ORIGINAL ARTICLE

Evaluation of wet bulb globe temperature index for estimation of heat strain in hot/humid conditions in the Persian Gulf

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Background: Heat exposure among construction workers in the Persian Gulf region is a serious hazard for health. The aim of this study was to evaluate the performance of wet bulb globe temperature (WBGT) Index for estimation of heat strain in hot/humid conditions by the use of Physiological Strain Index (PSI) as the gold standard. **Material and Methods**: This cross-sectional study was carried out on 71 workers of two Petrochemical Companies in South of Iran in 2010 summer. The WBGT index, heart rate, and aural temperature were measured by Heat Stress Monitor (Casella Microtherm WBGT), Heart Rate Monitor (Polar RS100), and Personal Heat Strain Monitor (Questemp II), respectively. The obtained data were analyzed with descriptive statistics and Pearson correlation analysis. **Results:** The mean (SD) of WBGT values was 33.1 (2.7). The WBGT values exceed from American Conference of Governmental Industrial Hygienists (ACGIH) standard (30°C) in 96% work stations, whereas the PSI values were more than 5.0 (moderate strain) in 11% of workstations. The correlation between WBGT and PSI values was 0.61 ($P = 0.001$). When WBGT values were less and more than 34°C, the mean of PSI was 2.6 (low strain) and 5.2 (moderate strain), respectively. **Conclusion:** In the Persian Gulf weather, especially hot and humid in the summer months, due to the WBGT values exceeding 30°C (in 96% of cases) and weak correlation between WBGT and PSI, the work/rest cycles of WBGT Index is not suitable for heat stress management. Therefore, in Persian Gulf weather, heat stress evaluation based on physiologic variables may have higher validity than WBGT index.

Key words: Heat strain, Persian Gulf, physiological strain index, wet bulb globe temperature index

INTRODUCTION

One of the physical harmful agents of workplaces is the heat exposure that may cause heat strain. Thermal strain stability would happen in the exposure of climate warming, heavy physical work in heat, and wearing personal protection or thermal insulation clothing or impermeable to water vapor. It may cause disorders due to heat, such as heat exhaustion,[1] heat syncope, muscle cramps, and heat exhaustion,[2] increasing human errors, reducing mental and physical performance,[3-5] increasing accidents, and ultimately reducing productivity.[6-8] Considering the consequences of heat strain, including some disorders in physical, safety and efficiency, monitoring it in workers exposed to heat is essential.

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In the Persian Gulf region, during the hot months, the heat is the main physical harmful agent in the workplaces. The area of the present study is Bushehr province (coordinates: 27° 14′ to 30° 16′ N, 50° 06′ to 52° 58′ E), which has a very hot climate. Based on data from meteorological Dayer station, the average temperature, the average of maximum temperature and average humidity (3 pm), in the months May to end September in years between 2000 and 2005, is measured, respectively, 33.4°C, 38.2°C, and 54.4%.

In United Arabic Emirates in the south of the Persian Gulf, in summer, the temperature and humidity can be higher than 45°C and 90% respectively,[9] which, it is one of the worst summer weather in the world.[10] Therefore, in such regions, exposure to hot–humid conditions and onset of heat stress is obvious. Therefore, heat stress evaluation is essential to preventing of heat-related illness, maintaining productivity and workers' injures.

In the last century to measure or predict heat stress in hot environments, several indices have been introduced in which a few of them have been widely used. One of these indices is the wet bulb globe temperature (WBGT) Index that enters the most important environmental

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factors in its structure.[11-13] WBGT values are calculated by Eqs (1) and (2).

WBGT = 0.7 NWB + 0.3 GT (indoors) (1)

WBGT = 0.7 NWB + 0.2 GT + 0.1 DB (outdoors with solar load) (2)

Where NWB = natural wet bulb temperature; DB = dry bulb (air) temperature; GT = globe thermometer temperature.

In the calculation of WBGT index, nonenvironmental factors [such as age and body mass index (BMI)] are not included and metabolic rate are used in the interpretation of the index [Table 1]. Many changes can often be seen in the estimation of metabolism rate, which fluctuates the results obtained from WBGT interpretation.[12-15] Several studies have shown that the WBGT index has overestimated the heat stress in the subjects exposed to heat in many developing countries, such as China, India, Thailand, and Dubai.[10,16]

