Relation between Wet-Bulb Globe Temperature and Thermal Work Limit Indices with Body Core Temperature

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ABSTRACT
Occupational exposure to heat stress in casting and smelting industries can cause adverse health effects on employees who working in such industries. The present study was set to assess the correlation and agreement of heat stress indices, including wet bulb globe temperature (WBGT), and thermal work limit (TWL), and the deep body temperature indices in workers of several casting and smelting industries located in the vicinity of Tehran, Iran. In This cross-sectional study 40 workers randomly selected and were examined. WBGT and TWL were the indices used for assessing heat stress, and the tympanic temperature and the oral temperature were measured as the heat strain indices. The correlation and agreement of indices were measured using SPSS vs.16. The results of the assessment of WBGT, TWL, the tympanic temperature, and oral temperature showed that 80, 17.5, 40, and 32.5 percent of workers exposed to heat stress higher than permissible limits proposed by standard bodies. Moreover, the present study showed that the significant correlation coefficient between heat stress and heat strain indices was in the range of 0.844- 0.869. Further, there was observed a good agreement between TWL and heat strain indices. The agreement between TWL and the oral temperature was 0.63 (P-value≤ 0.001) and between TWL and tympanic temperature was 0.612 (P-value≤ 0.001). However, the agreement between WBGT and heat strain indices was not satisfactory. These values were 0.154 (P-value ≥ 0.068) and 0.215 (P-value≥ 0.028) for the oral temperature and the tympanic temperature, respectively. The TWL index had a better agreement than WBGT with heat strain indices so TWL index is the better choice for assessing the heat stress in casting and metal smelting industries.

Key words: Occupational Exposure; Workers; Hot Temperature; Heat Stress Disorders; Body Temperature Changes

List of Abbreviations

WBGT	Wet Bulb Globe Temperature
ACGIH	American Conference of Governmental Industrial Hygienists
CET	Corrected Effective Temperature
WHO	World Health Organization
PHS	Predicted Heat Strain
UTCI	Universal Thermal Climate
ESI	Environmental Stress Index
NIOSH	National Institute for Occupational Safety and Health
PSI	Physiological Strain Index
ISO	Organization for Standardization
DB	Dry-Bulb Temperature
WB	Wet-Bulb Temperature
SPSS	Statistical Package for Social Sciences
BMI	Body Mass Index
Toral	Oral Temperature
Tear	Tympanic Temperature

INTRODUCTION

Heat stress is a well-known occupational hazard posed by working in hot environments which, dependent on the exposure characteristics, can give rise to various disorders, including heat cramps, heat exhaustion, skin rashes, fainting, kidney stones, and in severe cases even death. It is well documented by recent studies that exposure to heat would negatively influence the performance of employees and increase the probability of human error [1-7].

The American Conference of Governmental Industrial Hygienists (ACGIH) defines heat stress as "the net heat load to which a worker may be exposed from the combined contributions of metabolic heat, environmental factors, (i.e., air temperature, humidity, air movement, and radiant heat), and clothing requirements". Heat strain is defined as "is the overall physiological response resulting from heat stress" [8]. The direct way for evaluating heat exposure is to measure heat strain. According to studies carried out in this area, rectal temperature is the golden standard for evaluating the heat strain imposed on the body. Having a high correlation with hypothalamic temperature is the main reason that rectal temperature has been regarded as the most reliable index in the evaluation of heat strain. However, measuring the temperature of this part of the body has historically been faced many obstacles in occupational settings. Accordingly, researchers have always been trying to identify simpler methods of heat strain evaluation. The deep body temperature, heart rate, recovery heart rate, urine density, changes in body weight are such methods [9-13]. Among the methods by which the deep body temperature is measured, tympanic temperature and oral temperature are extensively used in occupational environments [13, 14]. However, although these new methods equip the practitioner with strong tools with respect to heat strain evaluation, they still require the involvement of employees which creates many problems in obtaining an accurate representation of heat strain. Therefore, other methods have been developed in the way that there is no need for employees to being involved in Wet Bulb Globe Temperature (WBGT), Corrected Effective Temperature (CET), Predicted Heat Strain (PHS), Universal Thermal Climate Index (UTCI), Environmental Stress Index (ESI), and Physiological Strain Index (PSI) are such tools which indirectly provide an index of heat strain imposed by occupation environment on the employees' bodies [15-20].

