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ORIGINAL ARTICLE

Examining the Relationship between the WBGT Index and Leukocyte Levels: A Case Study of Foundry Workers Exposed to Heat Stress

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ABSTRACT

Background: Iran's hot and arid climate, combined with frequent exposure to heat-generating industrial processes, presents significant occupational health concerns. These environmental conditions may influence white blood cell (WBC) levels and their functions in response to heat stress. This study investigates the relationship between the Wet Bulb Globe Temperature (WBGT) index and WBC levels among workers in a foundry setting.

Methods: This descriptive-analytical study was conducted on 55 male workers from two sections of a foundry: the cast iron section (35 participants) and the CNC section (20 participants). Blood samples were collected from all participants. Heat stress was assessed using the WBGT index. Intervening parameters—such as noise, lighting, and metabolic rates—were measured for each work group. Data analysis was performed using SPSS version 16.

Results: In the case group, a decrease in total WBC count and lymphocyte levels was observed, along with an increase in neutrophil levels and the neutrophil-to-lymphocyte ratio. No significant relationship was found between heat stress and the composition of other WBC types, including basophils, monocytes, and eosinophils. Correlation analysis revealed strong associations between the WBGT index and total WBC count ($R^2 = 0.93$), neutrophils ($R^2 = 0.85$), lymphocytes ($R^2 = 0.81$), and overall WBC composition ($R^2 = 0.82$).

Conclusion: Chronic exposure to heat stress may lead to significant alterations in WBC levels, potentially weakening and suppressing the immune system. The blood parameters examined in this study can serve as biomarkers affected by heat stress and merit further investigation.

KEYWORDS: *Heat stress, Wet bulb globe temperature (WBGT), Foundry, Leukocytes, Lymphocytes, Neutrophils*

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INTRODUCTION

Heat stress is one of the most significant and prevalent occupational hazards in various workplaces, with many employees being either directly or indirectly exposed to this harmful factor and its associated problems and diseases [1]. According to the American Conference of Governmental Industrial Hygienists (ACGIH), heat stress is defined as the total heat load on the body from both environmental sources and the individual's own metabolic heat [2]. This definition essentially describes the extent of heat exposure in extremely hot environments [2]. The physiological response of the body to heat stress is termed heat strain [3]. Exposure to heat stress conditions triggers several physiological reactions, including an elevated heart rate and skin temperature, fluctuations in blood pressure—either increased or decreased—and alterations in specific hormones (such as cortisol, adrenaline, and noradrenaline) [2, 4].

Short-term exposure to intense heat (acute exposure) can lead to an elevation in core body temperature, resulting directly in heat-related illnesses such as heat rash, heat cramps, heat exhaustion, and potentially fatal heat stroke. The consequences of long-term and chronic exposure to heat in workplaces have also been documented, including cardiovascular diseases [5], impacts on mental health [6], chronic kidney diseases [7], and a compromised immune system [8].

To assess heat stress and safeguard workers from excessive heat in the workplace, heat stress indices should be employed [9]. In most studies, the Wet Bulb Globe Temperature (WBGT) index has been utilized either alone or in conjunction with other indices to evaluate heat stress. A systematic review conducted by Nassiri et al., encompassing research from 2000 to 2015, revealed that 71 percent of the studies used the WBGT index either alone or alongside other indices for evaluating heat stress [10]. It is concluded that this index, while straightforward, demonstrates high efficacy in assessing environmental heat conditions and exhibits a strong correlation with physiological parameters [10].

White blood cells are categorized into two main groups: granulocytes (neutrophils, eosinophils, and basophils) and agranulocytes (monocytes and lymphocytes) [11]. Studies have shown that heat stress affects physiological and biochemical blood variables, leading to reduced metabolism, disruption of homeostasis, increased oxidative damage, changes in hormone levels, and quantitative and morphological changes in blood cells [12, 13]. It also impacts organs and systems such as the endocrine, cardiovascular, respiratory, and immune systems [14]. Additionally, exposure to heat stress has been reported to disrupt acid-base balance and reduce the levels of minerals in the bloodstream, such as poor absorption of calcium, potassium, and phosphorus (Ca, K, and P), and increased excretion of sodium, potassium, calcium, and copper (Na, K, Ca, Cu) [15].

