PSQI score
Nutritional Status	Anthropometric measurement	Numerical	BMI
Shift Work	Questionnaire	Categorical	Day/Night
Working Hours	Questionnaire	Numerical	Hours per day
Work Experience	Questionnaire	Numerical	Years
Workload	Observation/Questionnaire	Ordinal	Light/Moderate/Heavy
Work Fatigue	Digital Reaction Timer	Numerical	Reaction time in ms

C. Data Analysis Technique

Data analysis in this study consisted of descriptive and inferential statistical procedures. Descriptive analysis was conducted to summarize respondent characteristics and variable distributions using frequency tables, percentages, and cross-tabulations. Cross-tabulation was applied to describe the distribution of work fatigue levels across categories of biological and work-related factors. Inferential analysis was performed using the Chi-square test to examine the associations between independent variables and work fatigue levels. The Chi-square test was selected because the variables were measured on categorical and ordinal scales, and the research objective focused on identifying statistically significant relationships rather than causal. effects. The level of statistical significance was set at $p < 0.05$. All data analyses were conducted using statistical software to ensure accuracy and reliability of results.

III. RESULTS AND DISCUSSION

3.1 Descriptive Analysis of Independent Variables

This section presents the descriptive analysis of independent variables in this study, which consist of biological factors and work-related factors. The purpose of this analysis is to describe the distribution of respondent characteristics that may influence the level of work fatigue among construction workers.

3.1.1 Descriptive Analysis of Biological Factors

This subsection describes the distribution of respondents based on biological characteristics, including age, gender, sleep quality, and nutritional status. These variables represent individual physiological and behavioral conditions that may affect workers' endurance, recovery capacity, and susceptibility to work fatigue.

TABLE 4.4
DISTRIBUTION OF RESPONDENTS BASED ON BIOLOGICAL FACTORS

No.	Variable	Category	Frequency (n)	Percentage (%)
1	Age (X1)	<30 years	14	35.9
		31-40 years	15	38.5
		>40 years	10	25.6
2	Gender (X2)	Male	36	92.3
		Female	3	7.7
3	Sleep Quality (X3)	Good (≤5)	13	33.3
		Poor (>5)	26	66.7
4	Nutritional Status (X4)	Underweight (<18.5)	4	10.3
		Normal (18.5–24.9)	21	53.8
		Overweight (≥25)	14	35.9
		Total	39	100

The age distribution shows that most workers were in the productive age group, with the largest proportion belonging to the 31–40 years category (38.5%), followed by workers aged 30 years or below (35.9%) and those above 40 years (25.6%). This pattern reflects a relatively balanced age composition, although a substantial proportion of workers were in the older age group, which may imply reduce physiological capacity and slower recovery potential. In terms of gender, the workforce was heavily dominated by male workers (92.3%), which is typical in construction settings where tasks are physically demanding and male labor is predominant. Regarding sleep quality, more than two-thirds of respondents (66.7%) reported poor sleep quality,

International Journal of Marine Engineering Innovation and Research, Vol. 11(1), Mar. 2026. 223-232
(pISSN: 2541-5972, eISSN: 2548-1479)

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indicating insufficient recovery and a high risk of cumulative fatigue. Nutritional status analysis revealed that over half of the workers (53.8%) had normal BMI, while a considerable proportion were classified as overweight (35.9%), and a smaller group were underweight (10.3%). These findings suggest that although most workers had acceptable nutritional status, a significant number may experience metabolic or energy balance issues that potentially exacerbate fatigue vulnerability. This finding indicates that biological characteristics play an important role in determining the fatigue level of construction workers. Biological factors such as age, physical condition, and body capacity influence the body's ability to maintain alertness and reaction speed during work activities. Workers with

decreased physiological capacity tend to experience slower reaction responses, which indicate higher fatigue levels. In the construction industry, where tasks often involve physical exertion and environmental exposure, the influence of biological factors becomes more pronounced.

3.1.2 Descriptive Analysis of Work-Related Factors

This subsection presents the distribution of respondents based on work-related characteristics, including shift work, working hours, work experience, and workload. These variables describe the occupational conditions that determine exposure to physical and mental demands and may contribute significantly to the level of work fatigue among construction workers.

