RESEARCH ARTICLE

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Comparing the Core Body Temperature and the Heat Stress Indices of HSI and WBGT in Lorestan Steels Industry Workers, Iran

Sakineh Mahdavi[a,b,*], Arezo Esmaelzadeh[b], Farzad Ebrahemzadeh[c], Rajab Rashidi[b], Nayereh Naeimi[d]

[a] Nutritional Health Research Center, Lorestan University of Medical Sciences, Khorramabad, Iran.
[b] Department of Occupational Health Engineering, School of Health, Lorestan University of Medical Sciences, Khorramabad, Iran.
[c] Department of Epidemiology , School of Health, University of Medical Sciences, Khorramabad, Iran.
[d] Department of Environmental Health Engineering, School of Health, Bojnord University of Medical Sciences, Bojnord, Iran.
[*]**Correspondence** should be addressed to Ms. Sakineh Mahdavi; **Email**: smahdavi125@yahoo.com

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Background & Aims of the Study: Heat Stress is a major factor in many industrials and heat stress is one of occupational hazards in the workplace and severely affects the health and productivity, heat stress can decrease efficiency, increase accidents and reduce safety levels. Aim of this study was comparing the heat stress indices of HSI and WBGT and core body temperature in steels industry workers.

Materials & Methods: In this descriptive analysis study, 41 acclimatized and healthy male were participated in the study. Subjects selected by census method. Environmental climatic parameters were measured and then heat stress evaluated according to HSI index, WBGT index and core body temperature. This study was done in the hottest season in August and the hottest hours (11 to 14) at the location of the workers. All data analyzed by the SPSS version 16 and in order to establish a relationship between measured parameters and the core body temperature and the heat stress indices Poisson correlation coefficient was used.

Results: Regarding on the results, mean of WBGT index was 40.02 and mean of HSI index was 489.97. It showed that the all workers expose to high heat stress. Whilst mean of core body temperature was 37.19°c and maximum of core body temperature was 38.5°c.

Conclusions: For estimating heat stress is better use of the biological monitoring method such as core body temperature which may have been closer to reality heat stress in exposed workers. Pearson correlation coefficient between the core body temperatures has less correlation with globe temperature (r= 0.648), relative humidity (r= 0.307) and with natural wet bulb temperature (r= 0.469) than HSI and WBGT. WBGT has high correlation with globe temperature (r= 0.956) and natural wet bulb temperature (r= 0.877) so this finding can prove that WBGT index shows higher heat stress than core body temperatures. the Pearson correlation coefficient between HSI with relative humidity is r=0.619 and HSI has more correlation with relative humidity than core body temperature (r= 0.307) and WBGT(r= 0.494) the HSI index has not statistically significant relation with air velocity (p=0.058) and HSI index have limitations for assessing heat stress in environments with high relative humidity and low air movement.

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Background

Thermal stress is one of occupational hazards in the workplace and includes a series of physical and environmental work factors. Thermal stress cause enhances the thermal load on the body (1). Intensive

hot environments can damage the body's coping mechanisms and cause to a type of serious harm and physiological damage to human such as heat stress. Heat stress which performed by the thermal environment is on the human cause heat strain. Heat strain is body's physiological response and reactions to heat stress (1). Human body can show reaction and heat strain such as increase in skin temperature, heart rate, sweat rate, and increase in core body temperature. Under excessive conditions and long term exposure to heat and If not controlled heat stress heat strain may cause variety of symptoms and heat hazards and heat diseases ranging from mild disorders to fatal conditions such as heat cramps, fatigue, heat exhaustion, heat collapse and thermal shocks (2).

Some of the heat hazards also can cause reduced physical and mental performance and decrease efficiency and productivity even increase accidents and reduce safety levels (3, 4). High ambient temperatures, high metabolic loads, restricted evaporation of sweat by high humidity and protective clothing or any combination of these can cause increase in core body temperature and it can cause to development of heat illness (5).

Increase in core body temperature is one of the physiological responses to the heat stress and measuring the core body temperature is important for heat stress assessment and for prevention of heat stress disorder in workers in hot work environmental (6). According to ISO9886 the oral temperature (tor) as so as other indices such as Esophageal temperature (tes) rectal temperature (tre) intra-abdominal temperature(tab), tympanic temperature(tty), auditory canal temperature (tac) and urine temperature (tur) have been proposed as core body temperature indices (6). Commonly core body temperature limits recommended for industrial hyperthermia is 38 ċ (5, 7). In other hands, various scientific communities and researchers for measure of heat stress have developed some indices. Among them can be noted the WBGT (ISO7243, 1989) and HSI (Belding and Hatch, 1955) indices (8).