Heavy activity and exposure to heat stress in unnatural work environments can cause changes in the hormonal and immune systems. By stimulating the hypothalamic-pituitary-adrenal axis, these conditions lead to the release of stress hormones such as cortisol and an increase in the number of neutrophils [16]. With rising body temperature, levels of catecholamines, cortisol, anterior pituitary hormones, prolactin, and growth hormone also increase. It has been suggested that all or some of these factors can affect leukocyte and neutrophil changes during activity [17]. However, the primary reason for the accumulation of leukocytes is considered to be an increase in cardiac output, cortisol levels, and catecholamines. The initial increase in neutrophils resulting from activity in heat-stressed environments originates from the release of catecholamines, while the secondary increase is due to the release of cortisol [18].

Some researchers have reported that changes in the body's normal physiological balance in response to physical, psychological, or environmental pressures can alter the number and function of leukocytes and plasma proteins. These changes occur through stimulating or weakening the immune system, which reduces resistance to infection and disease. Additionally, these alterations can accelerate the clotting process. Ultimately, this can create a basis for adverse cardiac events. Therefore, disruption of physiological balance and immune system function can be one of the factors contributing to adverse events in individuals susceptible to infection, such as heart patients [19].

Studies have shown that hematological parameters can serve as response indicators for identifying, diagnosing, treating, and prognosing diseases caused by heat stress [14]. Most studies investigating the relationship between heat stress and leukocyte levels have been conducted on animals, with only a limited number on humans under laboratory conditions. Even fewer studies have examined these issues in real-world work environments. Given the widespread exposure to heat stress and its severe effects in workplaces—especially foundries—this study aimed to investigate the relationship between the WBGT index and leukocyte levels in foundry workers exposed to heat stress.

MATERIALS AND METHODS

Study Design

This descriptive-analytical study involved 55 male workers from the cast iron foundry and CNC (Computer Numerical Control) sections of a casting factory in Iran. The study group included 35 workers from the casting section, employed in three areas: melting, DISAMATIC molding machines (DISA), and Badische Maschinenfabrik Durlach (BMD). The control group consisted of 20 workers from the CNC or machining section. The control group was selected to ensure that environmental variables (noise, lighting, air pollution/contamination, etc.) were comparable to those in the casting section, thus minimizing confounding factors. All study subjects were male, healthy, aged 20–45 years, with work experience ranging from 1 to 19 years. The study received approval from the ethics committee of Shahid Beheshti University of Medical Sciences, and informed consent was obtained from all participants. Initially, all individuals in both sections completed a demographic questionnaire to identify suitable subjects. This questionnaire collected information on physical and mental health, height, weight, exercise habits, sleep patterns, symptoms experienced during heat exposure (such as fever and diarrhea), individual reactions to heat, and personal details. Based on the gathered information, individuals were assigned to the case and control groups within each section.

Blood Sample Collection and Analysis

Blood samples were collected from workers in both the cast iron and CNC sections during peak working hours (10:00 AM to 2:00 PM) in a single session. A nurse collected 5 cc of blood from each individual and transferred it to a dedicated CBC tube containing EDTA anticoagulant. All samples were transported to the central laboratory of Taleghani Hospital in Tehran under controlled conditions (in an ice box). Blood samples were analyzed at the central laboratory of this hospital using the CBC test method with a Cell-Sysmex Counter, High X 21 model, manufactured in Japan. The following parameters were measured: white blood cell (WBC) count, neutrophil count, lymphocyte count, neutrophil-to-lymphocyte ratio, and the combined count of basophils, monocytes, and eosinophils (Mix).

Heat Stress Assessment

Simultaneously with blood sample collection, heat stress assessment was performed by measuring the Wet Bulb Globe Temperature (WBGT) index. A WBGT meter, model QUESTEMP o10, manufactured in the USA, was used for this purpose. The measurement range of this device is from 5 to 60+ degrees Celsius. The device accuracy is ±0.5 °C, and its reading accuracy is ±0.1 °C. The device was calibrated before each measurement using its dedicated WBGT meter calibrator. The WBGT meter calculates the WBGT index value directly based on the readings of wet, dry, and radiant temperatures and displays it numerically on its screen.

After proper calibration, the device was prepared by attaching the temperature sensor probes. The water reservoir was filled with distilled water, and the wick was connected to the wet bulb temperature sensor. Once the wick was fully moistened, the device was placed at the worker's workstation. Before turning it on, the device was allowed to remain at the measurement location for five minutes. This allowed for heat exchange between the work environment and the temperature sensors, ensuring thermal equilibrium with the ambient temperature. The device was then turned on, and measurements were taken.

