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RESEARCH ARTICLE

Evaluation of Occupational Exposure to Heat Stress and Physiological Responses of Workers in the Rolling Industry

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Abstract:

Background and Objective:

Many indices are used to assess occupational heat stress at the work environments. The aim of this study was to evaluate heat stress using Wet Bulb Globe Temperature (WBGT) index and Discomfort Index (DI), and by measuring physiological responses in the workers of the rolling industry and comparing the appropriateness of these indices for measuring heat stress.

Methods:

This cross-sectional study was carried out on 90 healthy workers of a rolling industry in eastern Tehran in 2017. Physiological parameters of core body temperature (T_{cr}) and Heart Rate (HR) were measured during the working shift according to ISO9886 standard. At the same time, environmental variables such as the natural wet temperature (T_{nw}), dry temperature (T_d) and globe temperature (T_g) were measured and recorded at the workstations. Then, the DI and the WBGT indices were calculated using the related formulae. Data were analyzed using SPSS v. 21, t-test and Pearson correlation coefficient.

Results:

The mean heat stress indices were significantly higher in working conditions than resting conditions, and there was a significant difference between the physiological parameters of T_{cr} and HR in resting and working conditions ($P<0.001$). According to the screening criteria of DI, 43.3% of the workers were exposed to the moderate level and 56.7% to the severe level of heat stress. There was a significant difference between the mean WBGT and the Threshold limit values ($t= 4.903$, $P<0.001$). Pearson correlation test showed that there was a significant and direct linear relationship between the WBGT and the physiological parameters of T_{cr} and HR ($r=0.317$, $P=0.002$; $r=0.434$, $P<0.001$, respectively). The DI index had a significant and direct linear relationship with HR; ($r=0.229$, $P=0.03$).

Conclusion:

The results showed that WBGT is a more appropriate index for evaluating the heat stress of workers in the rolling industry. High heat stress levels at the workstations along with heavy physical activity are health risks for workers in this industry; therefore, interventions must be undertaken to reduce exposure.

Keywords: Heat stress, Wet bulb globe temperature, Discomfort index, Physiological parameters, Rolling industry.

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1. INTRODUCTION

Heat stress is one of the most harmful physical pollutants in the work environment, which is less studied among various harmful agents [1]. It is a profound damaging agent at hot workplaces if a worker is exposed to severe heat and humidity, radiations, physical contact with hot objects and heavy physical activity for a long time [1, 2]. Working in the rolling industry is a dangerous activity in terms of heat stress [3].

Most jobs need to be carried out in hot environments, which can affect the cooling system of the body when doing heavy physical work. Once the body is not able to maintain homeostasis between the captured and lost heat, heat damage can occur, which may get acute and even fatal in some cases [4]. Types of mild to severe heat disorders include: rash, heat cramp, syncope, heat exhaustion, and hyperthermia [5]. In addition, exposure to heat can cause disorders in mental health, increased medical expenditures and work accidents, reduced productivity and reduced physical capacity [5 - 7].

In order to ensure the health of workers, the heat stress and changes in physiological parameters under these conditions should be studied [8]. Evaluation of the heat stress in work environments can be performed by measuring environmental parameters and then their impact on the body by using a heat stress index or other indices [9]. Many attempts were made in the past century to develop indices that can adequately describe the amount of heat stress. Accordingly, a heat index has been developed to accurately predict the physiological strain of individuals in all thermal environments [10]. While a lot of research has been done to determine a final index, there is still much debate as to which index is more efficient and more correlated with physiological strains [11].

There is a dire to define a reliable and comfortable tool for monitoring of stressful conditions and prevent health damage to enhance the efficiency of workers in hot working environments. Many thermal indices have been developed for the evaluation of heat stress, and some of them have been specifically designed for industrial workplaces [12] and may not be suitable for small workshops such as the rolling ones.

These indices can be categorized in the three groups of rational, empirical, and direct indices [2]. The use of many of these indices necessitates the measurement of environmental variables, occupational conditions and various physiological parameters. Moreover, in order to measure some of these indices, there is a need for some special tools; the calculation process is also complex and requires the use of the computer. Among available thermal indices, the use of direct one was simple and easy with calculations based on environmental variables [13].

The Wet Bulb Globe Temperature (WBGT) is a simple heat stress index, which requires the natural wet temperature (T_{nw}), dry temperature (T_d) and globe temperature (T_g) measurements. This index has been introduced as a global standard and is applied to control the heat stress in many working environments [14]; being recommended by the International Standard Organization (ISO 7243) for the rapid assessment of hot environments [15]. It is the only index that measures T_g. On the other hand, the American Conference of Governmental Industrial Hygienists (ACGIH) has determined the limits of heat exposure, (Table **1**) [16], approved by the Occupational Health and Safety Organization (OSHA) and the American Industrial Hygiene Association (AIHA) [17]. The WBGT index, despite its extensive use, has a number of limitations [18].