Among these indices, WBGT is more reliable and is the one used by health and safety related bodies for developing guidelines and regulations [21]. International Organization for Standardization (ISO), National Institute for Occupational Safety and Health (NIOSH), ACGIH recommend this index for the evaluation of heat stress at occupational settings. WBGT is not difficult to measure which only needs dry, wet, and bulb globe temperatures [15]. However, it has low sensitivity in environments in which factors such as high humidity or low air speed limit the sweat evaporation from the skin. In addition, the interpretation of WBGT requires knowledge about other factors such as metabolisms of employees and their clothes types which can significantly affect the final inference. Moreover, the index is very conservative and the results tend to overestimate the actual heat strain [21].

Recently, another index has been suggested for evaluating the heat stress, which is known as Thermal Work Limit (TWL). This index estimates the maximum permissible metabolism rate taking into consideration various factors, including dry bulb temperature, wet temperature, bulb globe temperatures, air speed, and barometric pressure. Moreover, the index also considers clothes types of people. Physiologically adapted people with a balanced hydration would be able to maintain their deep body temperature at a safe level (lower than 38℃) and have an appropriate skin evaporation rate (1.2Kg per hour) while working in a specific hot environment [22].

Farshad *et al*. applied this index to evaluate heat stress among construction employees. They concluded TWL index is better than WBGT in discriminating acceptable and unacceptable levels of heat stress and can be more useful in planning intervention strategies and assessing their effectiveness [23]. Bits *et al.* also described this index as a better tool than WBGT for evaluating heat stress among employees who performed their tasks in warm and humid environments [24].

To the best of our knowledge, there is no study so far addressing the association among three indices, namely WBGT, TWL, and the deep body temperature in such workplaces as casting and metal smelting. Accordingly, the present study was set with the purposes of 1): Investigation of correlation between TWA and WBGT indices with deep body temperature and 2): Investigation of agreement between permissible and non-permissible levels of heat stress indices studied with deep body temperature indices levels.

MATERIALS AND METHODS

Study design

This cross-sectional descriptive and analytical study was performed to evaluate heat stress and strain of 40 male workers occupied in four traditional castings and metal smelting workshops in Iran during August to September 2014. The sample size was calculated based on the heat strain (tympanic temperature) in Iranian oil terminals workers and according to the study of Alimohamadi and colleagues (37.42±0.31) using equation 1 (α=0.05, d=0.3 and σ= 0.31). According to mentioned study, sample size estimated 44 subjects [14].

$$n = \frac{(Z_{1-\alpha/2})^2 \times (\sigma^2)}{(d^2)} \quad \text{Eq. 1}$$

This study was approved by the Ethical Committee of Hamadan University of Medical Sciences, Hamadan, Iran. All the participants filled out the informed consent and signed it.

Demographics

All employees who were exposed to heat in the desired industries were included in the study. However, the study had several exclusion criteria, as well. The least experience of employees was determined to be three months because this is the minimum time necessary for a person to be acclimatized to a warm environment. Moreover, employees suffering from diseases such as cardiovascular disease, diabetes, infectious diseases, hyperthyroidism, and kidney diseases were excluded, too. Lastly, from the 46 employees who were exposed to a hot environment, six ones were excluded and the others were selected for further investigations. The subjects were requested to disclose their demographic and occupational characteristics (such as age, height, weight and work experience) in a questionnaire form. Moreover, the medical records of participants were reviewed to verify whether they had any heat-related diseases in the last year before the beginning of the study.