Air parameters, including wet, dry, and globe temperatures, were measured at six workstations: furnace operators, holder operators, melting operator, pouring operator, milling machine operators, and CNC machine operators. To calculate the corresponding index, work groups were initially identified, and a job analysis was performed for each group. Given the heterogeneous nature of the environment, measurements for the WBGT index were taken at three heights at each workstation: ankle level (0.1 meters above the floor), abdomen level (1.1 meters), and head level (1.7 meters). The WBGT index value at each workstation was calculated using relevant equations [2].

The metabolic rate of individuals at different workstations was determined using tables from the ISO 7243:1989 standard [20]. Since the workers wore summer work clothes with a resistance coefficient of 0.6 clo, no correction was applied to the WBGT index.

Measurement of Intervening Variables

Considering that environmental hazards—such as noise, lighting, and various chemical pollutants in the workplace—can influence the results obtained and are inherent and natural components of the work environment, the assessment of these factors was deemed necessary. The average noise and lighting levels were recorded at 119 stations in the casting section and 108 stations in the machining (CNC) section as intervening variables.

Noise measurements were conducted in accordance with ISO 9612 using a digital sound level meter, IEC-651, serial number 1098794, manufactured by Bruel & Kjaer in Denmark. Prior to commencing measurements, the sound level meter was calibrated with its integrated 4230 IEC calibrator. The average sound pressure levels were determined for both sections. The average sound pressure level in the cast iron foundry section was recorded at 84 decibels, while in the CNC section, it was recorded at 83 decibels.

Lighting was measured using a digital lux meter, model DX-200, manufactured by INS in Hong Kong. The measurement range of this lux meter spans from 0 to 20,000 lux, with a measurement accuracy of ±0.2% and a response time of 0.3 seconds. The device was calibrated externally, and covering the photocell lens with a hand is expected to yield a zero reading. After calibrating and ensuring the accuracy of the device, the average lighting level was determined in both sections. The measurement height was 75–80 centimeters above the ground. The average lighting level in the cast iron foundry section was 155 lux, and in the CNC section, it was 165 lux.

Based on the results over the past three years regarding harmful factors within this industry, the levels of metal fumes and dust in the melting area were reported to be within permissible limits. In light of this consideration, individuals from the second parts of DIZA1 and DIZA2, as well as the first parts of BMD1 and BMD2, were selected. In these selected sections, the proximity to pollution control equipment and the work environment conditions reduced the likelihood of pollutant accumulation. Moreover, the rear space of the melting section featured an opening to the outdoor air, which significantly aided in diminishing the accumulation of chemical agents in this area. Metal fumes and dust in all areas of the machining (control) section were reported to be below permissible limits. Given the selection of individuals from the specified sections, a re-evaluation of chemical agents within this industry was deemed unnecessary.

Statistical Analysis

Quantitative data were presented as mean ± standard error (Mean ± S.E.), maximum, and minimum values. To compare blood factors between the two groups, the independent t-test was utilized when the distribution of variables was normal; otherwise, the Mann-Whitney U test was employed. Additionally, to examine the correlation between the WBGT index and blood factors, the correlation coefficient was calculated, and regression analysis was performed when necessary. The significance level for all tests was set at 0.05. All data analyses were conducted using SPSS version 21 software, while graphs and charts were generated using Excel software.

RESULTS

Demographic Parameters

Table 1 presents the mean and standard deviation of demographic characteristics for both the case and control groups. The results indicated no significant differences between the demographic variables in the two groups ($P > 0.05$).

Atmospheric Parameters

Table 2 shows the findings of the heat stress assessment conducted for both the case and control groups. Given that the workers were wearing summer-type uniforms with a resistance coefficient of 0.6 clo, the wet-bulb globe temperature index was not adjusted. The atmospheric parameter measurements identified a mean wet temperature of 27.5 degrees Celsius, a mean dry temperature of 37.5 degrees Celsius, and a mean globe temperature of 42.3 degrees Celsius for the case group. In contrast, the control group reported mean values of 21.2 degrees Celsius for wet temperature, 26.2 degrees Celsius for dry temperature, and 27.3

Table 1. Mean and Standard Deviation of Demographic Variables in Case and Control Groups

Variable	Mean ± Standard Deviation		P-Value
	Case	Control	
Age (years)	31.2 ± 2.82	32.1 ± 2.03	0.07
Work Experience (years)	8.73 ± 5.28	9.84 ± 7.44	0.14
Body Mass Index (kg/m²)	25.4 ± 1.47	25.72 ± 1.23	0.657