Another reliable index is Physiological Strain Index (PSI) developed from a database of heart rate and rectal temperature measurements (Eq. 3), which was introduced by Moran *et al.*[17]

$$PSI = 5 (T_w - T_r)/(39.5 - T_r) + 5 (HR_w - HR_r)/(180 - HR_r) \quad (3)$$

Symbols T_r and T_w indicate the rectal temperature at rest and work. Symbols HR_w and HR_r show the heart rate at rest and work respectively. This index has a numerical range between 0 and 10 [Table 2], which zero indicates the absence of heat strain, and 10 denotes the maximum heat strain.[17] Validity of this index for men and women has been studied under different conditions. This physiological index, can be evaluated amount of heat stress caused by environmental factors, clothing, physical work, and individual characteristics, such as gender and age.[18-20]

The question raised here is whether the WBGT index, is now widely used, would present a proper estimate of the physiological strain in the hot–humid region of the Persian Gulf in hot seasons. Therefore, the purpose of this study was to evaluate WBGT Index for estimation of heat strain in subjects under hot–humid conditions by use of the PSI as the gold standard. We hypothesized (H_1) that the WBGT Index correlated well with the PSI and it is as a relatively good predictor of PSI under hot–humid conditions.

MATERIAL AND METHODS

Subjects

This cross-sectional study was carried out on 71 male workers of two Iranian Petrochemical Company (total worker population of 350) in South Pars during July and August of 2010. Subjects were selected using systematic random sampling. Inclusion criteria were continuous presence at least two weeks in the workplace; exposure to several factors may contribute to heat stress (hot–humid conditions, work clothing, and personal protective equipment wearing) and voluntary participation in the study. Exclusion criteria included anatomic abnormalities in the external ear, cardiovascular disease, respiratory disease, infectious disease, diabetes, hyperthyroidism, and medicine use.

Table 1: Threshold limit value of wet bulb globe temperature by % work and metabolic rate category (ACGIH-2006)

% Work	Load work*			
	Light	Moderate	Heavy	Very heavy
75-100	30.0°C	28.2°C	-	-
50-75	31.2°C	29.0°C	27.6°C	-
25-50	31.8°C	30.1°C	28.8°C	27.9°C
0-25	32.3°C	31.3°C	30.5°C	29.8°C

Light= 180 W; Moderate= 300 W; Heavy=415 W and Very heavy= 520 W

Table 2: Evaluation and categorization of different heat strains by physiological strain index

Physiological strain	PSI value
No/little	0
	1
	2
Low	3
	4
Moderate	5
	6
High	7
	8
Very high	9
	10

Procedures

Prior to the beginning of this study, approval was obtained from Medical Ethics Committee of Tarbiat Modares University. All the procedures were in agreement with the Helsinki Declaration. The subjects were medically screened for anatomic abnormalities in the external ear, cardiovascular disease, respiratory disease, infectious disease, diabetes, hyperthyroidism, and no medicine use. All the study procedures were described to the subjects and the necessary instructions, such as adequate rest during night, no coffee, and alcohol consumption in the night before the measurement were clearly explained. The written consent forms were obtained from all the subjects.

On the testing day, after measuring height, weight, and recording the history of heat strokes, heart rate was measured by using the Heart Rate Monitor (Polar Electro RS100, Finland). This device included a sensor fixed to the

chest and a receiver was worn on the wrist of the subjects like a watch.[21] Then, sensor of the personal heat strain monitor (Questemp II, Quest Technologies, USA) was placed into the external ear canal to measure aural temperature;[22-25] this device has a processor and monitor that is installed on a belt. At the time of measuring aural temperature, the sensor of Personal Heat Strain Monitor was completely covered with foam insulation, to minimize the impact of weather conditions on aural temperature.[26]

In this study, variables such as heart rate, aural temperature, and WBGT Index were measured in both resting and working. After 30 min resting in a cool room (WBGT = 22.6 ±1.9), heart rate and aural temperature at times 20, 25, and 30 min were measured and the average of them recorded as baseline.[27] Then, without separation of measuring devices, the subject was asked to go to workplace and begin his work. If the work station was farther than 50 m from the cool room, the subjects would be transported by car. After starting the actual work, heart rate and aural temperature were measured at times 20, 40, 60 min.[25] Simultaneous measurement of heart rate and aural temperature, WBGT Index was also measured[12] at rest and work by Heat Stress Monitor (Microtherm WBGT, Casella, United Kingdom).

All measurements were performed in outdoor from 9 to 12 am and 15 to 18 pm, and at the end of the measurements, the PSI was calculated based on Eq. (3). The data obtained were analyzed with descriptive statistics, Pearson's correlation coefficient analysis, and regression analysis by SPSS-18 software (SPSS Inc, Chicago, IL, USA).

RESULTS

In this present research, subjects were 71 simple and semi-skilled workers employed in the jobs, such as construction, welding, piping, and installation equipment. Their average age, height, weight, and BMI were 31.6 ± 8.6 years, 171 ± 5.9 cm, 73.5 ± 13.3 kg, and 25.0 ± 4.0 kg/m^2, respectively. Twenty-one percent of the subjects had at least one history of heatstroke.

