Original Article

Heat Stress level and Physiological Parameters among an Open-Pit Mine Workers in Razavi Khorasan, Iran

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Abstract

Background: Heat stress is a common occupational health hazard at outdoor workplaces such as mining. The aim of this study was to determine the level of heat stress indices and by measuring physiological Parameters among mine workers and comparing the appropriateness of these indices for measuring heat stress in an iron ore open pit mine. **Material and Methods:** This cross-sectional study was conducted during summer 2014 on one hundred and twenty male mineworker. Tympanic temperature was measured using a digital thermometer (model FT70) and Heart rate was measured using a digital Emsig device (model BO26). The Physiological strain index was calculated using a standard formula. All environmental and physiological parameters were simultaneously measured and recorded during rest and work. Heat indices were calculated using the related formula. Moreover, the participants completed the Heat Strain Score Index questionnaire. **Results:** The mean Wet Bulb Globe Temperature index in work state was 30.76 ± 1.56°C, the mean Environmental stress index 29.23 ± 1.26°C, the mean Modified discomfort index 27.75 ± 1.23°C and the mean risk level of Heat Strain Score Index 19.38 ± 4.04. A statistically significant correlation was found between heat stress indices and physiological indices (P<0.01). According to the results of Pearson's correlation coefficient test, the correlations between Physiological strain index and the indices of Wet Bulb Globe Temperature, Environmental stress index, Modified discomfort index, and Heat Strain Score Index were 0.658, 0.612, 0.614, and 0.417, respectively. Environmental stress index had the highest correlation with the deep body temperature. Moreover, the highest correlation was observed between Wet Bulb Globe Temperature and heart rate and Physiological strain index. **Conclusion:** Wet Bulb Globe Temperature showed a better correlation with physiological indices. Thus, it can be concluded that Wet Bulb Globe Temperature is a more appropriate index to evaluate heat stress in such workplaces.

Keywords: Heat stress; Physiological strain index; Open-pit mine

Abbreviations: WBGT: Wet Bulb Globe Temperature index; ESI: Environmental Stress Index; HSSI: Heat Strain Score Index; PSI: Physiological Strain Index; DI: Discomfort Index; SWreq: Required Sweat Rate; PHSHR: Physiological Strain Index Based on Heart Rate; MDI: Modified Discomfort Index

Introduction

Heat stress is a common occupational health hazard at outdoor workplaces such as mining [1] and can be influenced by external and internal factors which can lead to fatigue and stress in the body in a long term. Internal factors that determine the level of heat stress imposed on the body include deep body temperature, acclimatization, natural heat tolerance, and heat produced by metabolism of the body which is dependent on the workload. On the other hand, the external factors include the ambient temperature, radiant temperature, air velocity, and humidity which in very hot workplaces can reduce productivity, increase the risk of accidents, and also increase the risk of heat-related disorders. [2,3]. Given the importance of heat in the workplace which acts as a hazardous physical agent and because of its long term effects on employees, this study investigated the effects of heat indices on work environment and evaluated the level of heat stress in workers in an iron ore open pit mine.

Because of an increase in the number of population, there is a growing need for iron to be used in industrial environments and building construction. Moreover, following the plan for the expansion of iron ore mines in the country, the number of employees in this industry is increasing every day. According

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to a report by the Statistical Center of Iran in 2011 our country had a total of 5246 mines with 84,528 employees; it suggests that a large population of employees is working in this industry. Hence, it is necessary to conduct comprehensive studies in mine workplaces.

Several studies have been conducted in the world at the different workplaces to assess heat indices and estimate heat strain. Morioka, et al. used Wet Bulb Globe Temperature index (WBGT) to study the effects of heat on the health status of construction workers. According to their findings, with an increase in WBGT index, the workers' blood pressure increased too. [4]. In a study by Moran, et al., the relationship between Environmental stress index (ESI) and physiological parameters was investigated and the results showed that there was a high correlation between ESI and physiological parameters such as deep body temperature, heart rate, and sweating. [5]. the study of Peiffer and Abbiss conducted on miners working in an iron ore mine in northwest of Australia, the effect of heat stress (WBGT>30°C) on the workers was investigated and the results showed that deep body temperature of the workers was higher at the end of shift work (37.6°C) than in the beginning of the shift work (37°C). Moreover, the dehydration of workers at the end of the shift work was higher than the standard level (USG=1.02); in addition, the workers had also higher levels of exhaustion at the end of the shift work. [6]. Hunt, et al. investigated heat strain and state of hydration in workers in operating units of an open pit mine; according to the results, the mean deep body temperatures was 37.5°C and urine-specific gravity was 1.024. Furthermore, the results showed that 73% of workers showed at least one of the heat-related illness symptoms during the shift work. [7]. The Dutta, et al. study showed that heat stress levels (mean WBGT equal to 32.4°C) were higher than standard exposure limits and construction workers suggest that heat-related symptoms increased in summer. [8].

