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Forced Vital Capacity (FVC) and heat stress with work fatigue in field workers at PT X

Kapasitas Vital Paksa Paru dan Heat Stress dengan Kelelahan Kerja pada Pekerja Lapangan PT X

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ABSTRACT

Background: *The rapid development of industry demands improvements in both the quality and quantity of production, which often burdens workers. Field workers, particularly at PT X, are exposed to various environmental factors that may affect pulmonary function, while heat stress significantly contributes to work fatigue.*
Objective: *This study aimed to evaluate the relationship between forced vital capacity and heat stress with work fatigue among field workers at PT X.*
Methods: *An analytical observational design with a cross-sectional method was employed, involving 32 field workers as research subjects. Forced vital capacity was measured using a Chestgraph Spirometer, heat stress was measured using a QuestTemp Heat Stress Monitor, and work fatigue was measured using a Reaction Timer. Data analysis was conducted using the chi-square test to determine the relationship between forced vital pulmonary capacity and heat stress with work fatigue.*
Results: *The results showed a significant relationship between forced vital pulmonary capacity and work fatigue (p = 0.011), as well as between heat stress and work fatigue (p = 0.014).*
Conclusion: *These findings were important as they provide an overview of workers' physiological conditions that can influence occupational safety and productivity. It is recommended that companies routinely evaluate working conditions and workers' health, and provide early training and heat stress management to prevent work fatigue and improve workers' well-being.*

Keywords: *field workers, forced vital capacity, heat stress, work fatigue*

ABSTRAK

Latar Belakang: Perkembangan industri yang pesat menuntut peningkatan kualitas dan kuantitas produksi, yang seringkali membebani pekerja. Pekerja lapangan, khususnya di PT X, terpapar berbagai faktor lingkungan yang dapat memengaruhi fungsi paru-paru dan heat stress berpengaruh secara signifikan terhadap kelelahan kerja.
Tujuan: Penelitian ini bertujuan untuk mengevaluasi hubungan antara kapasitas vital paksa paru dan heat stress dengan kelelahan kerja pada pekerja lapangan di PT X.
Metode: Penelitian ini menggunakan desain observasi analitik dengan metode cross-sectional. Subjek penelitian adalah 32 pekerja lapangan PT X. Kapasitas vital paksa paru diukur menggunakan *Chestgraph Spirometri*, *heat stress* diukur menggunakan *QuestTemp Heat Stress Monitor* sedangkan kelelahan kerja diukur menggunakan *Reaction Timer*. Analisis data dilakukan menggunakan uji chi-square untuk menentukan hubungan antara kapasitas vital paksa paru dan heat stress dengan kelelahan kerja.
Hasil: Hasil penelitian menunjukkan adanya hubungan yang signifikan antara kapasitas vital paksa paru dengan kelelahan kerja (p = 0,011) dan terdapat hubungan yang signifikan antara heat stress dengan kelelahan kerja (p = 0,014).

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Conclusion: Temuan ini penting karena memberikan gambaran kondisi fisiologis pekerja yang dapat memengaruhi keselamatan kerja dan produktivitas. Perusahaan disarankan untuk rutin mengevaluasi kondisi kerja dan kesehatan pekerja, serta menyediakan pelatihan dini dan manajemen heat stress guna mencegah kelelahan kerja dan meningkatkan kesejahteraan pekerja.

Kata kunci: *heat stress*, kapasitas vital paksa paru, kelelahan kerja, pekerja lapangan

INTRODUCTION

Increasing technological advancements have driven the industrialization process, as evidenced by the adoption of advanced and modern technology in various industries. One impact of this rapid industrial development is the challenge of the production process in companies, which must continue to produce to improve the quality and quantity of production to achieve maximum profits[1]. As a result, workers must work harder to achieve these goals. Furthermore, the demands of working faster and longer to meet production targets can increase the risk of physical and mental fatigue. The interaction between people, heavy equipment, and the dynamic work environment can exacerbate the workload, increasing the potential for fatigue[2].

Workplace fatigue can impact productivity, safety, and workers' quality of life. Some factors contribute to workplace fatigue that can be effectively prevented. One physiological factor that may influence workplace fatigue is vital pulmonary capacity. Vital pulmonary capacity is a measure of the pulmonarys' ability to hold and exhale air during a single breathing cycle. A good vital capacity indicates optimal pulmonary function, which is essential for meeting the body's oxygen needs during strenuous physical activity[3].