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Discomfort Index (DI) is a direct one that has been recommended for more than four decades along with WBGT for rapid assessment of hot environments. It is simple and does not require complicated tools, with easy results' interpretation [19]. It was introduced by Thom and modified by Sahar *et al.* (1962). The parameters of T_d and T_{nw} are needed to measure DI index. It has a high correlation with the WBGT index (R^2 = 0.947) [19]. DI values are quite similar to WBGT index. Specified criteria have been estimated for the heat stress and its relation with the heat sensation based on a large number of studies in a wide range of community groups and in different climatic conditions [19]:

- For the DI values under 22, there is no heat stress.
- For DI values between 22 and 24, most people have a mild heat stress sensation.
- For DI values between 24 and 28, the heat stress is relatively heavy, and people feel very hot and physical work may be interrupted.
- For DI values above 28, the heat load is extreme, body temperature cannot be maintained during physical work resulting in high risk of heat-related disorders.

The combined effect of exposure to ambient heat and body heat production due to metabolism can cause heat strain in the body. Direct methods for assessing heat exposure are based on the measurement of the body's heat strain; a body's response to heat stress measurable by physiological parameters [20]. Various physiological parameters for assessing the heat strain include core body temperature (T_{cr}), Heart Rate (HR), dehydration and Urine Specific Gravity (USG) [21]. HR is a primary indicator for a physiological strain especially during work and rest [22]. The oral, eardrum, rectal and the urine temperatures can be recorded as T_{cr} [23]; an important criterion for the adverse health effects. The eardrum temperature is a good alternative to internal body temperature at the workplace, being non-invasive and promptly responsive to alterations in body temperature [22].

Skimpy research is available on evaluation of thermal indices as well as heat stress in Iran; thus requires further studies. On the other hand, considering the health of workers, evaluation of heat stress in different work environments, especially small and indoor workshops, which can be of great importance from in terms of occupational health as it plays an important role in the better analysis of working conditions and occupational health standards. The aim of this study was to evaluate the heat stress of workers in the rolling industry using DI and WBGT and comparing their relations with the physiological responses of T_{cr} and HR.

2. MATERIALS AND METHODS

2.1. Research Design

This descriptive-analytical cross-sectional study was carried out on workers of a rolling industry located in eastern Tehran in summers of 2017. This industry consists of various cutting equipment (n=17), melting furnaces (n=24), lathing machine (n=12), power posts (n=7), and scales (n=3), and production line (n=27) included; hydraulic pitch roller, scissors, stands, vertical loops, cooling, and knot. In this study, all workers were included in the study in a census. The inclusion criteria were; heat adaptation (more than one year of work experience), no cardiovascular disease, thyroid disease, hypertension, diabetes, febrile illnesses, ear infections, no antidiuretic drug consumption, and not taking any drugs that may affect HR.

On the day before making measurements, the objectives of the study and need for observation of instructions like resting at night was described to all subjects. According to the workshop conditions, and after coordination with a number of subjects, each working unit was monitored. During measurements, it was tried to measure the parameters on subjects under the same conditions and, considering the working duration of personnel, total measurement time was considered to be 2 hours for each person. The demographic variables were collected by a questionnaire containing information like age, height, weight, disease history, clothing type and color, health conditions, type of activity, use of gloves and socks, heat status, smoking, type of medications and the number of off days.

2.2. Measuring Environmental Variables

The environmental variables of T_{nw}, T_d and T_g were measured and recorded by the WBGT digital device model BK 874 made in the UK and at the workstations according to ISO 7243 standards [14]. To determine air velocity (V_a) the VT50 digital heat anemometer made in France was used. The calibration of the devices was approved prior to measurement and by competent authorities. Measurements were carried out at the nearest point to the workplace of individuals; and given the uniformity of conditions, each measurement was generalized for all employees.

