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Heat Stress, Workload, and the Increase of Blood Pressure among Workers in A Limestone Industry

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Abstract
Introduction: Most workers in the limestone industry report health problems. Working under hot environmental conditions combined with strenuous labor increases the body's oxygen demand, which increases the pulse rate and blood pressure. This study aimed to analyze the association between heat stress, workload, and increased blood pressure among limestone industry workers in Puger District, Jember Regency, Indonesia.
Methods: This cross-sectional observational analytical study was conducted in a tertiary hospital in South Korea. Simple random sampling was used to include 41 subjects among 50 workers. Data were collected through interviews and measurements. Body weight and height were measured using a bathroom scale and microtoise, workload with a pulse oximeter, heat stress with the Heat Index WGBT Meter, and blood pressure using a digital tensimeter. Data were analyzed using Spearman's correlation and chi-square tests with a significance level of 0.05.
Results: Most of the participants were aged ≥45 years and had worked in the limestone industry for > 5 years. Most of the subjects had a normal BMI, had no history of disease, and 58.5% of them were moderate smokers. Older age (p=0.000), longer working period (p=0.001), smoking habits (p=0.006), higher workload (p=0.000), and heat stress (p=0.005) were significantly associated with higher blood pressure. Nutritional status (p=0.271) and history of disease (p=0.231) were not significantly associated with higher blood pressure.
Conclusion: The limestone workers who had worked longer, had a higher workload, experienced heat stress, and were smokers had higher blood pressure.

Keywords: heat stress, blood pressure, limestone industry, workers, workload.

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Introduction

Heat stress is a hazard from a group of physical factors that occur most often in various workplaces.[1] According to the Minister of Manpower Regulation No. 5 of 2018, the permissible working climate threshold for a medium workload with a working time of 75%–100% is 28 °C. Prolonged exposure to heat stress may increase blood pressure. Based on Pratiwi's [2] research, there were significant differences in workers' systolic and diastolic blood pressure before and after heat exposure. Working at extremely high temperatures places additional strain on the circulatory system because blood must simultaneously transport oxygen to active

muscles and dissipate internal body heat to the skin. [3]

In addition, excessive workload can cause worker fatigue and stress. Excessive energy consumption can lead to complaints such as dizziness, irritability, and fatigue. Fatigue can increase the need for oxygen, making it harder for the heart to deliver more blood to the muscles and increase blood pressure. [4] Research results by Ismayatun[5] showed that workers with heavy workloads experienced increased blood pressure due to fatigue.

The average normal blood pressure in adults is less than 120/80 mmHg. [6] Increased blood pressure occurs due to several factors. Apart from heat stress and workload, several other factors influence blood pressure, such as age, length of service, nutritional status, history of illness, and smoking habits.[7] Changes in blood pressure affect body homeostasis. [8] When this mechanism is disturbed, an imbalance arises, which causes diseases and even death. This increase in blood pressure over a long period can result in hypertension.[9]

Hypertension is the leading cause of premature death worldwide. Data from the World Health Organization (WHO) in 2018 showed that almost 1.3 billion people worldwide suffer from hypertension. Primary Health Research (Riskesdas) data for 2018 noted that most patients with hypertension in Indonesia were 55 – 64 years old (55.2%). In East Java, only 3,919,489 people with hypertension received health services (35.60%), while the estimated number of hypertensive sufferers was 11,008,334. In 2020, service coverage for hypertension sufferers reached 190,979 people (25.75%), while the estimated number of sufferers was 741,735. [10]

One of the sub-districts in Jember Regency with the most hypertension sufferers is Puger District.[11] Jember Health Data for 2020 also states that the Puger Community Health Center is in the fourth lowest position, with the number of hypertensive sufferers receiving health service coverage of only 1,253 people (6.8%). The Puger District has a limestone mountainous area called Mount Sadeng, which is administratively located in Grenden Village. With this limestone mountain, many locals work in the limestone processing sector. During processing, workers are always exposed to hot sunlight and furnace radiation, in addition to a heavy workload.