In a study Dehghan, et al. examined the relationship between Heat Strain Score Index (HSSI), WBGT, and PSI in a hot work environment; it was found that compared with WBGT, HSSI had higher correlation with PSI. [9]. The study by Falahati, et al., there was a significant correlation between heath indices with deep body temperature. Moreover, WBGT was the most accurate index for estimating heat stress in employees. [10]. In Monazzam, et al. study WBGT had the highest correlation with heart rate, systolic and diastolic blood pressure, and skin temperature (0.731, 0.451, and 0.375, respectively). Moreover, the correlation between DI and the mentioned items was 0.725, 0.446, 0.352, and 0.695, respectively. Furthermore, SWreq had the highest correlation with deep body temperature (0.766). [11]. In a study by Alimohamadi, et al., the results showed a statistically significant correlation between deep body temperatures (tympanic and oral) and the mentioned indices. Moreover, WBGT was the most accurate index to determine the heat stress in the studied workers. [12]. In Heidari et, al. study workers were experiencing high heat stress and the highest correlation was observed between aural temperature and WBGT. [13]. In this study, we aimed to determine the level of heat stress indices and by measuring physiological Parameters among mine workers and comparing the appropriateness of these indices for measuring heat stress in an iron ore open pit mine.

Material and Methods

The study area and sample size

This cross-sectional study was conducted in the summer of 2014 in various operating units of an iron ore open pit mine located in the East of the country. Using the sample size formula and considering the correlation coefficient (Eq. 1), a total of 120 male subjects were enrolled into the study.

$$N = \left(\frac{Z_{\alpha} + Z_{\beta}}{C(r)} \right)^2 + 3 = 120 \qquad (1)$$

In order to estimate the sample size, type I error i.e., α was set at 0.05, type II error (test power) i.e., β was set at 10%, and correlation coefficient i.e., Cr was set at 0.45 and these values were entered in the formula. Inclusion criteria were as follows: Lack of cardio-vascular diseases, thyroid diseases, blood pressure, diabetes, fever diseases, ear infections, and hyperthyroidism, not taking anti-diuretic drugs, and not taking the drugs affecting heart rate. The subjects entered into the study on a voluntary basis. Working hours of the subjects was as follows: they started working in different units at 7 am; they had lunch and take a rest from 12 pm to 13 pm; they worked again from 13 pm to 16 pm. Only the workers in Operation unit had a shorter working hour (usually from 8:30 am to 13 pm). On the day before the measurement, the subjects were introduced with the aim of the study and were recommended to observe some items such as getting enough rest at night. Taking into consideration the conditions of each operating unit, a prior coordination was made each day and a number of the subjects were monitored. While measuring the items, it was tried to monitor people in the same condition. Considering the likely time a person could cooperate, it was decided to monitor each person for two hours.

Collecting demographic data of the workers

A questionnaire was designed to collect data about the workers demographic features, and it was completed through questioning the people who were in expose to heat. Considering the inclusion criteria, the eligible persons were entered into the next stage of the study.

Measurement of physiological parameters

Physiological parameters of the subjects working in the two work units under the study were measured in two stages in accordance with the ISO9886-2001 standard. In every unit, other than operation unit, a break room or containers near the workplace is intended to be used for taking a break (lunch and prayer). In the first phase, after raking a rest for 30 minutes in the break room, physiological parameters were measured at the 20th, 25th, and 30th minutes of the break and their mean was recorded as the baseline value (Mean and standard deviation of WBGT Index in the break room was 23.72 ± 0.53°C). In the second phase, after the end of measurements at the time of the break, the subjects were asked to return to their workplace and start their work. The workers whose workplace was far from the break room, like those working in operation unit, were transported to their workplace by a car. After starting to work, physiological parameters were measured at the 20th, 40th, and 60th minutes of work and mean values were recorded. [14]. During the work activity, the person was monitored for 1 hour. A digital thermometer, model FT70 (Beurer) made in Germany, was used for measuring of the tympanic temperature. The device accuracy was ± 0.2°C and its measurement range is from 34°C to 43°C. Heart rate and blood pressure were measured using a digital sphygmomanometer, model Emsig BO26 made in Taiwan. People's metabolic rate during working hours was determined by the ISO8996 standard tables. Then, using equation 2 mean value of metabolism during shift work was calculated for each of them.

$$\bar{M} = \frac{1}{T}\sum_{i=1}^{n} M_i \times T_i \quad (2)$$

Mi: metabolic rate of each activity, Ti: time for each of different activities, T: duration of work time in a shifts, and $\bar{M}$: mean rate of metabolism in a shift work in terms of W/m^2.