2.3. Measuring Physiological Parameters

With environmental variables, physiological parameters of tympanic temperature, as the T_{cr}, and HR were measured simultaneously in two phases according to ISO 9886 standards [24]. In the first phase, after 30 minutes in the break room, at 20, 25 and 30 minutes, the physiological parameters including the T_{cr}, and HR were measured and their mean values were recorded as basic information. In the second phase, after measurements were done at the resting state and the worker got back to the workplace, the physiological parameters of the T_{cr}, and the HR were measured at 20, 40 and 60 minutes, and their means were taken. The eardrum temperature was measured by a digital thermometer FT70 (beurer) made in Germany. The accuracy of the device is ±0.2°C and its range is 34 to 43°C. The measurements of the tympanic temperature were made in the right ear. HR was measured by using LAICA MD 6132 made in Italy. This device is fastened to the arm of the subject by the cuff pressure and is able to measure the HR of people along with blood pressure. Workers' activities were carefully monitored and recorded to estimate the metabolic rate of individuals. The metabolism rate of individuals during the work shift was determined by the classification tables of the ISO8996 standard. Then, using Eq. **1**, the mean of metabolism rate was calculated for the subjects.

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

M_i: Metabolism rate of each activity, T_i: Time of each activity, T: the duration of work in a working shift, $\bar{M}$: Mean metabolism rate in each work shift in W/m^2.

In order to estimate the thermal insulation of clothing (Clo), workers' clothes were carefully investigated at work. Clothing type (long or short sleeves) and its thermal insulation were determined based on the ISO 9920 standard [25].

2.4. Measuring Heat Stress Indices

In order to calculate the WBGT index at indoor and outdoor environments, Eqs.**2** and **3** were used, respectively.

$$\mathrm{WBGT}_{in} = 0.7T_{nw} + 0.3T_g \quad (2)$$

$$\mathrm{WBGT}_{out} = 0.7T_{nw} + 0.2T_g + 0.1T_a \quad (3)$$

Considering that the work environment was somewhat inconsistent in some of the workstations, the measurement of the WBGT index was performed at three heights of ankle, waist and head, and the WBGT value was calculated using Eq.4 [15].

$$\mathrm{WBGT} = (\mathrm{WBGT_{head}} + (2 \times \mathrm{WBGT_{waist}} + \mathrm{WBGT_{Tankle}})/4 \quad (4)$$

Eq. 5 was used to calculate DI index [19].

$$DI = 0.5T_w + 0.5 \quad (5)$$

2.5. Statistical Analysis

Statistical analysis was performed using SPSS software (version 21, SPSS Inc., Chicago, IL, USA). Mean and standard deviation/SD (Minimum/Maximum) were reported for quantitative variables and frequency (percentage) for qualitative ones. Data were analyzed using T-test and Pearson correlation coefficient. The level of statistical significance was considered at $P<0.05$.

Table 1. Screening criteria for heat stress exposure based on ACGIH standard (WBGT values in °C).

Work and rest cycle	Acclimatized				Unacclimatized			
	Light	Moderate	Heavy	Very heavy	Light	Moderate	Heavy	Very heavy
100% work	29.5	27.5	26	-	27.5	25	22.5	-
75% work-25% rest	30.5	28.5	27.5	-	29	26.5	24.5	-
50% work-50% rest	31.5	29.5	28.5	27.5	30	28	26.5	25
25% work-75% rest	32.5	31	30	29.5	31	29	28	26.5

Table 2. Mean demographic variables of respondents (n=90).

Parameter	Min - Max	Mean ± (SD)
Age (years)	19 - 62	35.2 ± 8.74
Weight (kg)	54 - 115	75.71 ± 12.06
Height (cm)	160 - 190	173.05 ± 7.33
Metabolism (w/m^2)	140 - 295	182.94 ± 34.76

Table 3. Environmental variables measured at workplace of participants.

Variable	Rest state		Work state	
	Min - Max	Mean ± SD	Min - Max	Mean ± SD
T_{nw} (C)	22 – 24.5	22.88 ± 0.76	22.8 – 26.9	25.6 ± 0.92
T_a (C)	27 – 34	29.35 ± 2.18	27.4 – 36.9	30.95 ± 1.84
T_g (C)	28 – 36	31.07 ± 1.94	30.1 – 39.1	34.02 ± 1.98
V_a (m.s^{-1})	-	-	0.2 – 0.32	0.24 ± 0.04

Table 4. Physiological parameters of subjects.

Parameter	Rest		Work		*p*-value
	Min - Max	Mean ± SD	Min - Max	Mean ± SD	
T_{cr} (Aural) (C)	35.6 – 37	36.27 ± 0.3	36.3 – 38.9	37.61 ± 0.59	t=-19.95, P<0.001
HR (beats/min)	57 - 93	74.27 ± 6.87	73 - 117	92.97 ± 9.22	t=-16.12, P<0.001

Table 5. Heat stress indices at workstations.