TABLE 4.5
DISTRIBUTION OF RESPONDENTS BASED ON WORK-RELATED FACTORS

No.	Variable	Category	Frequency (n)	Percentage (%)
1	Shift Work (X5)	Day shift	23	59.0
		Night shift	16	41.0
2	Working Hours (X6)	≤8 hours	14	35.9
		>8 hours	25	64.1
3	Work Experience (X7)	≤5 years	17	43.6
		>5 years	22	56.4
4	Workload (X8)	Light	6	15.4
		Moderate	21	53.8
		Heavy	12	30.8
		Total	39	100

The distribution of work shifts shows that most respondents worked during the day shift (59.0%), while a substantial proportion were assigned to the night shift (41.0%), indicating that a significant number of workers were exposed to non-standard working hours. Regarding working hours, most respondents (64.1%) reported working more than eight hours per day, reflecting extended working schedules that may reduce recovery opportunities and increase cumulative fatigue risk. In terms of work experience, more than half of the workers (56.4%) had been employed for more than five years, suggesting prolonged occupational exposure to physically demanding tasks. Analysis of workload revealed that the majority of workers experienced moderate workload (53.8%), while nearly one-third (30.8%) were subjected to heavy workload, and only a small proportion (15.4%) performed light tasks. This pattern indicates that most respondents were consistently

exposed to moderate to high should be presented in a straightforward and concise physical demands, which may substantially contribute to the development and persistence of work fatigue in the construction environment.

3.2 Descriptive Analysis of Work Fatigue Levels

This section presents the descriptive analysis of work fatigue levels among construction workers based on Digital Reaction Timer measurement. The analysis aims to describe the distribution of fatigue categories across both work shifts, namely day shift and night shift. Fatigue levels were classified into four categories, namely normal, mild, moderate, and severe, based on reaction time thresholds. Descriptive statistics were used to summarize the prevalence of fatigue and to provide an overall picture of workers' physiological and cognitive condition during field operations.

TABLE 4.6
SUMMARY OF WORK FATIGUE LEVELS AND REACTION TIME STATISTICS BY WORK SHIFT

Fatigue Level	Work Shift	n (%)	Lowest Score (ms)	Highest Score (ms)	Mean (ms)	Range (ms)
Mild	Day Shift	11 (47.8%)	291.6	409.7	355.4	118.1
	Night Shift	5 (31.3%)	336.9	407.0	366.1	70.1
	Total	16 (41.0%)	291.6	409.7	359.0	118.1
Moderate	Day Shift	11 (47.8%)	450.6	544.7	488.6	94.1
	Night Shift	9 (56.3%)	411.6	531.9	475.0	120.3
	Total	20 (51.3%)	411.6	544.7	482.1	133.1
Severe	Day Shift	1 (4.3%)	584.2	584.2	584.2	0
	Night Shift	2 (12.5%)	727.9	754.6	741.3	26.7
	Total	3 (7.7%)	584.2	754.6	693.6	170.4

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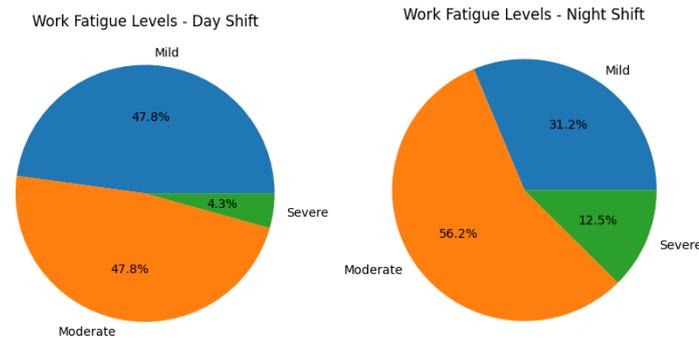*(pISSN: 2541-5972, eISSN: 2548-1479)*

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Figure 4. Work Fatigue Levels

3.3 Cross-Tabulation and Chi-Square Analysis of Independent Variables and Work Fatigue
3.3.1 Relationship between Biological Factors and Work Fatigue

This section presents the bivariate analysis between biological factors and work fatigue levels using cross-tabulation and Chi-square test. The analysis aims to determine whether age, gender, sleep quality, and nutritional status are statistically associated with work fatigue among construction workers.