UD X operates in limestone processing. This limestone processing process uses human power, and the working area is an open room with fire burning for approximately four–five days. Limestone needs to be heated to a temperature of 900–1100 ℃, which can cause the surrounding working environment to become too hot.[12] Based on brief interviews, most workers complained about hot temperatures from stove fires and sunlight, as well as the heavy burden of transporting wood and limestone. The processing begins with the breaking stage and continues by filling the furnace with lime, with working hours starting at 06.00-14.00. When entering the burning process, the workplace owner divides working hours into four shifts: morning shift from 06.00-12.00, afternoon shift from 12.00-18.00, evening shift from 18.00-00.00, and night shift from 18.00-00.00. 00.00-06.00. The final stage was the removal of limestone and making lime powder with working hours starting at 06.00-14.00.

Based on the results of the short interviews, most workers complained of headaches, weakness, sweating easily, getting tired easily, thirst due to carrying heavy loads, and high environmental temperatures. The company has not provided workers with optimal drinking water, and the exact amount of fluid intake remains unknown. Some of these complaints are symptoms of increased blood pressure after physical activity.[13] Based on the description above, this study aimed to analyze the relationship between heat stress, workload, and increased blood pressure among limestone industry workers.

Methods

This study used an observational cross-sectional design. This research was conducted with limestone industry workers at UD X, Puger District, Jember Regency, from March to June 2023. The research population comprised 50 people who

performed work activities in hot areas, with a sample of 41 people. Simple random sampling was employed. Data were analyzed using Spearman's correlation and chi-square tests, with a significance level of 0.05. The results are presented in tabular and narrative forms.

The independent variables consisted of respondent characteristics (age, length of service, nutritional status, history of illness, and smoking habits), workload, and heat stress. The dependent variable was the increase in blood pressure. Data were collected through observations, interviews, measurements, and documentation. Interviews regarding respondents' characteristics were conducted using a questionnaire. In addition, direct measurements of body mass index (BMI) were carried out using a bathroom scale and microtoise, workload with a pulse oximeter, heat stress with the Heat Index WGBT Meter, and blood pressure using a digital tensimeter.

The BMI of the workers was measured once before they started working. The workload was measured by taking the pulse twice, before and during work, with the measurement time adjusted to the respondent's work shift. Heat stress measurements were performed at three points. Measurements before and after the combustion process were performed thrice per work shift, and the results were averaged. Measurements during the combustion process were conducted once per work shift, according to working hours (6 h/day), using a Heat Index WGBT Meter for 10 min. Blood pressure was measured using a digital blood pressure meter before and after work; each was measured 2 times.

Results

The results of data collection regarding the characteristics of the respondents (age, length of service, nutritional status, history of illness, and smoking habits), workload, and hot environments, as well as the relationship between these variables and increased blood pressure are presented in Table 1.

Table 1 shows that 56.1% of respondents were aged ≥45 years (23 people); most respondents (82.9%) had worked in the limestone industry for more than 5 years (34 people); 61.0% had a normal category, (25 people). Most respondents (75.6 %) had no history of disease, 31 people, and 58.5% of respondents were moderate smokers (24 people).

The workload was obtained by measuring the pulse rate before and during work. Next, the workload was calculated using the %CVL (Cardiovascular Load) formula. The results of the workload measurements show that 58.5% of limestone industry workers have a medium workload, namely, 24 people. Heat stress measurements were performed using a WGBT Meter Heat Index measuring instrument. Measurements were performed at three points: T1 (top of the furnace) before firing, T2 (front of the furnace) during the combustion process, and T3 (front of the furnace core) when the limestone was removed. The average measurement results at these three points yielded an average ISBB value of 32.2 ℃.

Most workers have a moderate workload, with a division of 75%-100% working time and 25% rest, so that heat stress exceeds the predetermined NAB (>28 ℃). Blood pressure is measured before and after work using a digital monitor. The aim of this study was to determine the increase in systolic and diastolic blood pressure for each worker. The results showed that most respondents (70.7%) experienced a moderate increase in blood pressure, that is, 29 people.