WBGT values varied in the range of 26.6°C-39°C at workstations. The mean (SD) of WBGT value was 33.1 (2.7), which is higher than threshold limit values (TLV) published [Table 1] by the American Conference of Government Industrial Hygienists (ACGIH). WBGT values at 20, 40, and 60 min after exposure to heat were higher than threshold limit values (ACGIH) for continuous light workload (30°C) in 96% of the workstations. Frequency distribution of the subjects corresponding to the different values of the WBGT Index has been shown in Table 3.

The mean (SD) of heart rate during rest and work was 72[11] and 105[20] beats per minute (bpm), respectively. The average aural temperature for the period of resting and working was 36.4 (0.5)°C and 37.1 (0.7)°C, respectively.

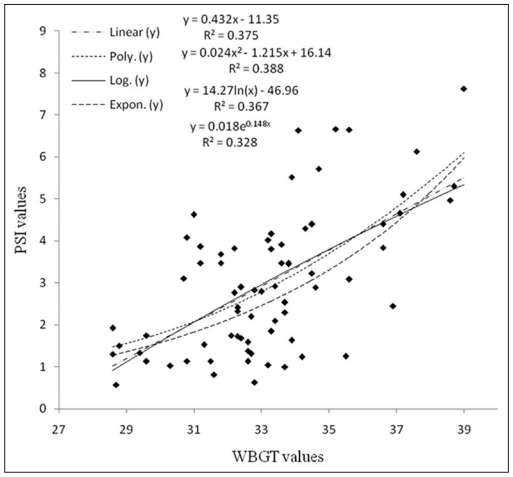
PSI values varied in the range of 0.7–7.6 at workstations. The mean (SD) of PSI value was 3.0 (1.6), which indicates low physiological strain. The mean (SD) values of PSI at 20, 40, and 60 min after being exposed to heat, were 2.40 (0.2), 2.7 (0.2), and 3.0 (0.2), respectively. Statistical distribution of PSI values corresponding to WBGT different levels are shown in table 3. According to these data, average of PSI values showed that the physiological strain were in the range of low (PSI = 2) to moderate (PSI = 4.7) levels at each time interval. So the PSI values greater than 5 (moderate to very high levels of physiological strain) were only seen in 11% of subjects.

In this study, when WBGT values were less than 34°C, the mean of PSI value was 2.6 (low strain), whereas when WBGT values were more than 34°C, the average of PSI value was 5.2 (moderate strain). The Pearson's correlations between WBGT and PSI values, age, and BMI adjusted, in total period, was 0.61 (P = 0.001). Graph 1 show details of the Scatter plot and trend lines between WBGT and PSI values. Polynomial regression line (R^2 = 0.39) provided

Table 3: Changes in physiological strain index values according to different levels of heat stress

WBGT[a] (°C)	PSI_{20}[b]		PSI_{40}[c]		PSI_{60}[d]	
	N	Mean (SD)	*N*	Mean (SD)	*N*	Mean (SD)
<31.9	19	2.0 (1.4)	13	2. 5 (1.4)	13	2.7 (1.5)
32.0-33.9	35	2.2 (0.9)	40	2.3 (1.1)	37	2.4 (1.0)
34.0-35.9	9	2.8 (1.8)	10	3.5 (1.5)	14	3.8 (1.8)
>36.0	8	3.7 (1.8)	8	4.2 (1.8)	7	4.7 (1.6)
26.6-39.0	71	2.4 (0.2)	71	2.7 (0.2)	71	3.0 (0.2)

[a]Wet bulb globe temperature; [b]Physiological strain index value at 20th min of heat exposure; [c]Physiological strain index value at 40th min of heat exposure; [d]Physiological strain index value at 60th min of heat exposure



Graph 1: Scatter plot and trend lines (linear and polynomial) between wet bulb globe temperatureand physiological strain index values after 60 min exposure to heat

better coefficient than other trend lines, such as linear regression. Based on polynomial regression equation, only 39% of the changes the PSI can be explained by WBGT Index, accordingly, the results indicate that the null hypothesis (H_0) not rejected. Therefore WBGT Index weakly associated with PSI and it is also a weak predictor for heat strain estimation.