Index	Rest		Work		*p*-value
	Min - Max	Mean ± SD	Min - Max	Mean ± SD	
DI (C)	25- 28.5	26.12 ± 0.93	25.9 – 31.85	28.28 ± 1.11	t= -13.96, P<0.001
WBGT (C)	24.4 – 26.9	25.34 ± 0.49	26 – 31.31	29.05 – 1.27	t= -26.94, P<0.001

3. RESULTS

The demographic variables of the subjects studied are shown in Table **2**. The mean age of subjects was 35.2 ± 8.44 years, weight 75.71 ± 12.06 kg and height 173.51 ± 7.33 cm. The mean metabolism rate of workers during the work was moderate and 182.94 ± 34.42 watts per square meter (w/m^2). About 41 (45.6%) of workers were wearing the overalls. The mean environmental variables were higher in working conditions than that of resting conditions. The mean of measured environmental variables by relaxation and working state of the subjects are presented in Table **3**.

The results of the physiological parameters of subjects are illustrated in Table **4**. The mean T_{cr} and HR were higher in working state than the resting state (P < 0.001).

Table **5** shows the mean of the calculated heat stress indices at rest and during work states. The mean DI and WBGT were significantly higher at work (P < 0.001).

Table **6** shows the exposure of respondents to heat stress based on DI criteria. About 39(43.3%) subjects experienced moderate and 51 (56.7%) severe levels of exposure to heat, and there was no mild level of exposure to heat stress. The workers of melting and then production line were more than exposed to heat stress. The average allowed limits of heat exposure was 28.32±0.38°C, most subjects were exposed to heat stress and there was a significant difference between the average WBGT and the threshold limit values (t=4.903, P<0.001).

Pearson correlation test showed that there was no significant correlation between metabolism with age and weight of the subjects (r = 0.023; r = 0.203, P <0.05, respectively). The results of the correlation coefficient related to heat stress indices and physiological parameters are presented in Table **7**. Pearson correlation test revealed a direct linear and significant relationship of WBGT with T_{cr} and HR. Pearson correlation test showed a significant direct linear relationship between the DI index and HR with r value of 0.229. The highest Pearson correlation coefficient was found between WBGT and HR (r = 0.434).

4. DISCUSSION

Heat stress at indoor work environments may occur by local exposure to heat sources, and may increase due to physical activity and clothing. Subjects who have been working for a long time in a hot environment with same conditions usually acclimatize to heat after a while due to physiological changes, which depends upon the level of activity as well as the duration of heat exposure. It is estimated that most people acclimatize gradually to the heat within 4 and 14 days

Table 6. Exposure to heat stress based on DI index criteria among study groups.

Criteria	Level	Total, n(%)	Cutting	Melting	Production	Lathing	Power and Scales
22 – 24	Mild	-	-	-	-	-	-
24 – 28	Moderate	39(43.3)	14(35.9)	-	4(10.26)	11(28.2)	10(25.64)
>28	Severe	51(56.7)	3(5.88)	24(47.06)	23(45.1)	1(1.96)	-

Table 7. Pearson's correlation coefficient between heat stress and physiological indices.

Index	T_{cr} (Aural)		HR	
	r	*p*-value	r	*p*-value
WBGT	0.317	0.002[a]	0.434	<0.001[a]
DI	0.019	0.859	0.229	0.03[b]

a, Significant at level p<0.01; b, Significant at level p<0.05

[26]. Improved heat tolerance is due to the ability to increase sweat and reduce HR. Sweating occurs in the lower core, with a reduction in skin temperatures and the amount of salt in sweat [27, 28].

This study was carried out on heat-acclimatized workers in the rolling industry with an aim of evaluation of occupational exposure to heat stress using the DI and the WBGT indices. The working conditions of most workers were in indoor environments, although the doors of the eastern and western sides were always open and the working environment has a public ventilation system. Moreover, the workers of cutting, power and scales units were also working in the outdoor environments. The results based on DI index criteria and WBGT index showed that most of the workers were exposed to heat stress. The values of WBGT were significantly different from the threshold limit values. In the study by Hamerezaee *et al.,* workers in the steel industry with $WBGT_{TWA}$ 35.76 C were exposed to higher values than the allowed limits. They also experienced more heat stresses than the present study [29]. According to Krishnamurthy *et al.* about 90% of the measured WBGT in steel workers exceeded the threshold limit values, which was related to the work units with radiation heat and moderate workload [30].