Excessive heat exposure, which causes heat stress, is also a contributing factor to work fatigue. Heat stress is a condition in which the body experiences stress due to exposure to high environmental temperatures[4]. This can occur in hot work environments or in situations where workers are directly exposed to heat sources, such as field workers with heavy physical workloads[5].

According to the International Labour Organization (ILO), work fatigue contributes to 20-30% of total work accidents in various industrial sectors.[6]The National Safety Council in the United States reports that more than 13% of workers experience significant fatigue each week, impacting productivity and workplace safety. National data from the Ministry of Manpower in Indonesia shows that approximately 25% of workers in the construction sector experience significant fatigue[7]. Similar conditions were also found in Australia, where the Safe Work Australia survey reported that approximately 21% of construction workers experienced chronic fatigue related to heat exposure and high physical workloads, which increases the risk of accidents[1]. As a construction company, PT X has a responsibility to ensure the health and safety of its workers. As a construction company, PT X has a responsibility to ensure the health and safety of its workers.

Field workers face various health risks that can affect their pulmonary capacity. This reduction in Forced Vital Capacity (FVC) can lead to symptoms such as shortness of breath and fatigue, which can ultimately impact productivity and workplace safety[8]. Workers with low pulmonary capacity experience fatigue more quickly, which can impact their performance and safety in the workplace.

When exposed to high heat, the body will work hard to maintain a stable body temperature. This requires more energy and can lead to increased fatigue. Prolonged heat exposure can cause dehydration, which affects the body's fluid balance and worsens fatigue[9]. Extreme heat conditions can reduce workers' physical abilities, such as muscle strength, endurance, and movement coordination. To minimize these impacts, heat stress management strategies are needed, such as providing shaded rest areas,

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providing sufficient drinking water, rescheduling work hours during peak temperatures, and using appropriate personal protective equipment (PPE).

PT X is a company engaged in the construction and manufacturing industry, where field workers are often exposed to harsh and physically demanding environmental conditions. In the construction sector, workers perform tasks such as concrete work, metalwork, foundation installation, and others, most of which are done manually. These work demands have a significant impact on workers. This occurs because workers experience heat stress and forced pulmonary capacity, which can lead to work fatigue.

Based on previous research on the relationship between work fatigue and forced vital capacity of the pulmonary in garment workers at PT. Vinsa Mandira Utama Sukoharjo, there is a significant relationship between work fatigue and forced vital capacity (FVC) values in female garment workers at PT. Vinsa Mandira Utama Sukoharjo[10]. Meanwhile, research from Firda (2023) regarding the effect of heat pressure on work fatigue in shaping folding workers concluded that there was an influence of heat pressure on work fatigue in workers[11]. The relationship between pulmonary capacity and heat stress with work fatigue can be influenced by various factors, such as the type of work, work environment conditions, and the individual's health condition[10]. However, research specifically examining the relationship between forced vital capacity and heat stress on work fatigue in construction field workers in Indonesia is still limited. The differences in work environments, physical loads, and heat exposure in this sector provide a unique context that has not been widely explored. Based on these conditions, this study was designed to analyze the relationship between forced vital capacity and heat stress on work fatigue in field workers at PT X.

METHODS

Study design

This study used analytical observation with a cross-sectional approach. The study was conducted at PT X in 2024, with data collection in June 2024.

Data source and sampling procedure

This study involved the entire population of 32 field workers. Sampling was conducted using a total sampling technique, so that the entire population that met the criteria were included as respondents [13]. Inclusion criteria were male workers aged 20–50 years, with a minimum of 6 months of work experience, and willingness to sign written informed consent. Exclusion criteria were workers who were currently ill or had a history of chronic pulmonary disease.

Variables of the study

The independent variables in this study were heat stress and forced vital capacity, measured based on the work environment temperature and the results of the Forced Vital Capacity (FVC) examination. The dependent variable was work fatigue in field workers, categorized as mild and moderate fatigue. The relationship between the independent and dependent variables was analyzed to determine the effect of work environment conditions and pulmonary function on work fatigue levels.

Data Collection

Forced vital capacity measurements were taken after respondents worked for 4 hours (8:00 AM–12:00 PM) with a 30-minute rest period. Heat stress measurements were taken after respondents were exposed to direct sunlight for 3 hours, followed by recording of temperature, humidity, and heat index. Work fatigue measurements were taken immediately after the heat stress measurements.

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Measurement and instruments

The instruments used include the Reaction Timer RT-300 (1 millisecond resolution) to measure work fatigue, Chestgraph Spirometry HI-801 (accuracy ±3%) to measure forced vital capacity, and QuestTemp® Heat Stress Monitor QT-34, which is equipped with a wet bulb temperature sensor, dry bulb temperature, and globe temperature to measure heat stress.