The results of this study showed that there was a relationship between age, work duration, smoking habits, and increased blood pressure. There was a relationship between workload and increased blood pressure, with a correlation coefficient of 0.869, which means that it was included in the very strong category with a positive correlation direction. There was a relationship between heat stress and increased blood pressure, with a correlation coefficient of 0.428, indicating a strong positive correlation. Body mass index and history of disease were not associated with increased blood pressure.

Table 1. Association between variables and increased blood pressure

Variables	Category	Participants	Increased Blood Pressure		p^
			Low	Medium	
		n (%)	**n (%)**	**n (%)**	
Age (years)	<45	18 (43.9)	12 (66.7)	6 (33.3)	0.000
	≥45	23 (56.1)	0 (0.0)	23 (100.0)	
Length of Service	<5	7 (17,1)	6 (85.7)	1 (14.3)	0.001
	≥5	34 (82.9)	6 (17.6)	28 (82.4)	
Body Mass Index (BMI)	Underweight	4 (9.8)	2 (50.0)	2 (50.0)	0.271
	Normal	25 (61)	8 (32.0)	17 (68.0)	
	Overweight	6 (14.6)	0 (0.0)	6 (100.0)	
	Obese	6 (14.6)	2 (33.3)	4 (66.7)	
History of Disease	Yes	10 (24.4)	1 (10.0)	9 (90.0)	0.231
	None	31 (75.6)	11 (35.5)	20 (64.5)	
Smoker	Moderate	24 (58.5)	11 (45.8)	13 (54.2)	0.006
	Heavy	17 (41.5)	1 (5.9)	16 (94.1)	
Workload	Light	13 (31.7)	12 (92.3)	1 (7.7)	0.000
	Medium	24 (58.5)	0 (0.0)	24 (100.0)	r = 0.869
	Heavy	4 (9.8)	0 (0.0)	4 (100.0)	
Hot Work Environment (℃)	30.3	18 (43.9)	9 (50.0)	9 (50.0)	0.005
	35.8	8 (19.5)	2 (25.0)	6 (75.0)	r = 0.428
	30.5	15 (36.6)	1 (6.7)	14 (93.3)	
Total	41 (100.0)	12 (29.3)	29 (70.7)		

*Results of Spearman's rank or chi-square analysis
^Indicate significance (p<0,05)

Discussion

Characteristics of Respondents

More than half of the limestone industry workers were aged ≥45 years. Increasing age is associated with higher levels of fatigue, as declining physical capacity causes individuals to become more quickly fatigued. Consequently, oxygen demand increases, requiring the heart to pump more forcefully to circulate sufficient blood to working muscles. [14]

Most respondents had worked for more than five years in their current jobs. A longer employment duration is generally associated with increased work ability and a relatively lower perceived workload. However, workers with more than five years of experience are also subjected to prolonged occupational heat exposure. Chronic exposure to heat can impair organ function, leading to reduced cognitive performance, diminished skin responsiveness to stimuli, and increases in blood pressure and heart rate.[7]

Nutritional status is a person's nutritional condition based on Body Mass Index (BMI), which is measured by dividing body weight (kg) by body height (m2). Based on the Regulation of the Minister of Health of the Republic of Indonesia Number 41 of 2014 concerning Guidelines for Balanced Nutrition, nutritional status is divided into five categories: very thin if BMI <17.0 kg/m2, thin if BMI 17–<18.5 kg/m2, normal if BMI 18.5–<25.0 kg/m2, obese if BMI 25.0–27.0 kg/m2, and very obese if BMI > 27.0 kg/m2. Most respondents were in the normal category based on their nutritional status. Blood carries the burning of substances that produce energy for oxygen needs to the muscles. However, when oxygen demand increases, the heart pumps harder to deliver more blood to the muscles, resulting in increased blood pressure.[15] Therefore, it is important to balance nutritional intake with work activities.