Perry *et al.* stated that to provide an optimal index based on physiological parameters, HR and T_{cr} were best parameters for estimating WBGT, DI and Required Sweat Rate index (SWreq) indices [31]. In this study, the physiological parameters of T_{cr} and HR were used to study the physiological responses of rolling industry workers. The results showed that the mean heat stress indices of DI and WBGT were significantly higher in working than at rest. Also, there was a significant difference between the mean T_{cr} and HR in both the working and the rest states. Heat stress is the net heat load that enters into the body of a person due to exposure to environmental variables, metabolic processes and clothing requirements, and the heat strain is the individual's physiological responses to environmental conditions; this response augments by increasing the amount of exposure to heat stress [32]. The physiological strain caused by heat stress is affected by four environmental variables: air temperature, humidity, air flow rate and thermal radiation, as well as energy consumption due to individual physical activity and thermal properties of the cloth (Clo). Besides, heat adaptation, hydration and body posture at work also affect the physiological strain caused by heat stress [33].

Ahasan *et al.* aimed at monitoring the heat stress of workers in the rolling steel industry, the T_{cr} and HR of workers were increased who worked in high-temperature units and radiation workshops [34]. Latzka *et al.* investigated the influence of physical activity on HR increase during exercise in hot laboratory conditions, the data showed that HR increased with the intensity of physical activity [35]. In the study of Maw *et al.* regarding effects of hot environment on T_{cr}, HR, and physiological strain, it was concluded that with increasing WBGT, HR, oral temperature, and physiological strain increased [36]. Dehghan *et al.* examined the correlation between the WBGT and Physiological Strain Index (PSI), their results showed that by increasing the WBGT index, the PSI also increased, an inference consistent with the findings of the present study [37].

WBGT had a direct and significant relationship with T_{cr} and HR, with it a better correlation with HR than the T_{cr}. DI index had a direct correlation with the T_{cr} and HR as well, association with the latter being significant. Fahad *et al.* conducted a study on steel industry workers in Turkey, in which although WBGT index had a high correlation with physiological parameters, it had an even higher correlation with the T_{cr} which was consistent with our study results [38]. A higher correlation with HR in such work environments can be related to the working conditions of workers who are under a higher physical burden. WBGT had a higher correlation with the physiological parameters than the DI, similar results were depicted by Fahad *et al.* [38]. Hamerezaee *et al.* showed that the WBGT is a more appropriate index than Predicted Heat Strain (PHS) for the evaluation of heat stress among steel industry workers [29]. In the study of Golbabaei *et al.*, the WBGT index showed a better correlation with physiological parameters of HR, blood pressure and the skin temperature (T_{sk}) compared to the DI index; results being consistent with this study [39]. According to Chen *et al.* physiological parameters of HR, systolic and diastolic blood pressure and T_{sk} were most correlated with the WBGT index and the physiological parameter of T_{cr} had the highest correlation with the SWreq among steel workers [40]. In a study by Brahmapurkar *et al.*, most workers in the glass factory were exposed to heat stress, and T_g was higher than T_d at all work units [41]. Also, in the present study, the average T_g was higher than the T_d, so the radiation heat could be one of the main causes of heat stress.

It should be noted that each of the thermal stress indices has its own advantages and disadvantages, and WBGT index is no exception to this rule, despite its high acceptability and widespread use [18]. Industries that are exposed to heat, they are required to provide the device, and by using it correctly, effective measures can be taken to reduce heat stress of work environments.

This study was conducted at a short interval, which could be among the limitations of the present study. However, in industries like rolling with regard to the working conditions, heat stress can exist in all seasons of the year, and it is a permanent problem. Due to the fact that heat-related complications can be prevented, due consideration should be made to promote the culture of occupational health among workers. This strategy will have a good impact on the health of industrial workers. Health measures such as the supply of cool drinks, schedules for rest periods and training of workers need to be considered.

CONCLUSION

In the rolling industry, heat stress exceeds the recommended exposure limits in many workstations. Due to the heavy physical activity of workers, interventional measures should be taken to reduce exposure. Also, WBGT index showed a better correlation with the physiological parameters of T_{cr} and HR, which is easy to use and can be used to assess the risk of heat stress and to determine the health hazards of workers exposed to heat.

ETHICAL APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the student research committee of the Shahid Beheshti University of Medical Sciences, Tehran, Iran. No. 1396/65558.

HUMAN AND ANIMAL RIGHTS

No animals were used in this research. All human research procedures followed were in accordance with the ethical standards of the committee responsible for human experimentation (institutional and national), and with the Helsinki Declaration of 1975, as revised in 2013.

CONSENT FOR PUBLICATION

Informed consent was obtained from all subjects prior to data collection.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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