Heat Stress Assessment

Heat stress assessment was conducted for each employee at different working stations. For this purpose, the dry-bulb temperature (DB), the wet-bulb temperature (WB), the bulb globe temperature, air speed, and atmospheric pressure were measured and using them WBGT and TWL were computed. WBGT computation was done in accordance with ISO-7243 standard [25]. It should be mentioned that the dry-bulb temperature, the wet-bulb temperature, and the bulb globe temperature was measured using micro herm WBGT meter (Casella CEL), and air speed was measured using portable hot wire thermo anemometer (KIMO instruments, model VT50). Similarly, the atmospheric pressure was determined based on data obtained from a local meteorological organization. In order to estimate the permissible limit of WBGT, the time-weighted average of working metabolism of employees was determined, which in turn used for judging heat stress imposed by the environment on employees [25]. Moreover, the clothes index was computed using procedures recommended by ISO 9920:2007 standard [26]. The duration of each work shift was regarded as eight hours so that follow a 75% work and 25% rest pattern. This pattern of work shift was used for determining the metabolism rate of employees [25]. According to a study carried out by Brik *et al*. the values of TWL index are divided into four sections, based on their different intervention strategies are advised. In the cases that TWL < 115 w/m^2 or DB> 44$^{℃}$ or WB > 32$^{℃}$, the work is too hazardous for employees' health to be continued and an immediate intervention is necessary. In the cases that TWL were is between 115 and 140 w/m^2, known as the buffer zone, the work can be continued if special interventions such as not working alone or increasing wind speed by 0.5 m/s for each workers upper torso are introduced. In the cases that TWL is between 140 and 220 w/m^2 employees would acclimatize to the environment, and there is no restriction for working in an environment with a TWL above 220 w/m^2 [22].

Heat Strain Assessment

Tympanic and oral temperatures were measured as representatives of heat strain which is a function of the deep body temperature [9]. The oral temperature was measured using a digital oral thermometer (Bliss Technology Co, Model: FT-A41CN). Moreover, the tympanic temperature also was measured using an infrared tympanic thermometer (Omron Co, Gentle temp 520). In order for minimizing errors of oral temperature measurement, the employees were asked to avoid smoking, eating, and drinking within 30 minutes before the experiments. In addition, before measuring the tympanic temperature, the middle section of employees' ears was cleaned using an ear swap. Further, in order to minimize the effects of the surrounding temperature on the tympanic temperature, the thermometer sensor was totally insulated with a foam resistant to heat. Each measurement was repeated three times and the average was reported as the final result of that experiment.

The permissible exposure limit of heat strain and heat stress indices

ACGIH guidelines were applied for distinguishing permissible and non-permissible level of exposure to heat strain [8]. In this regard, the permissible limit of WBGT was computed by considering such factors as working metabolism, acclimatization status, clothes type, and duration of shift work for each employee. Pertaining to TWL, the values above 140w/m^2 were considered to be permissible, while values lower than 140w/m^2 were known as non-permissible [22]. Moreover, ACGIH guidelines also were utilized to judge the permissibility of the deep body temperature. Accordingly, the uppermost limit of this index was set at 38.5$^{℃}$ [8].

Statistical Analysis

All analyses were performed using the statistical package for social sciences (SPSS) version 16.0 for Windows (IBM Corporation, New York, United States). Spearmen correlation coefficient was applied to evaluate the association between heat stress and strain indices. In order to evaluate the agreement of permissible and non-permissible limit of indices the Cohen's kappa coefficient was employed. The significant level of correlation tests was 0.01, while the Cohen's kappa coefficient was performed at the 0.05 level of significance.

RESULTS

Demographic information of employees participated in the present study is summarized in Table 1. According to this table, average body mass index (BMI) of participants was in a normal range considering the information published by the world health organization (WHO). Reviewing medical records of employees revealed that none of them had an acute disorder resulting from exposure to heat stress in the occupational environment. However, only one employee was observed who suffered from skin rushes.

The results of environmental measurements and heat stress and heat strain indices investigated in the present study are showed in Table 2. The findings demonstrated that the average value of TWL index was in the permissible regions (185.35±42.49). Moreover, indices of heat strain also were permissible so that the average tympanic and oral temperature were lower than the limit recommended by ACGIH guidelines (38.5$^{\circ C}$). Fig. 1, moreover, represents the findings about the permissibility of heat stress and strain based on various indices. Evaluation of WBGT demonstrated that 80 percent of employees were in a non-permissible region of heat stress exposure for acclimatized people, while only seven employees (17.5 percent) were in this area according to TWL index.