Table 2. Results of the Evaluation of Atmospheric Parameters in the Two Groups (Case and Control)

Thermal Indices	Measurement Area	Mean ± Standard Deviation		P-Value
		Case	Control	
Wet-Bulb Temperature	Head	27.5 (6.2)	21.5 (0.6)	<0.0001
	Abdomen	27.7 (7.3)	21.1 (0.5)	<0.0001
	Ankle	27.3 (6.1)	21.2 (0.53)	<0.0001
	Average	27.5	21.2	<0.0001
Dry-Bulb Temperature	Head	37.6 (5.1)	26 (0.5)	<0.0001
	Abdomen	37.4 (5.2)	26.2 (0.55)	<0.0001
	Ankle	37.8 (5.7)	26.6 (0.51)	<0.0001
	Average	37.5	26.25	<0.0001
Globe Temperature	Head	41.8 (5.8)	27.2 (0.61)	<0.0001
	Abdomen	42.5 (5.3)	27.4 (0.63)	<0.0001
	Ankle	42.7 (6.2)	27.3 (0.67)	<0.0001
	Average	42.3	27.3	<0.0001
Wet-Bulb Globe Temperature (WBGT) Index	Head	32.55 (7.3)	22.5 (0.5)	<0.0001
	Abdomen	32.74 (7.1)	22.7 (0.51)	<0.0001
	Ankle	32.38 (7.7)	22.25 (0.53)	<0.0001
	Average	32.6	22.5	<0.0001

Table 3. Results of Measuring Wet-Bulb Globe Temperature and Metabolism in Different Groups

Group	Workshop	Section	Work Groups	Number of workers	Metabolism (Kcal/hr)	WBGT (°C)
Control	CNC	CNC	Milling Machine Operator	10	314.84	22.7
			CNC Machine Operator	10	314.69	22.4
Case	Casting	Melting	Furnace Operator	21	213.5	29.41
	DIZA		Holder Operator	4	254.6	32.42
			Pouring Operator	4	161.84	31.5
	BMD		Melting operator	6	252.76	37

degrees Celsius for globe temperature. The results of the independent samples t-test indicated that the mean values, standard deviations, wet and dry temperatures, globe temperatures, and wet-bulb globe temperature indices were statistically significantly higher in the case group compared to the control group.

In this study, atmospheric conditions were measured in four selected job groups in the case group (furnace operators, holder operators, melting operator, and pouring operator) and two selected job groups in the control group (milling machine operator and CNC machine operator). The wet-bulb globe temperature index and metabolic rate were determined. Finally, the average wet-bulb globe temperature index was calculated for the two groups. Table 3 presents the results of the wet-bulb globe temperature index measurements in these groups. All individuals in the case group had a moderate work metabolism (200–300 kilocalories per hour); therefore, the role of metabolic heat was less significant, and the major changes were due to the heat of the work environment.

The results indicated an average wet-bulb globe temperature (WBGT) of 22.5°C for the CNC workshop (control group) and approximately 32.8°C for the iron casting workshop (case group). Considering that operators of melting, milling, and CNC machines work continuously, while operators of holders, pouring, and melting work only 15% of the time and rest 50% of the time, the permissible limits of the WBGT index were determined from the relevant tables (20). Figure 1 compares the measured values of the wet-bulb globe temperature index with the permissible limit values across different sections of the study. This assessment revealed that individuals in the case group experienced heat stress, whereas individuals in the control group worked under thermal comfort.

Blood Parameters

In Table 4, the mean, standard deviation, maximum, and minimum values of the measured leukocyte levels in the case and control groups are presented.

The levels of white blood cells, lymphocytes, and the combined count of basophils, monocytes, and eosinophils (referred to as Mix) were lower in the case group compared to the control group. A significant inverse correlation was observed between heat stress exposure and both white blood cell and lymphocyte levels ($P < 0.05$). Additionally, a significant direct correlation was found between heat stress exposure and neutrophil levels, as well as the neutrophil-to-lymphocyte ratio ($P < 0.05$). As heat stress levels increased in the case group, both neutrophil levels and the neutrophil-to-lymphocyte ratio rose significantly. However, no significant relationship was detected between heat stress exposure and the combined levels of basophils, monocytes, and eosinophils (Mix) ($P > 0.05$).

Leukocyte levels were measured separately in different sections of the foundry, namely, melting, DISA, and BMD. The lowest leukocyte levels were observed in the BMD section of the foundry. There was no significant difference between the measured values in different sections of the foundry. According to Tables 5 and 6, there was no significant difference in the mean leukocyte levels among different age groups and years of service ($P > 0.05$)..