TABLE 4.7
CROSS-TABULATION BETWEEN AGE AND WORK FATIGUE

Age Category	Mild	Moderate	Severe	Total	p-value	Result
≤30 years	8	5	1	14	0.032	Significant
31–40 years	5	9	1	15		
>40 years	3	6	1	10		
Total	16	20	3	39		

a. Age and Work Fatigue

The Chi-square analysis indicates a statistically significant relationship between age and work fatigue (p = 0.032). Younger workers aged 30 years or below tended to experience lower fatigue levels, with the majority classified as mild fatigue. In contrast, workers aged above 30 years showed higher proportions of moderate and severe fatigue. This pattern suggests that increasing age is associated with reduced physiological resilience and slower recovery capacity, which increases vulnerability to fatigue accumulation. These findings support the theoretical assumption that age influences endurance and neuromuscular efficiency. Older workers may require longer recovery periods and experience faster exhaustion when exposed to prolonged physical workload. In construction settings where physical demands are high, age becomes a critical determinant of fatigue and severity. These results are consistent with previous studies which reported that increasing age is associated with reduced neuromuscular response speed and decreased cognitive alertness. As workers age, physiological changes in the nervous and muscular systems may reduce the ability to respond quickly to external stimuli. This condition may lead to slower reaction times and increased susceptibility to work fatigue, particularly in physically demanding occupations such as construction work.

TABLE 4.8
CROSS-TABULATION BETWEEN GENDER AND WORK FATIGUE

Gender	Mild	Moderate	Severe	Total	p-value	Result
Male	15	18	3	36	0.684	Not significant
Female	1	2	0	3		
Total	16	20	3	39		

b. Gender and Work Fatigue

The Chi-square test shows no statistically significant relationship between gender and work fatigue (p = 0.68). Both male and female workers exhibited similar distributions of fatigue levels, with moderate fatigue being the dominant category. This result indicates that gender does not play a decisive role in determining fatigue levels in this study context. The lack of significance may be attributed to the relatively homogeneous nature of job tasks performed by workers regardless of gender, as well as the limited number of female workers in the sample.

International Journal of Marine Engineering Innovation and Research, Vol. 11(1), Mar. 2026. 223-232
(pISSN: 2541-5972, eISSN: 2548-1479)

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TABLE 4.9
CROSS-TABULATION BETWEEN SLEEP QUALITY AND WORK FATIGUE

Sleep Quality	Mild	Moderate	Severe	Total	p-value	Result
Good	9	4	0	13	0.004	Significant
Poor	7	16	3	26		
Total	16	20	3	39		

c.   Sleep Quality and Work Fatigue.

The Chi-square analysis reveals a statistically significant association between sleep quality and work fatigue (p = 0.004). Workers with good sleep quality were predominantly classified in the mild fatigue category, whereas those with poor sleep quality exhibited much higher proportions of moderate and severe fatigue. This finding confirms that sleep quality plays a crucial role in physiological and cognitive recovery. Poor sleep reduces restorative processes and leads to cumulative fatigue, which directly impairs reaction time and functional performance. In physically demanding work environments, insufficient sleep substantially increases fatigue and severity.

TABLE 4.10
CROSS-TABULATION BETWEEN NUTRITIONAL STATUS AND WORK FATIGUE

Nutritional Status	Mild	Moderate	Severe	Total	p-value	Result
Underweight	2	2	0	4	0.412	Not significant
Normal	9	11	1	21		
Overweight	5	7	2	14		
Total	16	20	3	39		

d.   Nutritional Status and Work Fatigue

The Chi-square test indicates no statistically significant relationship between nutritional status and work fatigue (p = 0.412). Although workers with overweight status showed slightly higher proportions of moderate and severe fatigue, the difference across categories was not statistically meaningful. This result suggests that nutritional status alone does not directly determine fatigue levels in this sample. Other factors such as workload intensity, sleep quality, and working hours may exert stronger influence than body mass index. Nutritional status may function as a background health condition rather than a primary fatigue determinant in construction work contexts.

3.3.2 Relationship between Work-Related Factors and Work Fatigue

This section presents the bivariate analysis between work-related factors and work fatigue levels using cross-tabulation and Chi-square test. The analysis aims to determine whether shift work, working hours, work experience, and workload are statistically associated with work fatigue among construction workers.