DISCUSSION

The WBGT Index was higher than ACGIH threshold limit values in majority of the workstations for the acclimated workers and continuous light work. Therefore, based on the values of WBGT, heat of the working environment was stressful for all subjects. Comparing the results of monitoring environmental conditions (WBGT values) and physiological monitoring (PSI values), rising levels of WBGT [Table 3] shows that in case of steady increase in the WBGT index in the range above ACGIH threshold limit values, the PSI values in each 20, 40, and 60 min period, had relatively small incremental changes and the values indicate that the physiological strain was in the range of low to moderate [Tables 1 and 3]. A similar study for the assessment of heat stress in a coastal area in the South of Iran, Motamedzadeh *et al.* concluded that although the heat exposure of all workers were higher than the ACGIH threshold limit values, only 16.25% of the subjects showed heat strain based on heart rate and oral temperature.[28]

With regular increase of WBGT Index, increase of the PSI is relatively regular [Table 3], which in the values higher than 3 (low to high strain) have occurred in amounts higher than 34°C of WBGT Index, besides this the physiological strain is low when WBGT was less than 34°C, whereas in terms of environmental conditions with WBGT Index greater than 34°C, it represents the stress to the cardiovascular system [Table 3]. Therefore, it appears that environmental conditions with the WBGT index greater than 34°C are stressful for the subjects.

The WBGT Index is an empirical index that just enters important environmental factors to its structure, and ignores some of the nonenvironmental factors,[29] such as, self-pacing, age, and BMI. In this study, one of the reasons for incompatibility of change process for WBGT with PSI values, may be due to the self-pacing to reduce the severity of heat strain,[30] that occurs in individuals exposed to very hot weather as a protective behavior; the role of the self-pacing to reduce heat strain has been showed in several studies.[10,30-33] Donoghne *et al.* investigated the role of training deep underground miner to improve self-pacing under the hot environmental conditions, as necessary priorities to reduce heat exhaustion among them.[30,34] Brake *et al.* in a study conducted on the fatigue levels in underground miners exposed to environmental heat stress (WBGT = 30.8), found that it is very likely that workers were self-pacing.[35] Soule *et al.* found that hot environmental conditions with wet temperature more than 33.5°C, lead to increase in the deep body temperature and self-pacing.[36] Mairiux *et al.* concluded that self-pacing of work–rest cycle by workers exposed to heat, is an effective way to protect themselves against the physiological strain.[33] Miller *et al.* perceived that in self-pacing, the average heart rate rarely goes beyond 110-115 bpm.[37] Rastogi *et al.* examined the relationship between WBGT and heart rate in workers at a glass factory, and concluded that WBGT Index alone cannot estimate the heat strain,[38] which is consistent with the results of this study. It seems that in too hot environmental conditions of Persian Gulf (the WBGT Index in 95% of the subjects was more than 30°C and in 82% of workstations, more than 32.0°C); self-pacing phenomenon has led WBGT Index to provide a weak estimate of physiological responses in the body, so that correlation between WBGT and aural temperature was low. In a similar study, Bate *et al.* examined the physiological responses of construction workers in the United Arabic Emirates and showed that in case of the supply of body fluids and self-pacing, workers can work in summer without serious physiological consequences. They concluded that the use of WBGT in Persian Gulf weather conditions was not precise and reliable; therefore, the Thermal Work Limit index was proposed for evaluating the heat stress.[10] Also Miller *et al.* believed that the results of WBGT Index are often too conservative and its careful execution in many cases is largely ignored because of unacceptable and unnecessary losses in productivity.[37] In the Persian Gulf weather conditions during hot seasons, due to the higher dry and radiant temperature (37.4°C and 38.9°C, respectively, in this study) than the skin temperature (35°C-36°C), body absorbs heat through convection and radiation. Therefore, the mechanisms of heat losses through radiation and convection are inadequate, and the only way to dispose body heat is evaporation of sweat from the skin surface. On the other hand, due to high humidity, in such conditions, efficiency of heat loss through evaporation is reduced. Therefore, where there is lack of work–rest cycles to decrease heat stress, workers reduce heat inside the body by self-pacing; therefore despite stressful environmental conditions based on WBGT Index of threshold limit values (ACGIH), the PSI index, which represents the physiological response to hot environmental conditions, is ranging from low to medium; only 21% of the subjects had a history of heat stroke in hot–humid climatic conditions. So we can conclude that the WBGT index overestimated heat stress in the Persian Gulf weather conditions as well as in many tropical countries, including the United Arabic Emirates, Thailand, China, and India.[15,20]

CONCLUSION

In the Persian Gulf weather, especially hot and humid in the summer months, due to the WBGT values exceeding 30°C (in 96% of cases) and weak correlation between WBGT and PSI, the work–rest cycles of WBGT Index is not suitable for heat stress evaluation. PSI (indicator of heart rate and body temperature) remained within acceptable limits when WBGT index was higher than threshold limit values of ACGIH, which is probably due to self-pacing phenomenon. Therefore, in Persian Gulf weather, heat stress evaluation based on physiological variables may have higher validity than WBGT Index.

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