Table 1: Demographic characteristics of employees participated in the present study

Variable	Mean ± Std.	Min.	Max.
Age (year)	35.32 ± 5.40	24.00	49.00
High (cm)	173.05 ± 5.79	160.00	187.00
Weight (kg)	69.72 ± 7.91	54.00	87.00
BMI	23.26 ± 2.20	18.69	29.76
Job (year)	9.40 ± 2.10	1.00	14.00

Table 2: Descriptive results of environmental measurements and heat stress and strain indices

Parameter	Mean ± Std.	Min.	Max.
Dry bulb temp (°C)	31.44 ± 1.69	27.50	34.00
Wet bulb temp (°C)	22.78 ± 2.79	18.20	27.00
Air velocity (m/sec)	0.65 ± 0.18	0.30	0.90
WBGT (°C)	27.59 ± 3.40	24.00	32.00
TWL (w/m^2)	185.35 ± 42.49	131.00	310.00
Toral (°C)	37.77 ± 1.05	35.90	39.00

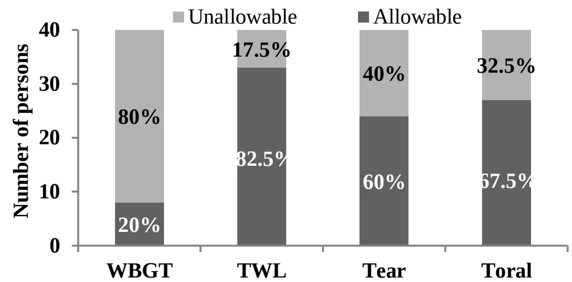

Fig. 1: The frequency of employees who exposed to allowable or unallowable levels of heat stress according to various indices

Table 3 presents the results of correlation and agreement between heat stress and heat strain indices. The results revealed that there was a significant correlation between WBGT and heat strain indices. As evident in this table, the correlation coefficient of WBGT with the tympanic temperature and the oral temperature was as high as 0.869 and 0.866, respectively. Likewise, there was observed a significant negative correlation between TWL and heat strain indices, so that the correlation of TWL and the tympanic temperature was -0.844 and the correlation between TWL and the oral temperature was -0.850. Besides, the results associated with the correlation and agreement between heat strain and stress indices also are presented in Table 3. The results demonstrated a high level of agreement between TWL and heat strain indices which were statically significant (p-Value≤ 0.001). In this regard, Cohen Kappa coefficient, as indicative of agreement between indices was 0.612 between TWL and the tympanic temperature and 0.630 between TWL and the oral temperature. In contrast, the agreement between heat strain indices and WBGT was insignificant. As showed in Table 3, the Cohen Kappa coefficient of WBGT and the tympanic and oral temperatures were 0.215 (p-Value≤ 0.028) and 0.154 (p-Value≤ 0.068), respectively.

Table 3: The correlation and agreement between heat strain and stress indices

Paired Parameters	Kappa	P-Value*	Spearman	P-Value**
WBGT_Toral	0.154	0.068	0.866	≤ 0.001
TWL_Toral	0.630	≤ 0.001	-0.850	≤ 0.001
WBGT_Tear	0.215	0.028	0.869	≤ 0.001
TWL_Tear	0.612	≤ 0.001	-0.844	≤ 0.001
WBGT_TWL	0.101	0.145	-0.928	≤ 0.001

*. Agreement is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

DISCUSSION

The present study was conducted to investigate the association between heat stress indices, including TWL and WBGT, and heat strain indices, including tympanic temperature and oral temperature, and assess their agreement in differentiating the permissible and non-permissible levels of heat exposure. The results revealed that there is a high association among three indices of TWL, WBGT, and the deep body temperature. However, when their agreement was assessed, it was revealed that the TWL index was superior to WBGT in differentiating permissible and non-permissible limits and had a stronger agreement with the strain indices.

