2008-5435/14/63-9-13
INTERNATIONAL JOURNAL OF OCCUPATIONAL HYGIENE

IJOH 8: 9-13, 2016

ORIGINAL ARTICLE

Comparing the Association between Wet Bulb Globe Temperature (WBGT) and Heat Stress Score Index (HSSI) Thermal Indices with Physiological Parameters in a Melting Plant

MOHAMMAD REZA GHOTBI RAVANDI[1]; SAJAD SALIMI[1]; NARGES KHANJANI[2]; MOHAMMAD JAVAD JAFARI[3*]

[1]*Department of Occupational Health Engineering, School of Public Health, Kerman University of Medical Sciences, Kerman, Iran;*

[2]*Department of Statistics and Epidemiology, School of Public Health, Kerman University of Medical Sciences, Kerman, Iran;*

[3]*Department of Occupational Health Engineering, School of Public Health, Shahid Beheshti University of Medical Sciences, Tehran, Iran.*

Received September 08, 2015; Revised December 07, 2015; Accepted January 01, 2016

This paper is available on-line at *http://ijoh.tums.ac.ir*

ABSTRACT

The best association between a heat stress index and physiological parameters has always been a major concern. We aimed to compare the association of two heat stress indices with physiological parameters. This cross-sectional study was conducted on 54 acclimatized mail subjects working in a steel complex in May 2014. After enrolling individuals based on inclusion criteria, Wet bulb globe temperature (WBGT) and Heat Stress Score Index (HSSI) (heat stress indices) as well as physiological parameters were recorded during their work shift. Then the relationship between physiological parameters and the calculated indices were determined. The study population had a mean age of 29.3±4.2 yr. The average values of the WBGT and HSSI indices were 27.3 ± 2.9 °C and 22.7±3.6 respectively. The average relative humidity and air velocity were 35.9-±1.9% and 1.5±0.4 m/s respectively. The correlation between WBGT and tympanic temperature was statistically significant ($P \leq 0.01$). However, the HSSI was not significantly correlated with tympanic temperature ($P=0.37$). Correlation coefficients between WBGT and HSSI with heart rate were 0.458 and 0.191 respectively. It was concluded that WBGT is likely to offer a better assessment of thermal stress in comparison to HSSI in melting industry workers.

KEYWORDS: *Correlation, Heat stress, WBGT, HSSI, Physiological parameters*

INTRODUCTION

Exposure to heat is one of the workplace risk factors, which may lead to thermal strain (physiological responses), such as rising heart rate and body temperature [1]. Exposure to thermal stress (tension) may have health risk potential in addition to reducing efficiency of the workers. Heat stress may have direct or indirect impacts on each individual's health. It may harm tissues, organs and systems of the body in its direct impact while it may increase occupational accidents in its indirect impact [2-4].

Air temperature, relative humidity, radiant temperature, air velocity, activity level, type of clothing and age can influence the thermal stress intensity. The combination of these factors has already been proposed to represent heat stress level

*** Corresponding Author: Mohammad Javad Jafari**

Email:* *jafari1952@yahoo.com

as a number called heat stress index [2, 5-6]. The purpose of introducing a heat stress index is to summarize the relationship between the environmental, occupational, psychological and emotional factors quantitatively, in order to facilitate the measurement and control of thermal stress [2, 7].

Indices proposed for evaluating thermal stress at workplaces have been classified in tow main groups of empirical and analytical indices. Empirical indices combine environmental parameters including dry bulb temperature, wet bulb temperature and radiation globe temperature. Empirical indices are based on human body's physiological response to different environmental factors. Analytical indices have been developed based on human body’s heat balance with its surrounding environment.

Some empirical indices are based on integration of physiological and environmental factors requiring complex calculations [4, 8]. Among the empirical indices, wet bulb globe temperature (WBGT) has been widely used in many countries. This index has been recommended as a standard heat stress index based on standard ISO 7243. It is the only index that measures radiation temperature. The American Conference of Governmental Industrial Hygienists (ACGIH) defines the threshold limit values of heat based on WBGT [2, 9]. In recent years, indices such as MDI, PSI and HSSI have also been introduced [4, 9].

Physiological parameters, including core temperature and heart rate have also been used as markers to assess the impact of environmental heat on humans, mainly due to their fair correlation with thermal conditions [2, 10]. In Palestine, Egypt and America, MDI, DI and WBGT indices were used for evaluating heat stress and showed that in contrast to DI and WGT indices, MDI and WBGT were directly related together in different geographical conditions [11-12].