Ken Parsons In a paper presented heat stress Standard ISO 7243, which is based upon the wet bulb globe temperature index (WBGT), and considered its suitability for use worldwide (9).

Jafari's study to determine the optimal index for foundry's shift workers showed that MRT, P4SR, CET indices had highest correlation with the WBGT index and the HSI index highly dependent on the flow rate of air in the study. It showed that WBGT index was significantly higher than the other Heat stress indices (10).

In other hand Grahame stated that WBGT have most serious limitation, when the evaporation of sweat is restricted by high humidity or low air movement a given level of the WBGT index are more stressful than when evaporation is free (11).

With regard to that the heat stress is important subject in the work place so aim of this study was to assessment Heat Stress indices (HSI) and Wet Bulb Globe Temperature index (WBGT) as indices of heath stress an measure oral temperature (tor) as core body temperature (physiological parameter) for judge about lorestan steels industry workers heat stress finally compare the values of HIS, WBGT and values of core body temperature with permissible threshold limit and study the difference between the HSI, WBGT and values of core body temperature.

Materials & Methods

This study was a descriptive analysis the aims of this study was to determine heat stress among41acclimatized healthy male worker at steels industry workers in the Lorestan steels industry. Subjects selected by census method. There are a lot of environmental parameter such as air dry temperature (ta), natural wet bulb temperature (tnw), relative humidity (RH), air velocity (av), globe temperature (tg) were measured at near each worker in worker location by calibrated WBGT meter CASELLA,. By WBGT, HSI indices heat stress was assessment in the hottest season in August and the hottest hours (11 to 14). Sublingual temperature (Physiological parameters) was measured by thermometer for core body temperature estimate. According to recommendations of organizations such as ACGIH, and ISO7933, The limit value of core body temperature is 38°C (7,12). A quarter before measuring, the workers should not be drinking any kind of drinks. All measurement ware conducted in abdomen part of worker's body. All data obtained was analyzed by the SPSS version 16 and In order to establish a relationship between measured parameters and the core body temperature and the heat stress indices Poisson correlation coefficient was used.

In this study the heat stress exposure was assessment by HSI and WBGT indices as shown in equations (1,2), and so core body temperature was measured ,WBGT index consists of a simple weighting of the globe temperature, natural wet bulb temperature, and natural dry bulb temperature.

According to ISO7243 Standard which was published in 1982 WBGT index evaluated at all workers indoors location, according to equation (1):

$$WBGT = 0.7t_{nwb} + 0.3t_g \quad (1)$$

ISO7243 Standard resembles the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) as so as revealed in Table 1 and demands with rest periods

Table1) ACGIH recommended WBGT for 8h work (ACGIH, 2000)(13).

Work Demands	Light (200kcal/h)	Moderate(350kcal/h)	Heavy (350kcal/h)	Vary Heavy
100% work	29.5 ċ (27.5 ċ)	27.5 ċ (25 ċ)	26 ċ (22.5 ċ)	-
75% work-25%Rest	30.5 ċ (29 ċ)	28.5 ċ (26.5 ċ)	27.5 ċ (24.5 ċ)	-
50% work-50%Rest	31.5 ċ (30 ċ)	29.5 ċ (28 ċ)	28.5 ċ (26.5 ċ)	27.5 ċ (25 ċ)
25% work-75%Rest	32.5 ċ (31 ċ)	31 ċ (29 ċ)	30 ċ (28 ċ)	29.5 ċ (26.5 ċ)

For un-acclimatized () represents

The Heat Stress Index (HSI) use for heat stress assessment this index is related to strain, essentially in term of body sweating, HSI calculated by ratio of E_{req}/E_{max} as equation (2), at this equation E req is evaporative heat loss that it's need for heat balance and E max is maximum evaporative capacity.

$$HSI = \frac{E_{req}}{E_{max}} \times 100 \quad (2)$$

According to Table 2 HSI values varies from -20 to >100, so that HSI<0 represents mild cold strain to cold environmental whilst HSI=0 shows No thermal strain and HSI=100 is represented maximum strain tolerated daily by fit acclimatized young men.

Table 2) Interpretation of Heat Stress Index (HSI Index) Values (BOHS, 1996) (14).