Measurement of environmental variables

A measurement station at each work unit near the workers workplace was selected and, in addition to the measurement of the physiological parameters, the environmental variables were simultaneously measured and recorded. Moreover, in order to compare the measured values with the standards, environmental variables were measured at different times during the work shift, and the time-averaged of WBGT index was calculated. To measure environmental variables, WBGT meter model Casella and hygrometer model Casella were used; in addition, air velocity was measured using a silver-plated kata thermometer model N240 Casella London, with a Kata factor of 420 and a cooling rate of 52-55°C. In accordance with ISO7243 standard and based on the pre-test the working environments of the workers were congruent in terms of temperature, hence the measurements were carried out only in the waist of the workers (1.1 m) and the Factor for clothing (Clo) was estimated in accordance with ISO 9920 standard.

Measurement of heat indices

WBGT index was calculated using equation 3. As the studied workers were using usual work clothes and worker jumpsuits, after estimating the WBGT index the estimated values were modified based on the type of the clothes. [15]

$$\mathrm{WBGT} = 0.7 \times t_{nw} + 0.2 \times t_g + 0.1 \times t_a \quad (3)$$

To calculate the time weighted average WBGT index from equation (4) below were used.

$$WBGT - TWA = \frac{(WBGT1 \times T1) + (WBGT2 \times T2) + \ldots + (WBGTn \times Tn)}{T1 + T2 + \ldots + Tn} \quad (4)$$

$WBGT_n$: WBGT at different hours shift work (°C)

T_n: Duration of exposure (8 hours)

ESI Index also by using Equation 5 was calculated. [16] In order to measure the Modified discomfort index (MDI) we used Equation 6.

$$ESI = 0.62 \times t_a - 0.007 \times RH + 0.002 \times SR + 0.0043 \times (t_a \times RH) - 0.078 \times (0.1 + SR)^{-1} \quad (5)$$

$$MDI = 0.75 \times t_{nw} + 0.3 \times t_a \quad (6)$$

The questionnaire of Heat Strain Score Index (HSSI) on the Iranian women workers with Cronbach's alpha coefficient 0.68 was validated. [17] This questionnaire was completed for all the subjects. The questionnaire included 17 questions; items 1 to 12 were completed via asking the questions and items 13 to 17 were completed by observing the subjects at work. Finally, the resulting score was calculated for each individual to determine the level of risk for each worker. There were three levels of risk as follows: the total scores of less than 13.5 indicated that the person did not have a heat stress (green area), the total scores between 13.6 and 18 indicated that the person was likely to have a heat stress (yellow area), and the total scores of greater than 18.1 indicated that the person had a heat stress (red area). [18] In order to measure the PSI, we used Equation 7.

$$PSI = 5(T_{ret} - T_{re0}).(39.5 - T_{re0})^{-1} + 55(HR_t - HR_0).(180 - HR_0)^{-1} \quad (7)$$

In the above equations Tri and Tr0, are the deep body temperatures (°C) and HRi and HRo are an indicator of heart rate (Beats/min), respectively, at rest and work. PSI has a 10-point scale in which the numbers zero and 10 indicate lack of strain and the highest rate of strain, respectively. [19]

Data analysis

After calculating the heat indices, statistical analysis was performed using SPSS software Version 22. Kolmogorov-Smirnov test was used to check the normal distribution of variables. As the variables were normal, Pearson correlation test was used for analysis.

Results

A total of 120 male workers who were active in the main working units of the mine were enrolled into the study. Table 1 presents the demographic characteristics of people who participated in the study. The subjects' metabolism of the workload was moderate (165.9 ± 23.8 W/m^2; range about 101-245). About half of the studied workers were using worker jumpsuit (Two-Layer). The mean and standard deviation of the Body Mass Index (BMI) of the subjects was 24.93 ± 3.59 kg/m^2.

Table 2 presents the mean value of the environmental parameters measured at the work hours. Table 3 presents the results of physiological parameters of the workers including the tympanic temperature, heart rate, and PSI. The mean (SD) of physiological parameters of tympanic temperature and heart rate in the work hours, respectively, were 37.5 ± 0.56°C and 87.5 ± 9.4 beat/min which were higher than the values observed at the time of the break (i.e., tympanic temperature: 36.3 ± 0.35°C and heart rate: 74.7 ± 6.9 beat/min. Moreover, the mean (SD) PSI index increased from 0.6 ± 0.36 at rest to 2.5 ± 1.4 at the work hours.