Relationship between WBGT Index and Leukocyte Levels

Figure 2 illustrates the relationship between changes in the WBGT index and each of the measured blood parameters. Each of the four points depicted on the

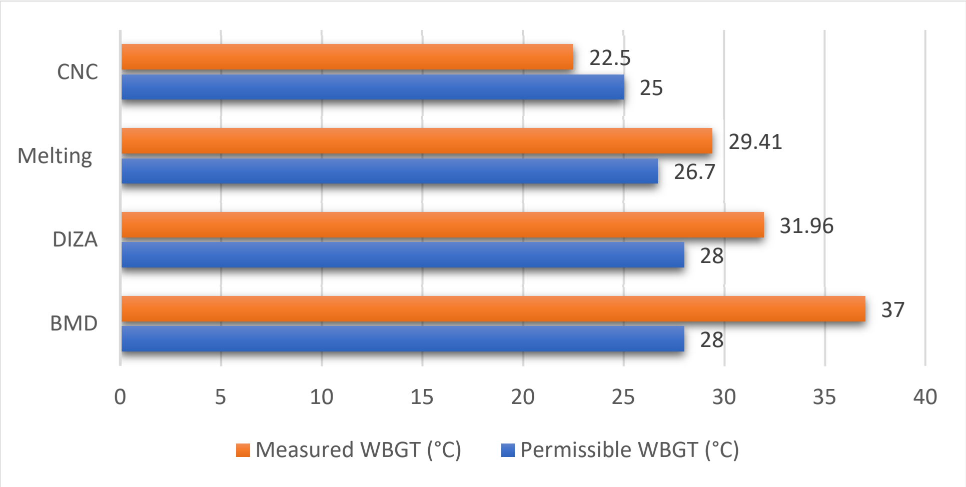

Figure 1. Comparison of Measured WBGT Values with Permissible Exposure Limit Values Across Various Study Sections

Table 4. Results of measuring leukocyte levels

Variables	Mean ± Standard Deviation		Maximum		Minimum		P-Value
	Case	Control	Case	Control	Case	Control	
White Blood Cell Count (thousands per milliliter)	6.1 ± 16.0	7.02 ± 1.07	8.3	8.7	4.2	5.2	0.008
Neutrophils (%)	56.3 ± 6.89	51.51 ± 8.41	68	67	40	32	0.015
Lymphocytes (%)	35.33 ± 6.4	40.52 ± 8.36	50	60	25	24	0.022
Neutrophil-to-Lymphocyte Ratio	1.67 ± 0.4	1.37 ± 0.5	2.68	2.67	0.8	0.53	0.03
Mix* (%)	8.34 ± 2.01	9.52 ± 1.5	12	12	4	5	0.226

* The combined count of basophils, monocytes, and eosinophils

Table 5. Average leukocyte levels in different age groups

Age Group (Years)	20-25 (n=4)	26-30 (n=14)	31-35 (n=23)	36-40 (n=9)	41-45 (n=5)	P-Value
White Blood Cell Count (thousands per milliliter)	6	6.87	6.22	6.63	6.26	0.711
Neutrophils (%)	53.33	57	54.54	54.42	52.4	0.737
Lymphocytes (%)	37.66	34.22	37	37.15	40.2	0.474
Neutrophil-to-Lymphocyte Ratio	1.43	1.75	1.56	1.58	1.4	0.547
Mix* (%)	1.73	8.77	8.54	8.54	8.2	0.96

Table 6. Average leukocyte levels in different categories of work experience

Work Experience Category (Years)	<5	5-10	11-15	16-20	P-Value
Number of Workers	5	28	18	4	
White Blood Cell Count (Thousands per microliter)	6.32	6.55	6.58	6.3	0.873
Neutrophils (Percentage)	52.28	56.78	54.4	51.81	0.151
Lymphocytes (Percentage)	38.14	34.63	38.13	39.6	0.18
Neutrophil-to-Lymphocyte Ratio	1.38	1.74	1.56	1.37	0.152
MIX (Percentage)	9.57	8.55	7.86	9	0.195