Moreover, heat stress indices were measured for several work stations. WBGT-TWA was calculated taking into account such factors as the clothes index and working metabolism. The results showed that the heat stress crossed the permissible limits recommended by ACGIH in 80 percent cases. Regarding to TWL index, none of work stations did categorize in the limited region (TWL<115). Further, only 17.5 percent of cases were regarded as non-permissible, having an index value higher than 140.

It should be noted that the present study, to our knowledge, is the first one in which the heat stress induced by working in metal smelting industry has been assessed applying TWL index. However, the results are found to be in a good agreement with previous studies in which the heat stress has been evaluated in processes such as casting and metal smelting workers using WBGT index. Mei-Lien Chen *et al*. conducted a study in a steel plant and concluded that the level of heat exposure of workers who working in such an industry was higher those limits recommended by regulatory bodies [27]. Parameswarappa *et al.* also reported that people who working in metal smelting industries are exposed to an unacceptable level of heat stress [28].

The human body, as a warm-blooded creature, can tolerate the small changes in its deep body temperature, which has a range from 36.7 to 37 ℃. In workplaces inducing a high level of heat stress, the heat absorbed by the employees' body from the environment and the metabolic heat produced by physical activities will accumulate and increase the deep body temperature. The continuation of this process causes adverse physiological effects and thus create heat strains [29]. The results of the present study revealed that there is a strong correlation between heat strain and stress indices so that the heat strain indices increased as the heat stress indices increased. The correlation coefficient between these two categories of indices has a range from 0.844 to 0.869. Moreover, there was a strong negative correlation between WBGT and TWL. The results were similar to those reported by Margaret Vane *et al.* and Dehghan *et al.*, in which the association of WBGT and heat strain indices has been investigated [13, 30]. In another interesting study, Montazeri *et al*. found a significant correlation between TWL index and the urine density index as a predictor of heat strain [31].

As well as having a linear relationship with the deep body temperature, a good heat stress index should be capable of discriminating permissible and non-permissible level of heat exposure correctly. Improper classification of employees into a non-permissible region, in the majority of cases would lead in stopping the work which imposes a huge cost on the company. In the present study, although WBGT and TWL both had a good linear relationship and a strong association with heat strain indices, TWL was better in terms of its capability in discriminating permissible and non-permissible level of exposure to heat stress. This finding emphasized on the inappropriateness of WBGT for estimating the risk posed by a hot environment. The same results were achieved by Miller *et al.* who explained that, TWL provides a more realistic picture of heat stress, while WBGT has a more conservative approach in estimating such stresses [32]. Further, the results are in line with those reported in previous studies [12, 24, 33, 34]

The results of WBGT demonstrated that 80 percent of workstations had an unacceptable level of heat stress, while by reviewing the medical records of employees it was revealed that only one of them had suffered from skin rush during the last year before the beginning of the study. One of the main reasons behind obtaining different management protocols using these two indices is the cooling effect of atmospheric parameters (wind flow rate); which is mainly ignored by WBGT. The reduction of air speed and increase of humidity can reduce air evaporative capacity up to one third, hence mental and physiological strains will increase in such environments [21]. In contrast to WBGT, TWL has an acceptable sensitivity to the cooling effect of airflow, suggesting that it is a more proper index for assessing heat stress at workplaces [35]. Another advantage of TWL over WBGT is that it does not take into account the working metabolism. TWL directly calculates the maximum permissible metabolism using some important psychometric characteristics. It is important in this respect that many practitioners are not expert enough to assess the working metabolism of employees.

CONCLUSION

The results of the present study revealed that there is a strong linear relationship between heat stress indices, including WBGT and TWL, and heat strain indices, including tympanic temperature and oral temperature. TWL is a better index than WBGT because of its capability in differentiating permissible and non-permissible levels of heat exposure, which is in accordance of heat strain indices such as the deep body temperature. Moreover, due to the strong association between TWL and the deep body temperature, it can be used as a substitution of WBGT for assessing heat stress in industries such as metal smelting and casting.

ETHICAL ISSUES

This study was approved by Ethical Committee of Hamadan University of Medical Sciences, Hamadan, Iran

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

AUTHORS' CONTRIBUTION

All authors have made a contribution into the review and finalization of this manuscript. All authors read and approved the manuscript.

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