Table 4 shows the calculated heat indices. The mean (SD) of Empirical heat indices in the work state was higher than that the break time. The mean risk of HSSI in the work state was estimated to be 19.4 ± 4.04.

Table 5 presents the estimated values for the correlation coefficient between the Heat Stress Indices as independent variables and physiological parameters of the subjects and the physiological strain index (PSI) as dependent variables. To examine the relationship between heat indices and physiological indices we used the Pearson correlation test and the results showed a significant direct linear relationship between each of the heat indices and physiological indices (P<0.01). Based on the results of Pearson correlation test, the estimated value of R for the changes in the relationship between PSI index at rest and work and WBGT, ESI, MDI, and HSSI were 0.593, 0.591, 0.501, and 0.327, respectively.

Table 1: Demographic variables of the studied workers

Parameters	Range	Mean ± (SD)
Age (years)	18-55	33.92 (7.79)
Weight (kg)	50-115	72.25 (12.49)
Height (cm)	153-191	173 (0.075)

Table 2: Environment variables measured in work state

Variables	Min	Max	Mean ± SD
Ta (°C)	33.5	43	38.5 ± 2.96
Tnw (°C)	19	23	21.6 ± 0.85
Tg (°C)	47	58	53.8 ± 2.52
SR (W.m^{-2})	960	1004	982.8 ± 10.23
RH (%)	12	34.5	21.9 ± 6.32
Va (m.s^{-1})	0.92	14.5	6.7 ± 3.23

Table 3: Physiological parameters of subjects at rest and work states

State	Rest		Work	
Parameter	Range	Mean ± SD	Range	Mean ± SD
Core temperature (Aural) (°C)	35.5-37.1	36.3 ± 0.35	36.3-38.9	37.54 ± 0.56
Heart rate (beats/min)	57-93	74.7 ± 6.9	68-112	87.48 ± 9.4
PSI	0-1.6	0.6 ± 0.36	0.4-5.7	2.5 ± 1.4

Table 4: Values heat stress indices are calculated at rest and work states

State	Rest		Work	
Index	Range	Mean ± SD	Range	Mean ± SD
WBGT (°C)	23-25.2	23.7 ± 0.54	27.1-33.8	30.76 ± 1.56
ESI (°C)	23.3-26.4	24.07 ± 0.7	26.5-31.8	29.23 ± 1.26
MDI (°C)	24-26.6	24.76 ± 0.55	24.5-30.2	27.75 ± 1.23
HSSI (Risk Level)	-	-	12.78-28.6	19.38 ± 4.04

Table 5: Pearson's correlation coefficient between heat stress indices and physiological indices

Index	Core temp. (Aural)		Heart rate		PSI		PSI Differences	
	r	P-value	r	P-value	r	P-value	r	P-value
WBGT	0.592	0.001	0.624	0.001	0.658	0.001	0.593	0.001
ESI	0.614	0.001	0.482	0.00	0.612	0.001	0.591	0.001
MDI	0.589	0.001	0.479	0.001	0.614	0.001	0.501	0.001
HSSI	0.373	<0.01	0.450	<0.01	0.417	0.001	0.327	<0.01

According to Table 5, comparing the correlation between the heat index and the physiological indices, it was found that ESI had the highest correlation with the deep body temperature (0.614). The highest correlation values observed between WBGT and heart rate and PSI were 0.624 and 0.658, respectively.

Discussion

In many mineral environments, long-term heat stress can cause fatigue and discomfort. Over the past 100 years, more than 50 heat stress indices have been introduced and developed to measure and assess the heat stress. [20] Moreover, some efforts have been made to devise a valid and complete index in order to evaluate heat stress and describe working conditions in terms of environmental stress. [21]

In this study, the heat stress indices were measured and physiological parameters were simultaneously measured and recorded during rest and work. The result of this study showed that the level of heat stress indices was higher in work state, as expected. The maximum WBGT was in work state and equal to 30.76 ºC which is higher ISO 7243 recommended limits, defined the allowed WBGT equal to 30 ºC. The most of studied subjects had a warm working condition, moderate metabolism and their mean physiological parameters were lower than the recommended standards.