The category of pulmonary restriction is determined based on the Forced Vital Capacity (FVC) value from the spirometry examination, namely mild restriction if the FVC value is at 60–79% of the normal predicted value, and severe restriction if the FVC value is <60% of the predicted value.

Ethical Considerations

This research has obtained research ethics approval from the Ethics Committee of Moewardi Regional Hospital with number 1.042/IV/HREC/2024, which includes written consent from participants, data confidentiality, and use of data only for research purposes.

Data Analysis

Data analysis was performed using univariate and bivariate methods. Univariate analysis was used to describe the frequency distribution and percentage of each variable: forced vital pulmonary capacity, heat stress, and work fatigue. Bivariate analysis was conducted to determine the relationship between forced vital pulmonary capacity and work fatigue, as well as the relationship between heat stress and work fatigue using the Chi-square test. A p-value <0.05 was considered to indicate a statistically significant relationship.

RESULTS

Univariate Analysis

Table 1. Distribution of respondents based on Forced Vital Capacity (FVC), heat stress, and work fatigue

Variabel	Category	n	Percentage (%)
Pulmonary Forced Vital Capacity (FVC)	Mild restriction	18	56.3%
	Severe restriction	14	43.8%
Heat stress	Medium (28.9°C)	17	53.1%
	Medium (29.8°C)	15	46.9%
Work Fatigue	Mild	15	46.9%
	Moderate	17	53.1%
Quantity		32	100

Based on Table 1, of the 32 respondents, the majority experienced mild restriction (18 people) (56.3%), compared to severe restriction (14 people) (43.8%). In the heat stress variable, the majority of respondents were at a temperature of 28.9°C (17 people) (53.1%), slightly higher than the temperature of 29.8°C (15 people) (46.9%). Meanwhile, work fatigue was dominated by the moderate category (17 people) (53.1%), compared to mild fatigue (15 people) (46.9%).

Bivariate Analysis

Chi-Square Test

Based on table 2, it can be seen that the p-value obtained is 0.011 because the p-value is <0.05 so it can be concluded that there is a relationship between forced vital capacity and work fatigue in PT X field workers in 2024.

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Table 2. Relationship between Forced Vital Capacity and Work Fatigue

Forced Vital Capacity	Work Fatigue		n (%)	*p-value*
	Mild	Moderate		
Mild restriction	12 66.7%	6 33.3%	18 100%	0.011
Severe restriction	3 21.4%	11 78.6%	14 100%	
Total	15 46.9%	17 53.1%	32 100%	

Source: Primary Data, 2024

Table 3. Relationship between Heat Stress and Work Fatigue

Heat stress	Work Fatigue		n (%)	*p-value*
	Mild	Moderate		
28.9ºC (Moderate)	13 76.5%	4 23.5%	17 100%	0.014
29.8ºC (Moderate)	5 33.3%	10 66.7%	15 100%	
Total	14 56.3%	18 43.8%	32 100%	

Source: Primary Data, 2024

Based on table 3, it can be seen that the p-value obtained is 0.014 because the p-value is <0.05, so it can be concluded that there is a relationship between heat stress and work fatigue in PT X field workers in 2024.

DISCUSSION

The results of this study indicate a significant relationship between forced vital capacity (FVC) and work fatigue, as well as between heat stress and work fatigue in field workers at PT X. Workers with a severe restriction category of forced vital capacity tend to experience higher work fatigue than workers with mild restrictions. This can be caused by a decrease in the pulmonary's ability to exchange air optimally, so that the oxygen supply to body tissues is reduced affecting stamina while working.

Meanwhile, exposure to environmental heat, which falls into the moderate heat stress category, also contributes to increased work fatigue. Heat exposure triggers the body's mechanisms to maintain core temperature, which requires additional energy and can lead to dehydration, decreased muscle strength, and impaired concentration.[14]The combination of decreased pulmonary function and prolonged heat exposure can accelerate the onset of work fatigue. Preventive measures can include adjusting work and rest schedules, providing shade and adequate hydration, and regularly checking pulmonary capacity to monitor workers' health.

In addition to pulmonary capacity and heat stress, work fatigue in field workers can also be influenced by several other factors, such as age, length of service, physical workload, hydration status, smoking habits, and work environment conditions, such as ventilation and dust exposure. These factors can contribute to a decrease in the body's physiological capacity and accelerate the onset of work fatigue. Work environments with high levels of heat and dust particles can place a heavy burden on the respiratory and cardiovascular systems, increasing oxygen requirements during work activities.