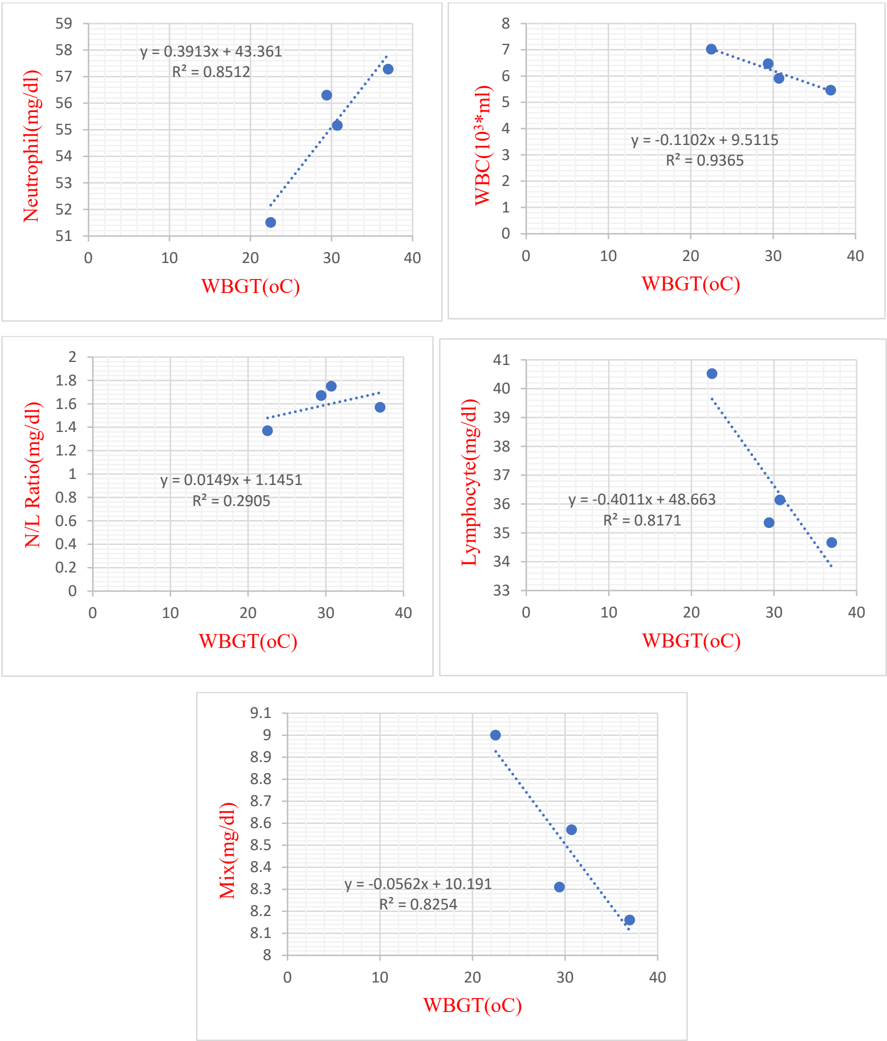

Figure2. Relationship between changes in the WBGT index and each of the measured blood parameters

Table 7. Average measurement results of interfering variables (sound and lighting)

Variables \ Statistical Indicators	Case	Control	P-Value
	Mean (Standard Deviation)		
Sound (dB A)	84 (4.8)	83 (3.91)	0.252
Light (Lux)	155 (9.88)	165 (6.73)	0.07

graph represents the average values from the four groups analyzed in this research, including one control group and three case groups, categorized according to the measured WBGT index. The results indicate a linear relationship characterized by a high correlation coefficient among the number of white blood cells ($R^2 = 0.93$), neutrophils ($R^2 = 0.85$), lymphocytes ($R^2 = 0.81$), and mixed white blood cells ($R^2 = 0.82$) with the wet-bulb globe temperature index. The strongest correlation was noted between the heat stress index and the number of white blood cell.

Table 7 presents the mean results of measurements for the intervening variables (noise and lighting) in both the case and control groups. The mean noise level in the case group was 84 decibels, while the control group exhibited a mean noise level of 83 decibels. There was no significant difference in the mean noise levels between the two groups ($P > 0.05$). The mean lighting level in the case group was 155 lux, whereas the control group demonstrated a mean lighting level of 165 lux. Similarly, there was no significant difference in the mean lighting levels between the two groups ($P > 0.05$).

DISCUSSION

The average wet-bulb globe temperature (WBGT) for the CNC workshop (control group) was measured at 22.5°C, whereas the average for the foundry (case group) was 32.79°C. The WBGT index across various workstations in the foundry was 29.41°C for 24 furnace operators, 32.42°C for 15 holder operators, 37°C for 4 melters, and 31.5°C for 8 pouring operators. In contrast, the WBGT index at different workstations in the machining (CNC) workshop was 22.7°C for 30 milling machine operators and 22.4°C for 30 CNC machine operators. By comparing these results to established standards, it can be inferred that individuals working in the foundry were exposed to heat stress, while those in the machining workshop experienced thermal comfort (Figure 1).