A history of illness influences an individual's strength and productivity. In this study, the disease history was categorized into two groups: the presence and absence of a prior or current medical condition. Respondents were classified as having a disease history if they had been previously diagnosed with or were currently experiencing hypertension, heart disease, or kidney disease. The results indicated that most workers in the limestone industry

did not have a history of disease. The interview findings revealed that hypertension was the most commonly reported condition among workers with a history of disease. Workers with pre-existing conditions such as hypertension, heart disease, or kidney disease are more susceptible to complaints, including excessive sweating and thirst, dizziness, and fatigue during heavy work activities. These symptoms can impair cardiac function in pumping blood efficiently to deliver oxygen to the working muscles.[13]

Smoking refers to the activity of burning a cigarette, inhaling it, and exhaling it again in the form of smoke. Smoking habits were determined based on the number of cigarettes smoked per day. Smoking habits were divided into three categories: light (1–4 cigarettes per day), moderate (5–14 cigarettes per day), and heavy (>15 cigarettes per day) smoking. The results show that more than half of the limestone industry workers fell into the moderate smoking category. The duration of smoking has an impact on exposure to dangerous chemicals contained in cigarettes. Nicotine causes blockage of blood vessels in the brain and heart.[16] In addition, carbon dioxide in cigarettes can accelerate the buildup of plaque on the walls of blood vessels, resulting in obstruction of blood flow.[17]

Workload

Workload calculations were performed using the %CVL (Cardiovascular Load) formula. From the %CVL results, the workload was categorized into 5, namely light (<30%), moderate (30%–<60%), heavy (60%–<80%), and very heavy (80–100%). %), and very severe (≥100%). The results show that more than half of the limestone industry workers experienced a moderate workload.

The lime processing process requires workers to transport large amounts of limestone and firewood manually without tools. Workers repeatedly haul limestone and wood without fixed breaks. When they feel tired, workers take turns taking breaks. The sufficient rest time was approximately 10-15 minutes per shift. The rest time is used to drink, eat, or sit in front of the stove with a tin roof. Except during the burning process, the rest of the work was done in front of the stove at approximately 1 m because the temperature was very high.

Four workers experienced heavy workloads in the study. This heavy workload is experienced by workers during the combustion process. This could be caused by heavy work activities combined with exposure to fire radiation from furnaces and sunlight. The workload experienced by workers during the burning process was heavier than that experienced by workers before and after the burning process. The measurement results showed that the pulse rate of the worker during the combustion process was higher than that before and after the combustion process.

Hot Work Environment

Heat stress (heat strain) is a physical factor in the work environment that arises due to modifications in air humidity, air movement speed, radiant heat, and air temperature [18]. The results of heat pressure measurements at three points in the limestone industry, namely, before burning, during the burning process it was 35.8 ℃, and during lime expulsion, were 30.3 °C, 35.8 °C, and 30.5 ℃, respectively. From the results of the measurements at these three points, an average ISBB value of 32.2 ℃ was obtained. The highest ISBB heat pressure value occurred in the combustion process, namely 35.8℃. This is because the heat source during the combustion process comes from radiation from the furnace fire, where workers insert wood into the furnace at a close distance from the fire.

Sunlight and furnace fire radiation affect the temperature of the working environment. The rest time arrangements for limestone industry workers are uncertain, and when they feel tired, several workers take turns resting. During the process of inserting and removing limestone, workers were exposed to hot sunlight for 8 h, with intermittent rest periods. The workers' rest location was in the front yard of the furnace with a tin roof. During the combustion process, workers are exposed to heat from the burning furnace. When the fire appears to be going out, workers repeatedly insert wood through the mouth of the stove to prevent it

from going out. Therefore, it is necessary to control heat exposure in workers by improving the workplace, heat sources, and activities carried out.[19]

Increased Blood Pressure

One of the physiological responses to heavy work activities combined with heat stress that exceeds the time-weighted average (TWA) is an increase in blood pressure.[20] In this study, the increase in blood pressure was categorized as mild (increase in systolic or diastolic blood pressure of 1-10 digits), moderate (increase in systolic or diastolic blood pressure of 11-20 digits), and severe (increase in blood pressure). systolic or diastolic blood >20 digits).

Most limestone industry workers experienced moderate increases in blood pressure. The increase in the blood pressure of lime industry workers is caused by several factors because it is multifactorial. Several individual factors influence the increase in blood pressure, including age, length of service, nutritional status, history of illness, workload, and blood pressure.[7]

From the measurement results, it is known that workers in the combustion process experience a higher increase in blood pressure than those in other processes do. During the combustion process, exposure to hot furnace temperatures, solar radiation, and heavy carrying loads affects workers' fatigue levels. Thus, workers involved in the combustion process will experience a higher increase in blood pressure than workers involved in other processes.