In the present study, as compared with other indices, ESI had a higher correlation with the physiological parameter of deep temperature. However, a relatively weak correlation was observed between the HSSI and the deep body temperature. According to the results of a study conducted by Dehghan et al., HSSI, compared with the WBGT, had a higher correlation with the deep body temperature that is not consistent with the results of the present study. [9] The weak correlation observed in the present study could be due to environmental parameters such as cross-flow wind, low relative humidity in the workplace, and high level of exposure to direct sunlight; the mentioned factor could affect and cause disproportional changes in the deep body and skin temperatures, and lead to further dispersion and weaker correlation. In a study by Ghotbi et al., no significant correlation was observed between the HSSI score and the body deep temperature. [22] It is relatively in line with the results of the present study.

Claassen and Kok's study showed that the heat strain was underestimated when the WBGT had a value above 30 and when relative levels were humidity high. [23] Budd described one of the limitations of the WBGT; according to Budd, when the evaporation of sweat becomes limited due to the increase in humidity or decrease in the flow of air, the WBGT cannot correctly reflect the increased level of strain caused by reduced level of evaporation. [24] Therefore, environmental factors such as relative humidity and air flow can be effective parameters in the estimation of heat strain in the workplace. This study was conducted at a work condition with low relative humidity and moderate air flow which can prove the results of previous studies.

The results of a study by Hajizadeh et al. showed that the WBGT was significantly correlated with deep body temperature, heart rate, and the temperature of carotid artery of ear. [25] The results of this study are in line with the findings of Falahati et al. and Negahban et al. [10,16] In addition, the results of a study by Moran et al. also showed that a high correlation existed between ESI and deep body temperature, which is consistent with the results of this study. [5].

Heart rate can be used as a primary physiological index that increases when exposed to heat [11]. In this study, the correlation between heat stress indices and heart rate parameters indicated a significant relationship between the heat stress indices and heart rate. WBGT showed a higher correlation than the other indices; however, the HSSI showed a lower correlation with the heart rate. The results of this study are consistent with the findings of Monazzam et al. study. [11]. According to Dehghan et al.'s study HSSI had a moderate correlation with the heart rate which is consistent with the results of this study. [9]. In Dehghan, et al. study on workers in Hot/Humid working conditions (WBGT>30°C), the heart rate of subjects was increased and the overweight workers was showed cardiac strain higher in compared with that in normal weight workers. [27].

Previous studies have proven that the use of combined heat indices to measure heat strain will result in better outcomes. [28]. In this study, several indices of heat stress were used. The results of Pearson correlation test showed a significant association between heat stress indices and PSI. WBGT showed a higher correlation than the other indices, however, the HSSI showed a weaker correlation with PSI. The results of a study by Moran et al. showed a high correlation between environmental stress and psychological strain that is in line with the results of this study. [5]. Moreover, making an allowance for ESI and PSI, Moran et al. defined a cycle of work and rest at the workplace. [29]. In Dehghan et al. study, the deep body temperature parameter had a much higher correlation with a HSSI than the WBGT index. In addition, PSI was more correlated with the HSSI than the WBGT index; it is not consistent with the results of the present study. [9]. The findings of a study by Habibi et al. confirmed the results of this study and showed that the WBGT had a direct significant correlation with the physiological variables of heart rate, oral temperature, and PSI. With increasing the WBGT index, there was an increase in heart rate, oral temperature, and PSI. [28].

In this study, the MDI had a higher correlation with the PSI than the ESI. In addition, it showed a high correlation with the physiological parameters of deep temperature and heart rate; it is consistent with the results of Monazzam et al.'s study. [30]. According to previous studies the MDI, which is calculated based on the two parameters of dry and wet temperatures, have shown a high correlation with WBGT Index; thus it can be used in places where there is no suitable tool to evaluate heat stress. [31].

The mean PSI index at rest was calculated to be 0.6, indicating that the studied subjects did not have a strain. However, the mean PSI index at the work state was 2.5 ranging from 0.4 to 5.6, indicating that the subjects had low to moderate strain. Given that considerable variation exists between rest and work condition, the correlation between each of heat indices and the changes in PSI were evaluated at rest and work. The results showed significant correlation between heat stress indices and changes in PSI index. WBGT showed more correlation than other indices. Moreover, a relatively weak correlation was observed between the HSSI and changes in PSI.

Conclusion

According to the study results, the Heat Stress Indices had significant relations with deep temperature, heart rate, and PSI. In addition, WBGT index showed better correlation and had the highest correlation with the PSI. It can be concluded that to evaluate heat stress index in such workplaces, WBGT is more appropriate and valid.

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Conflicts of Interest

The authors declare that there are no conflicts of interests regarding the publication of this article.

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