Numerous studies have used the WBGT index to assess heat stress, and the results of these studies have shown that this index has good reliability [21, 22]. Hajizadeh et al. conducted a study to validate heat stress indices for heavy activities in hot and dry climates, demonstrating that, due to its ease of measurement and calculation—and considering some limitations associated with other indices, such as the heat stress index (HSI)—the WBGT can be introduced as the most reliable empirical index of heat stress [23].

The results of this study indicated that heat stress can lead to a decrease in the number of white blood cells (WBC) in the exposed group ($P < 0.05$). Rahman et al. found that an increase in temperature results in significant changes to plasma biochemical indices and elevated hemoglobin levels, concurrent with a decrease in white blood cell counts [24]. Berian et al. also highlighted the same result [14]. Bao et al. conducted a study comparing two groups subjected to heat stress (35°C) and a control group (28°C) in animals. Blood samples were collected at 0, 6, 12, 24, and 48 hours post-exposure. The results of this study revealed that white blood cell levels increased, reaching a maximum after 12 hours of exposure before subsequently decreasing. It is noteworthy that the findings from this study were examined during the acute phase, while the results of our study were assessed in the chronic phase. This discrepancy in findings may be attributed to this distinction. Furthermore, this study indicated that prolonged exposure to heat stress leads to significant changes in metabolism, leukocyte levels, and the immune system [25].

Heat stress resulted in a decrease in lymphocyte levels in the exposed group ($P < 0.05$). However, no significant relationship was observed between mixed white blood cells and heat stress ($P > 0.05$). A study by Xu et al. (2018) demonstrated that heat stress leads to a reduction in lymphocytes [26]. Zafalon-Silva et al. (2017) investigated nuclear abnormalities in red blood cells and leukocyte characteristics following exposure to heat stress in fish and found a decrease in circulating lymphocytes alongside an increase in monocyte levels. However, no significant changes were noted in the total number of mixed white blood cells (basophils, monocytes, and eosinophils) [27]. Overall, most studies have reported disturbances in lymphocyte levels [28]. This decrease in lymphocyte levels after exposure to heat stress suggests a reduction in the number of viable cells and their responsiveness to mitogens [29].

The results of the study indicated that heat stress caused an increase in neutrophils ($P < 0.05$). A study by Behera et al. aimed to investigate the ameliorative effect of vitamin C on hematobiochemical and oxidative parameters in animals during the summer. They found that after 45 days of exposure to heat stress, lymphocyte levels decreased, while neutrophils and the neutrophil-to-lymphocyte ratio increased [13]. Cortisol is a primary factor responsible for the increase in neutrophil counts following activity in hot environments. These hormonal changes are associated with an elevation in core body temperature. However, some studies have reported an increase in total leukocyte and neutrophil counts in the absence of cortisol [30]. Factors such as catecholamines, cardiovascular changes, growth hormone, and prolactin have been identified as additional, unknown contributors to elevated neutrophil levels [16, 31].

One of the most important and reliable physiological indicators of the response to environmental stressors in animals is the heterophil-to-lymphocyte ratio, whereas in humans, it is the neutrophil-to-lymphocyte ratio [32]. This ratio increases in response to various stressors, such as heat stress—a finding that is consistent with the results of the present study and those reported by Asghari et al. [33]. In their study, stressors were shown to inhibit the production of factors that influence lymphocyte proliferation, such as interleukin-2 (IL-2). Consequently, the production of neutrophils from bone marrow in individuals facing unfavorable environmental conditions, such as heat stress or challenges from other pathogens, is elevated, ultimately resulting in an increased neutrophil-to-lymphocyte ratio. Generally, the production of neutrophils is stimulated by cytokines known as colony-stimulating factors (CSF). These cytokines are secreted by various cell types in response to infection and exert their effects on bone marrow cells, resulting in the proliferation and maturation of neutrophil precursors.

The results of leukocyte level measurements among the three different sections (DIZA, BMD, Casting) in the case group (foundry) showed that the lowest lymphocyte count and the highest neutrophil count were observed in the BMD section, which had the highest wet-bulb globe temperature index. Additionally, the highest lymphocyte count in the case group was found in the melting section, which had a lower WBGT index compared to other sections. However, no significant difference was observed between the measured blood values in the different sections of the foundry ($P > 0.05$). The lack of significance could be attributed to the small sample size.