HSI Value	Effect of Eight Hour Exposure
-20	Mild cold strain(e.g. recovery from heat exposure)
0	No thermal strain
10 – 30	Mild to moderate heat strain Little effect on physical work but possible effect on skill
40 – 60	Severe heat strain, involving threat to health unless physically fit Acclimation required
70 – 90	Very severe heat strain Personal should be selected by medical examination, adequate water and salt intake must be ensured.
100	Maximum strain tolerated daily by fit acclimatized young men
Over100	Exposure time limited by rise in deep body temperature

Results

Heat exposure measurement and heat stress assessment were performed among 41 acclimatized healthy male workers in steel industry. The results of the environmental

Table 3 shows mean and standard deviation, minimum, maximum of environmental parameter such as dry temperature, natural wet bulb temperature, global thermometer, air movement, relative humidity, Core body and WBGT and HSI indices.

Table 4 shows Pearson Correlation and statistical value between core body temperature, HSI, WBGT index and measured Environmental parameters.

Table 5 shows Pearson Correlation and statistical value between core body temperatures, HSI and WBGT index.

Table 3) Mean and standard deviation values of the measured Environmental parameters and core body thermometer, WBGT and HSI indices

Index	N	Mean	Std. Deviation	Min	Max
dry temperature(°C)	41	39.68	1.86	36.7	43.2
natural wet bulb temperature(°C)	41	39.6	2.48	32.0	44.0
globe temperature (°C)	41	40.69	2.21	37.7	44.6
air velocity(m/s)	41	.2398	.01943	.20	.27
Relative humidity(%)	41	98.3	2.45	90	100
WBGT(°C)	41	40.027	2.135	36.7	44.1
Core body thermometer (°C)	41	37.19	.574	36.9	38.5
HIS	41	489.9756	100.02987	323.00	693.00

Table 4) Analysis of statistical value between core body temperature, HSI, WBGT index and measured Environmental parameters.

Measured index	value statistical	dry temperature(°C)	Environmental parameter			
			globe temperature(°C)	relative humidity (%)	natural wet bulb temperature(°C)	air velocity(m/s)
core body thermometer(°C)	Pearson Correlation	.576	.648	.307	.469	.206
	P. value	.000	.000	.051	.002	.196
	N	41	41	41	41	41
WBGT(°C)	Pearson Correlation	.977	.956	.494	.877	.390
	P. value	.000	.000	.001	.000	.012
	N	41	41	41	41	41
HIS	Pearson Correlation	.888	.882	.619	.823	.299
	P. value	.000	.000	.000	.000	.058
	N	41	41	41	41	41

Table 5) Analysis of statistical value between core body thermometer, WBGT and HSI indices

Measured index	value statistical	Measured index		
		core body thermometer(°C)	WBGT(°C)	HSI
core body thermometer(°C)	Pearson Correlation	1	.597	.537
	P. value		.000	.000
	N	41	41	41
WBGT(°C)	Pearson Correlation	.597	1	.928
	P. value	.000		.000
	N	41	41	41
HIS	Pearson Correlation	.537	.928	1
	P. value	.000	.000	
	N	41	41	41

Table 3 shows, mean of dry temperature is 39.68(°C), mean of natural wet bulb temperature is 39.6(°C), mean of globe temperature is 40.69(°C), mean of air velocity is .2398(m/s), mean of relative humidity is 98.3(%), mean of Core body temperature is 37.19(°C) and mean of WBGT index is 40.027(°C) and mean of HSI index is 489.9756. According to Table1, WBGT was recommended by ACGIH for Light (200kcal/h) work and for acclimatized workers is 29.5(°C), whilst According to Table 3 mean value of

WBGT index was evaluated at all workers indoors location is 40.027(°C), it showed that the calculated WBGT has exceeded the Threshold Limit Value (TLV) suggested by the ACGIH Standard so that we can conclude that the all workers expose to high heat stress.

According to standard so as Table 2 shows, the permissible HSI index values is between 0 -10 with No thermal strain. Whilst Table 3 shows that the evaluated mean value of HSI for all workers is 489.9756. Therefore it is more than HSI standard.

In this study the mean of core body temperature was 37.19(°C) and maximum of core body temperature was 38.5(°C) whilst the limit value of core body temperature is 38(°C). (5, 7).

Discussion

The present study was done in the steels industry in Lorestan. The environmental parameters and Sublingual temperature (Physiological parameters) were simultaneously studied. The heat stress exposure was assessment by HSI and WBGT.

Regarding on the results, mean of WBGT index was 40.027(°C) and mean of HSI index was 489.9756. It showed that the all workers expose to high heat stress. Whilst mean of core body temperature was 37.19(°C) and maximum of core body temperature was 38.5(°C). It showed that 4.88 percent of workers expose to high heat stress.