Considering the importance of comprehensive thermal indices in heat stress assessment, in British standards (BS EN ISO 10551: 2004), a standard entitled "Evaluation of hot environments using personal judgment" has been defined and is a guide for thermal stress assessment by using mental or emotional judgments [13]. Dehghan et al. introduced HSSI (Heat Stress Score Index) based on the four-stage strategy of Malchaire et al. for screening hot workplaces [14]. This observational checklist method was successfully applied as a screening tool in a closed and steel industry in the warm and humid climate of the Persian Gulf shores and Asalooye region, southern Iran.

HSSI is based on the subjective judgment of individuals facing heat exposure and observing effective factors (the observational-judgment technique) and is capable of rapid, cheap screening (with no need to use measurement tools) [5, 8]. Due to the harmful effects of heat stress on workers, in order to adequately describe the environmental conditions in terms of heat stress, the validity of heat stress indices should be determined [15].

Hostler et al. developed an emotional hyperthermia index based on a laboratory pilot study and reported that there is a relatively strong correlation between the Perceptual Hyperthermia Index and deep body temperature, under different environmental thermal loads [16].

In a study on the health effects of heat stress on construction workers in the hot season, the levels of WBGT were between 23 and 34 °C [17]. In that study, the increase of blood pressure was also reported. There is a strong correlation between physiological indices and WBGT index in workers at an open mine [18]. While in an underground mine, there was little correlation between WBGT index and physiological variables [18]. At one of the Tehran's steel industries, the WBGT index exceeded the recommended limits [19].

In order to find the most suitable heat stress index for evaluation of occupational exposure to heat stress and controlling health hazards, more researches are necessary in this field. This study aimed to evaluate the relationship between WBGT and HSSI indices with physiological parameters (including heart rate and blood pressure) in order to investigate the effect of environmental heat on workers and to introduce the proper index for evaluating the occupational exposure to heat stress in the steel industry.

MATERIALS AND METHODS

This cross-sectional study was conducted on 54 healthy acclimatized steel workers in a steel plant in June 2014. The main objective of the study was to evaluate the relationship between WBGT and HSSI indices with physiological parameters (including core temperature, and heart rate) of workers. All workers who matched the inclusion/exclusion criteria were enrolled. The inclusion criteria included absence of cardiovascular disease, thyroid disease, hypertension, diabetes, fever and infectious diseases.

At the beginning of the work shift and after a break of 15 min the demographic characteristics were recorded for each worker. Then, their heart rate and tympanic temperature were measured. Heart rate was measured by a digital device fastened to the workers arm. Tympanic temperature was measured by an infrared thermometer. Then workers performed their daily tasks and activities. The physiological parameters of individuals were measured at 10 a.m., 12 noon and 3 p.m. at their break hours.

The metabolism rate of the workers for each task was estimated based on the standard ISO 8989 table. Clothing insulation was determined in Clo unit from standard tables. Finally according to the ISO 9920 standard and the rest / work hours, the time weighted averaged metabolic rate was determined.

WBGT was measurement using the WBGT meter at each working station.

WBGT was calculated from Equation 1 based on ISO 7243 standard, in indoor workplaces where solar radiation is negligible [9].

(Equation 1)

$$WBGT = 0.7t_{nw} + 0.3t_g$$

Where t_g and t_{nw} are the radiation and natural wet bulb globe temperatures respectively.

Since the difference in measured parameters at different heights was more than 5% thus, the environment was heterogeneous, therefore the WBGT index was measured at ankle (0.1 m), lumbar (1.1 m) and the head (1.7 m) height [20-21].

WBGT index was calculated from Equation 2 according to US-NIOSH for each workstation.

(Equation 2)

$$WBGT == \frac{WBGT_{head} + 2WBGT_{lumbar} + WBGT_{ankle}}{4}$$

Due to environmental changes during each working shift, therefore the time weighted averaged WBGT was determined using Equation 3.

(Equation 3)

$$WBGT_{twa} = \frac{\sum_{i=1}^{n} WBGT_i \times t_i}{\sum_{i=1}^{n} t_i}$$

Where WBGTi was the measured WBGT at each task period and ti was the relevant duration of ach task.

The Assman psychrometer was used to measure dry and wet bulb temperatures. Relative humidity was determined using psychometrics chart, after correcting for the local altitude from sea level. In order to determine the air velocity a silvered kata thermometer was used.