Other factors contributing to heat-related disorders include obesity, chronic diseases, certain medications, heat intolerance, low-salt diets, and inappropriate workwear [34]. Tables 5 and 6 analyze the effects of heat stress on different age groups and work experience. However, no significant difference was observed in the mean leukocyte levels among various age groups and work experience within the study population. This finding may be due to the small and unequal sample sizes in each group. The majority of individuals [23] were aged 31–35, and 28 workers had 11–15 years of experience. According to Moradi et al., who examined the effect of age and exercise stress on blood cell counts in three groups—young (30 individuals), middle-aged (30 individuals), and elderly (27 individuals)—it was demonstrated that blood cell (leukocyte) responses are not age-dependent, and no significant difference was observed among the three groups [35]. However, some studies have reported significant changes in blood cell counts with advancing age [36]. It is recommended that these parameters (age and years of service) be investigated in larger sample sizes to draw more definitive conclusions.

Based on the presented graphs (Figure 2), there is a strong inverse linear relationship between the number of white blood cells, lymphocytes, and mixed white blood cells (basophils, monocytes, and eosinophils) and the wet-bulb globe temperature heat stress index. Conversely, there is a strong direct linear relationship between the heat stress index and the number of neutrophils. However, the graph of changes in the neutrophil-to-lymphocyte ratio in relation to changes in the heat stress index showed a direct linear relationship with a low correlation coefficient.

Previous studies indicate that the WBGT index is a suitable indicator for assessing heat stress conditions and has a high correlation with hematological [21], physiological [34], and functional parameters [4]. A study by Kim et al. on animals showed a correlation between the WBGT index and some blood parameters, such as white blood cells and lymphocytes, with a high correlation coefficient ($R = 0.8368$) [37]. Another study by Adriani et al., which aimed to investigate the correlation between blood parameters and the temperature-humidity index (THI), showed results similar to the current study. It found a positive correlation between the heat stress index and neutrophils (R = 0.78) and a negative correlation between the heat stress index and lymphocytes (R = -0.12). Blood leukocytes can be evaluated as biomarkers of heat stress [38].

The results of the measurements indicated no significant differences in the mean lighting and sound levels between the two groups (P > 0.05). A study by McCarthy and colleagues, which aimed to investigate the effects of noise stress on leukocyte function, revealed that neutrophil function was altered, while lymphocyte function remained unchanged after exposure [39]. Another study conducted by Zheng and colleagues demonstrated that acute exposure to noise stress may enhance immune responses, whereas chronic exposure may suppress cellular and humoral immune functions [40]. In the present study, the intervening parameters between the two groups were standardized as closely as possible to mitigate their impact on the primary factors. Heat stress is an undeniable hazard in workplaces, particularly in developing countries, and is regarded as one of the detrimental factors in the work environment [41]. Overall, the findings of this study suggest that working in hot environments can lead to chronic reductions in leukocyte levels, subsequently weakening and suppressing the immune system. Environmental stressors, such as heat stress, have been shown to affect immune system function, leading to alterations in both cellular and humoral immunity, thus making individuals more susceptible to infections. The physiological responses elicited after working in hot environments can be attributed to the activation of the hypothalamic-pituitary-adrenal (HPA) axis and the parasympathetic nervous system [8]. Workers in the foundry industry, which poses a high risk for heat-related diseases and injuries, should undergo regular evaluations and monitoring. The lack of an occupational health and safety program to protect these workers may result in irreversible consequences. Limitations of this study include a small sample size and the potential confounding effects of other hazardous factors present in the work environment on the study outcomes.

CONCLUSION

The average wet-bulb globe temperature (WBGT) index for individuals in the case group was 32.79°C, with all workers in this group exposed to heat stress. The findings of this study indicate that the WBGT index is an effective tool for assessing heat stress in workplace environments and shows a strong correlation with leukocyte levels. Heat stress can lead to a reduction in white blood cells and lymphocytes, while increasing neutrophils and the neutrophil-to-lymphocyte ratio in the case group compared to the control group. Further research in this area is essential to elucidate the trends in changes to the studied blood components when exposed to heat stress, taking into account other harmful factors to corroborate the hypotheses presented in this research.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

ETHICS APPROVAL ETHICS APPROVAL

Ethical approval for this study was obtained from the Ethics Committee of Shahid Beheshti University of Medical Sciences.

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