Correlation between Individual Characteristics and Increased Blood Pressure

Age was associated with increased blood pressure in limestone industry workers (p-value 0.000 ≤0.05). Most workers aged > 45 years experienced moderate increases in blood pressure. The results of this study are also supported by Amalia[7], who found that the correlation between age and increased blood pressure had a p-value of 0.001. An increase in age is followed by physiological changes in the body, such as arterial wall thickening. Thickening of the arterial walls when a person is 40 years old causes the blood vessels to become narrow, stiff, and lose their elasticity (arteriosclerosis). If blood pressure is high, complications such as hypertension, stroke, heart disease, kidney disease, and other degenerative diseases can occur. [21]

Length of service was associated with increased blood pressure in limestone industry workers (p-value 0.001 ≤0.05). Most workers with ≥5 years of work experience had a moderate increase in blood pressure. These results are in line with the research by Siregar[22], who found that the working period increased the blood pressure of production workers at PT. X has a p value <0.05. A longer working period is directly proportional to an increase in a person's work ability and level of adaptation to work and the work environment. This adaptation process can negatively impact the resilience of the body owing to excessive pressure during the work process. This causes fatigue, which results in a decrease in the body's physiological responses, such as changes in blood pressure after work.[23] According to Gopinath et al.[24], an increase in blood pressure over a period of up to 5 years will cause hypertension, and 60% of patients are at risk of dying from heart disease over a period of more than 10 years.

There was no significant relationship between nutritional status and increased blood pressure (p = 0.271 and p > 0.05, respectively). Most workers had a normal nutritional status but experienced moderate increases in blood pressure. This may be because the increase in blood pressure is multifactorial, with other factors such as age ≥45 years, working period ≥5 years, nutritional obesity status, history of disease, and smoking habits. In addition, the work process, which is always exposed to heat with heavy work activities such as repeated lifting of wood and limestone, results in fatigue, thus affecting blood pressure. Therefore, even if the nutritional status is normal, it does not guarantee that workers will have normal blood pressure.

Six workers with an obese nutritional status experienced a moderate increase in their blood pressure. These results are consistent with those of Fitriani

et al.[25] for PT workers. Gresik reported that nutritional status was significantly related to blood pressure (p =0.006). It should be noted that workers who weigh more will need more oxygen, so the pressure on the arterial walls will be higher. [25]

The determinant of disease history was not related to the occurrence of increased blood pressure (p = 0.231 > 0.05). Most workers had no history of illness but experienced moderate increases in their blood pressure. This may be because the increase in blood pressure is multifactorial, meaning that other factors such as age ≥45 years, working period ≥5 years, obesity, nutritional status, history of disease, smoking habits, heat stress exceeding the NAB, and heavy workload can also affect blood pressure. Therefore, even if workers do not have a history of illness, this does not guarantee that they will have normal blood pressure after work.

Ten workers had a history of illness and were admitted for hypertension. A person with a history of hypertension already has high blood pressure. When they work, workers with hypertension stimulate the heart to work harder in pumping blood, which carries oxygen throughout the body.[19] As a result, high blood pressure increases as work activities increase. Increased blood pressure over a long period causes a person to experience hypertension.

Smoking habits were associated with increased blood pressure in limestone industry workers (p = 0.079 ≤0.05). Most workers were moderate smokers and experienced moderate increases in blood pressure. Toxic chemicals from cigarettes that enter the bloodstream can cause blood vessels to narrow, so that several body organs, such as the heart, muscles, and brain, lack oxygen. Over a long period of time, nicotine causes stiffness in the walls of blood vessels, so that the body's organs lack an oxygen supply.[24]

These results are in line with those of Asyik[26], who found a relationship between smoking status and increased blood pressure in PT. Phillips Seafood Indonesia (p-value=0.035). The narrowing of blood vessels causes the heart to pump harder, resulting in increased pressure in the blood vessels [7]. The effects of smoking are not felt immediately, but they takes approximately 10-20 years after smoking. A smoker's blood vessels do not return to normal, even if smoking is discontinued. [16]