TABLE 4.11
CROSS-TABULATION BETWEEN SHIFT WORK AND WORK FATIGUE

Shift Work	Mild	Moderate	Severe	Total	p-value	Result
Day shift	11	11	1	23	0.041	Significant
Night shift	5	9	2	16		
Total	16	20	3	39		

a. Shift Work and Work Fatigue

The Chi-square analysis indicates a statistically significant relationship between shift work and work fatigue (p = 0.041). Night shift workers showed a higher proportion of moderate and severe fatigue compared to day shift workers. While nearly half of day shift workers experienced mild fatigue, most night shift workers were classified in the moderate fatigue category. This finding suggests that night work increases fatigue severity due to disruption of circadian rhythms, reduced sleep quality, and prolonged exposure to physical workload during biologically suboptimal hours. Working at night impairs alertness and recovery, making workers more vulnerable to cumulative fatigue.

TABLE 4.12
CROSS-TABULATION BETWEEN WORKING HOURS AND WORK FATIGUE

Working Hours	Mild	Moderate	Severe	Total	p-value	Result
≤8 hours	9	5	0	14	0.018	Significant
>8 hours	7	15	3	25		
Total	16	20	3	39		

b. Working Hours and Work Fatigue.

The Chi-square test shows a statistically significant association between working hours and work fatigue (p = 0.018). Workers who worked more than eight hours per day experienced substantially higher levels of moderate and severe fatigue compared to those working within standard hours. This result indicates that extended working duration reduces recovery opportunities and

International Journal of Marine Engineering Innovation and Research, Vol. 11(1), Mar. 2026. 223-232
(pISSN: 2541-5972, eISSN: 2548-1479)

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accelerates fatigue accumulation. Long working hours increase both physical and cognitive demands, which directly impairs psychomotor performance and reaction speed. Work-related factors such as working hours and workload also contribute significantly to fatigue development. Prolonged working hours may reduce recovery time and increase cumulative fatigue during the work shift. In construction environments, workers are frequently exposed to repetitive tasks, physical strain, and environmental stressors, which can accelerate the onset of fatigue. Therefore, managing work duration and workload distribution is essential to maintain worker performance and safety.

TABLE 4.13
CROSS-TABULATION BETWEEN WORK EXPERIENCE AND WORK FATIGUE

Work Experience	Mild	Moderate	Severe	Total	p-value	Result
≤5 years	8	8	1	17	0.527	Not significant
>5 years	8	12	2	22		
Total	16	20	3	39		

c. Work Experience and Work Fatigue

The Chi-square analysis indicates no statistically significant relationship between work experience and work fatigue (p = 0.527). Both groups exhibited similar distributions of fatigue levels, with moderate fatigue being the dominant category. This finding suggests that length of employment alone does not determine fatigue severity. Workers may develop adaptation strategies over time, while new workers may experience fatigue due to lack of physical conditioning, resulting in relatively balanced fatigue levels across experience groups.

TABLE 4.14
CROSS-TABULATION BETWEEN WORKLOAD AND WORK FATIGUE

Workload	Mild	Moderate	Severe	Total	p-value	Result
Light	5	1	0	6	0.009	Significant
Moderate	8	11	2	21		
Heavy	3	8	1	12		
Total	16	20	3	39		

d. Workload and Work Fatigue

The Chi-square test reveals a statistically significant relationship between workload and work fatigue (p = 0.009). Workers exposed to heavy workload showed higher proportions of moderate and severe fatigue compared to those performing light tasks. This result confirms that physical and mental demands play a critical role in fatigue development. Increased workload requires greater energy expenditure, prolonged muscle activation, and sustained cognitive effort, which directly contributes to faster exhaustion and reduced functional performance.

The extended descriptive analysis shows that moderate fatigue was the most dominant category, affecting more than half of the workers (51.3%), followed by mild fatigue (41.0%), while severe fatigue was observed in a smaller proportion of respondents (7.7%). In the mild fatigue category, reaction time ranged from 291.6 ms to 409.7 ms, with an overall mean of 359.0 ms, indicating moderate psychomotor slowing. In the moderate fatigue category, reaction time increased substantially, with values ranging from 411.6 ms to 544.7 ms and a mean of 482.1 ms, reflecting marked functional impairment. The severe fatigue category exhibited the most extreme reaction time values, with a minimum of 584.2 ms and a maximum of 754.6 ms, resulting in an overall mean of 693.6 ms, which indicates critical degradation in cognitive and motor responsiveness.