The cross-tabulation results between vital pulmonary capacity and work fatigue showed that some respondents who experienced mild restriction also experienced severe work fatigue. This illustrates that vital pulmonary capacity can influence work fatigue. According to Donce's theory [15], narrowing and accumulation of the pulmonary airways by pollutants, especially particulates, will affect pulmonary function and oxygen used for metabolic processes. This narrowing interferes with the formation of carbon

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dioxide in the process. When blood flow decreases, metabolites will accumulate, and muscle oxygen supply will rapidly decrease. Metabolism will shift to anaerobic, which increases lactic acid production and accelerates fatigue.

From the results of the work fatigue measurement on 32 respondents, it was found that all respondents experienced work fatigue, with 53.1% experiencing severe work fatigue and 46.9% experiencing moderate work fatigue. This can be caused by several factors, including long working hours, namely 12 hours per day with only a one-hour break. In addition, workers often do heavy work such as concrete casting and welding, so they experience heavy physical stress. Workers do their work in a standing position, often without even realizing that they are standing static for a long time, which can cause work fatigue[16].

The results of forced vital capacity measurements of the respondents showed that 56.3% had mild restriction disorders and 43.8% had severe restriction disorders. According to Darmawan [17], this restrictive disorder is generally caused by narrowing of the respiratory tract due to exposure to dust, smoke, or microparticles in the work environment. In the construction sector, field workers are highly susceptible to exposure to cement dust, sand, and vehicle exhaust fumes, especially if they do not wear personal protective equipment (PPE) such as masks. This exposure, combined with long work hours and high-intensity physical activity, contributes to a decrease in forced vital capacity[18]This decrease in pulmonary capacity can cause workers to experience physical and mental fatigue more quickly, especially when working under heat exposure and heavy workloads[19].

Through statistical analysis, a significant relationship was found between heat stress and work fatigue. Heat stress measurements were conducted at PT X on field workers. The measurement results showed that the temperature varied between 28.9ºC to 29.8ºC during the work that lasted for 8 hours a day. According to the standards of the Minister of Manpower and Transmigration Regulation Number 5 of 2018 concerning Threshold Limit Values for Physical and Chemical Factors in the Workplace, this heat exposure has exceeded the accepted threshold value. The recommended standard is a maximum heat exposure of 28ºC for workers with a work duration of 75% - 100% and a 25% rest period under moderate workload conditions based on heart rate[20].

The cross-tabulation results between heat stress and work fatigue show that at a temperature of 28.9°C, the majority of respondents experienced mild work fatigue (76.5%), while at a temperature of 29.8°C, the majority of respondents experienced severe work fatigue (66.7%). This illustrates that heat stress can affect work fatigue levels. Increased heat stress can be caused by environmental factors such as direct sunlight exposure, high humidity, inadequate ventilation, and heavy physical workloads. Efforts to reduce heat stress include adjusting work hours to avoid peak temperatures, providing shaded rest areas, using appropriate PPE, and providing sufficient drinking water to prevent dehydration.

If workers are exposed to workplace temperatures exceeding the threshold of 28ºC for moderate work, this can lead to occupational diseases caused by heat stress, which can ultimately lead to fatigue. This condition can significantly reduce work productivity. Research shows that various factors, including fatigue, can contribute to decreased work productivity[21]. When exposed to hot environments, workers may experience uncomfortable symptoms such as increased core body temperature, increased heart rate, headaches, or nausea. However, with repeated exposure to hot environments, workers can adapt and experience beneficial adaptive effects[22].

Practically, the results of this study demonstrate the importance of risk factor control efforts in the workplace. Companies can take preventive measures such as providing

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adequate rest areas, regulating work-rest cycles, providing drinking water to maintain worker hydration, consistent use of personal protective equipment, and conducting regular health checks, including pulmonary function tests. Furthermore, occupational health education and regular monitoring of work environment conditions are also necessary to prevent fatigue among field workers.

CONCLUSION

This study shows a significant relationship between forced vital capacity of the pulmonarys and heat stress with work fatigue in field workers at PT X. This condition indicates that decreased pulmonary function and moderate heat exposure can increase the risk of work fatigue. Therefore, preventive measures are needed in the form of regular pulmonary function checks, work schedule arrangements, and providing adequate rest facilities. PT X is recommended to implement an integrated heat stress management program that includes worker education, workload adjustments, and routine monitoring of work environment conditions.

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