According to Table 3 WBGT values have significant positive correlation whit dry temperature (ta), natural wet bulb temperature (tnw), relative humidity (RH) and globe temperature (tg).

So that Table 3shows, According to Pearson correlation coefficient test, the core body temperature has a significant positive correlation (p =0.051) with relative humidity and also, the core body temperature has a significant positive correlation with dry temperature, globe temperature (tg) and the natural wet bulb temperature (tnw). But WBGT and HSI have more correlation than core body temperature with environmental parameters.

according to Table 3, the Pearson correlation coefficient between the core body temperature with globe temperature (tg) is r= 0.648, the Pearson correlation coefficient between the core body temperature with natural wet bulb temperature is r= 0.469 and the Pearson correlation coefficient between the core body temperature with relative humidity is r= 0.307 Whilst, the Pearson correlation coefficient between WBGT with globe temperature (tg) is r= 0.956, the Pearson correlation coefficient between WBGT with natural wet bulb temperature is r= 0.877 and the Pearson correlation coefficient between WBGT with relative humidity is r= .494 also, the Pearson correlation coefficient between HSI with globe temperature (tg) is r= 0.882 and the Pearson correlation coefficient between HSI with natural wet bulb temperature is r=0.823.

Pearson correlation coefficient between the core body temperatures has less correlation with globe temperature (r= 0.648), relative humidity (r= 0.307) and with natural wet bulb temperature (r= 0.469) than HSI and WBGT. WBGT has high correlation with globe temperature (r= 0.956) and natural wet bulb temperature (r= 0.877) so this finding can prove that WBGT index shows higher heat stress than core body temperatures.

WBGT Index didn't provide a precise estimate of physiological responses in the body, so that Table 5 shows correlation between WBGT and core body thermometer is moderate (r=0.597). Bate examined the physiological responses of construction workers in the United Arabic Emirates, his study 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 Emirates weather conditions was not precise and reliable (15).

Goh See Ben's study showed no significant correlation between the WBGT measured with the body temperature in plastic industry workers. Even though the measured WBGT were slightly above the recommended ACGIH threshold level, the body temperature rate measured did not reach unacceptable level of physiologic strain (1).

Grahame's study showed that WBGT has serious limitation, this limitation is that environment at a given level of the index are more stressful when the evaporation of sweat is restricted by high humidity or low air velocity than when evaporation is free (11).

Golmohammadi comparing the Heat Stress Index of HSI and WBGT in the Hamedan bakeries, his study showed that the HSI values had high dependence on air velocity (r =-0.811). Conclusion Values of HSI index had a wide scatter in variances in Golmohammadi's study fields comparing of WBGT index that had a minimal scatter Golmohammadi's study showed the HSI index had any weakness (16).
Jafari's study to determine the optimal index for foundry's shift workers showed that MRT, P4SR, CET indices had highest correlation with the WBGT index and the HSI index highly dependent on the flow rate of air in the study. It showed that WBGT index was significantly higher than the other Heat stress indices (10).
It should be noted that contrary to expectations and according to table 3 unlike the results of other studies such Golmohammadi's and Jafari's study, the HSI index has not statistically significant relation with air movement (p=0.058) (10.16). Whilst the Pearson correlation coefficient between HSI with relative humidity is r=0.619 and HSI has more correlation with relative humidity than core body temperature (r= 0.307) and WBGT (r= 0.494) .the air velocity and vapor pressure are required parameters for estimating of HSI index whit regard to that HSI has not significant relation with air velocity (p=0.058) and with regard to that vapor pressure is effective parameter for estimating of relative humidity also, it can be concluded that in the environments with high relative humidity and low air velocity rate HSI index is more influenced by relative humidity thus it can demonstrated that HSI index have limitations for assessing heat stress in environments with high relative humidity and low air movement.
Montain's study showed that, the HSI values in the hot/wet climate higher than the HSI values in the hot/dry climate (HSI= 105±3.1 and 95±1.8) (17).
So that NIOSH believed HSI index is useful index but have limitations for environments with high humidity (NIOSH 1986) (8).

Conclusions

In this study the estimation of heat stress by using HSI and WBGT indices was higher than biological monitoring (measuring the core body temperature). It can be concluded that estimation of heat stress by using biological monitoring in hot environments under condition of high humidity or low air velocity is closer to reality of heat stress in exposed workers.

Footnotes

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Conflict of Interest:
The authors declare no conflict of interest.

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