Comparatively, night shift workers consistently showed higher maximum scores and wider ranges, particularly in the moderate and severe categories, suggesting greater variability and higher fatigue severity under nocturnal working conditions.

An important contribution of this study lies in the use of a digital reaction timer as an objective tool for measuring work fatigue. Unlike conventional approaches that rely on subjective assessments such as questionnaires or interviews, reaction time measurement provides a more direct indication of cognitive and psychomotor performance. Slower reaction times reflect decreased alertness and delay neural response, which are commonly associated with fatigue conditions. Therefore, the use of digital reaction timer measurement can provide more reliable data for evaluating fatigue levels among construction workers. From an occupational engineering perspective, the findings of this study provide practical implications for fatigue management in construction projects. Monitoring worker fatigue using objective measurement tools such as digital reaction timers can support early detection of fatigue conditions. This approach may assist project managers and safety officers in implementing preventive strategies, such as optimizing work schedules, improving rest periods, and adjusting workload distribution to reduce fatigue-related risks in construction workplaces.

This study has several limitations that should be acknowledged. First, the sample size was relatively small and limited to a single construction project, which may restrict the generalizability of the findings. Second, the

International Journal of Marine Engineering Innovation and Research, Vol. 11(1), Mar. 2026. 223-232
(pISSN: 2541-5972, eISSN: 2548-1479)

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cross-sectional design only captures fatigue conditions at one point in time and does not reflect long-term fatigue accumulation. Future research is recommended to involve larger samples and longitudinal measurements to better understand fatigue dynamics in construction environments. In addition, future research could integrate environmental and ergonomic factors such as temperature exposure, work posture, and task intensity to obtain a more holistic assessment of fatigue risk. The integration of digital fatigue monitoring tools with occupational safety management systems may also provide valuable insights for improving fatigue prevention strategies in construction workplaces.

IV. CONCLUSION

This study aimed to analyze the relationship between biological factors and work-related factors and the level of work fatigue among construction workers using Digital Reaction Timer measurement as an objective indicator. This study confirms that biological factors such as age and work-related factors such as working hours significantly influence work fatigue among construction workers. The use of digital reaction timer provides an objective measurement of fatigue levels and can be applied in occupational safety monitoring. The results of this study indicate that both biological factors and work-related factors have a significant relationship with the level of work fatigue among construction workers. Biological characteristics such as age and physical capacity influence the workers' ability to maintain alertness and respond to stimuli, while work-related factors including working hours and workload contribute to the accumulation of fatigue during work activities.

The results showed that most workers experienced moderate fatigue (51.3%), followed by mild fatigue (41.0%), while severe fatigue was found in 7.7% of respondents. Reaction time measurements indicated that fatigue levels increased as reaction time values became longer, demonstrating measurable deterioration in psychomotor performance among workers. The bivariate analysis revealed that several variables were significantly associated with work fatigue. Among the biological factors, age ($p = 0.032$) and sleep quality ($p = 0.004$) showed significant relationships with fatigue levels. Workers of older age groups and those with poor sleep quality tend to experience higher levels of fatigue. In contrast, gender ($p = 0.684$) and nutritional status ($p = 0.412$) were not significantly associated with work fatigue. For work-related factors, shift work ($p = 0.041$), working hours ($p = 0.018$), and workload ($p = 0.009$) were found to have significant relationships with work fatigue. Night shift workers, workers who worked more than eight hours per day, and those exposed to heavier workloads showed higher proportions of moderate and severe fatigue. Meanwhile, work experience ($p = 0.527$) did not demonstrate a statistically significant relationship with fatigue levels.

The findings demonstrate that the use of a digital reaction timer provides an objective approach for evaluating fatigue levels through reaction time measurement. Slower reaction responses indicate decreased alertness and neuromuscular performance, which are important indicators of fatigue in physically demanding occupations such as construction work. Compared with conventional fatigue assessments that rely on questionnaires or interviews, reaction time measurement offers a more direct and measurable indicator of worker fatigue.

From an engineering and occupational safety perspective, the application of digital reaction timer measurement can support more effective fatigue monitoring in construction workplaces. The use of objective fatigue detection methods may assist project managers and safety practitioners in identifying fatigue risks, improving work schedule management, and implementing preventive strategies to reduce fatigue-related accidents among construction workers.

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