Relationship between Workload and Increased Blood Pressure

Workload was associated with increased blood pressure (p-value 0.000 ≤0.05). These results are consistent with those of Febriandani [27] on workers in the smelting section of PT. Antam Tbk UBPN Southeast Sulawesi stated that workload was related to increased blood pressure (p < 0.05). An increase in workload is directly proportional to the increase in blood pressure. They complained about the hot working environment, repetitive transport work, and heavy wood loads, particularly by workers in the burning section. Workers exposed to heat combined with a heavy workload will cause workers to tire easily owing to the loss of salt and fluids. A heavy workload is followed by an increase in the nutrition and energy required by the body. Activities with heavy workloads cause pumping strength and heart rate to increase, thus affecting the blood pressure of workers.[28]

Relationship between Heat Stress and Increased Blood Pressure

Heat stress was associated with an increase in blood pressure in limestone industry workers (p-value 0.005 ≤0.05), such that an increase in blood pressure in the moderate category was experienced more by respondents who worked in front of a furnace with an ISBB value of 35.8℃. The average heat pressure in the limestone industry was 32.2 ℃. These results are in line with the research by Lestari [9], who reported that heat pressure measurements in the X steel industry production area in Cilegon city produced an average ISBB value of 30.2℃. The results of the statistical correlation test showed that the p-value was <0.05, indicating a relationship between heat stress and an increase in workers' blood pressure.

The heat source originates from sunlight and radiation from burning furnaces. A hot environment can increase the amount of water lost from the plasma, reducing blood flow to the central veins,

heart, and skin, leading to vasoconstriction and an increase in heart rate as the demand for working muscles increases. Long-term loss of water from blood plasma, vasoconstriction, and high cardiac workload in the long term will result in increased blood and plasma viscosity. When blood viscosity increases, the total peripheral resistance, which is related to blood pressure, also increases.[9]

Ideally, for eight hours of work, seven hours are used for work, while one hour is used for rest. Similarly, for other work processes that are exposed to greater heat, working hours can be reduced by considering a reference of 25% rest time from the total working hours. The aim of reducing working hours is to ensure that workers are not exposed to heat for too long and that the workload is not too heavy, thereby reducing the risk of health problems for workers.

Conclusion

Most limestone industry workers were over 45 years old, had more than 5 years of work experience, had a normal nutritional status, had no history of disease, and had moderate smoking habits. The average heat pressure measurement results at three points in the limestone industrial area were 32.2 ℃. Most limestone industry workers had a moderate workload and increased blood pressure. The individual characteristics that were significantly related to increased blood pressure were age, length of service, and smoking habits. Heat stress and workload were also significantly associated with increased blood pressure in limestone industry workers.

Recommendations for industrial owners include installing roofing made of heat-reducing materials, providing wheelbarrows and an adequate supply of drinking water, and collaborating with local health centers to deliver health education and conduct routine medical examinations for workers. Industrial owners are also encouraged to reduce the availability of cigarettes in the workplace and provide appropriate personal protective equipment (PPE), including head coverings, safety goggles, and heat-resistant gloves. Workers are advised to wear cotton, light-colored clothing; maintain adequate hydration; consume a balanced and nutritious diet; obtain sufficient rest; regularly monitor their blood pressure; use mechanical aids, such as wheelbarrows; and reduce cigarette consumption.

Future research should further examine additional factors that may influence blood pressure, including alcohol and caffeine consumption, physical activity levels, duration of heat exposure, differences in work shifts, and workers' hydration status. Researchers should also incorporate other variables, such as occupational hazards and respiratory disturbances resulting from exposure to limestone dust. Furthermore, expanding the sample size by including workers from other limestone industrial centers would help to generate more diverse and representative data.

Ethics approval

This study was approved by the Health Research Ethics Committee (KEPK) of the Faculty of Public Health, University of Jember, under the ethics approval number 170/KEPK/FKM-UNEJ/IV/2023.

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Author Contribution

Researchers play a role in the research process, starting with preliminary studies, data collection, data analysis, and compiling results for the final research article.

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