Table 1. Mean and standard deviation of WBGT, HSSI, relative humidity and airflow at workstations

Working station	N	WBGT(°C)	HSSI	Related humidity (%)	Air velocity (ms^{-1})	WBGT(°C)
Furnace	72	26.6±1.84	23.25±3.71	36.1±1.06	0.26±1.62	26.6±1.84
Casting	60	29.4±2.95	22.56±3.41	34.91±2.45	0.20±1.82	29.4±2.95
QC	30	24.5±1.48	21.63±3.73	1.52±36.74	1.02±0.27	24.5±1.48
Total	162	27.3±2.91	22.7±3.63	35.92±1.91	1.49±0.42	27.3±2.91

RESULT

The measured physiological parameters were heart rate and tympanic temperature that were recorded while working hours at three times (10 a.m., 12 noon and 3 p.m.). The measured physiological parameters before work and during work are presented in Table 2.

WBGT index during work had the highest correlation coefficient with tympanic temperature and heart rate, which was statistically significant. However, the HSSI index did not have a significant correlation with the tympanic temperature.

The correlation coefficient between this index and heart rate was weak but statistically significant (Table 3).

In comparison of correlations between thermal indices with changes of physiological parameters (from work to the rest), the WBGT index had the highest correlation with changes of physiological parameters of the tympanic temperature and heart rate which were 0.526 and 0.537 respectively.

The correlation of HSSI index with tympanic temperature changes was not statistically significant. But, the correlation coefficient between this index and the changes in heart rate was 0.176 and was statistically significant (Table 3).

Table 2. Physiological parameters before work and during working

Work station	N*	Heart rate (bpm)		Tympanic temperature (°C)	
		Working time	Before work	Working time	Before work
Furnace	72	86.9±8.01	69.9±6.14	37.07±0.43	36±0.38
Casting	60	88.7±11.91	68±8.08	37.79±0.39	35.8±0.43
QC	30	79.5±5.82	4.57±69.7	37.06±0.67	36±0.35
Total	162	86.18±9.88	69.2±6.72	37.33±0.59	35.9±0.41

*The number of samples before work was one third of the working state.

Table 3. Relationship between indices with physiological parameters

Parameter	HSSI		WBGT	
	P value	R	*P* value	R
Tympanic temperature (°C)	0.37	0.070	0.01≥	0.515
Tympanic temperature change (°C)	0.25	0.0.92	0.01≥	0.526
Heart rate (bpm)	0.02	0.191	0.01≥	0.458
Heart rate change (bpm)	0.03	0.176	0.01≥	0.537

DISCUSSION

The purpose of this study was to evaluate the correlation between WBGT and HSI indices with physiological parameters and to assess the ability of these indices in evaluating thermal stress imposed on the workers at a steel mill complex.

Whole-body heat stress caused some physiological response observed during exercise [20]. The present study also found a positive correlation between physiological parameters and thermal stress indexes. Besides, tympanic temperature and heart rate increased by increasing thermal stress.

The present study showed a fair correlation between WBGT and physiological parameters, which well agreed with those, obtained in other studies [15, 21-22]. A significant and direct association between thermal indices with heart rate was experienced in present study. The WBGT index had a higher correlation with heart rate, which was similar to the results of the present study [23]. Moreover, in a glass factory, the correlation between the WBGT index and heart rate was significant, which was consistent with our findings [22].

The results of present study showed that the WBGT index had a direct and high correlation with the investigated physiological parameters. For evaluating imposed heat stress on workers the combined application of WBGT index and physiological parameters (heart rate and body temperature) would be more effective. Their results are consistent with our results [24].

The results of Dehghan et al’s study[25] performed in the hot and humid climate of the Persian Gulf region, showed that the correlation between the WBGT index and physiological parameters (heart rate and core temperature) was low, which is inconsistent with the results of the present study. This difference may be due to the hot and dry climate in present study compared to their hot and humid environment.

The results of another study in Iranian oil terminals also showed that among the studied heat stress indices, WBGT had the highest correlation coefficient with core (tympanic) temperature [26]. The results of their study were consistent with present study.

According to the findings of the present study, there was no significant correlation between HSSI index and tympanic temperature. Moreover, HSSI had a weak correlation with heart rate. The results of this study indicate that the HSSI index had a low correlation with the studied physiological parameters. The results of a study in a glass factory also showed a weak correlation between HSSI index and physiological parameters (tympanic temperature, heart rate and blood pressure) [27]. However, the correlation between physiological parameters (body temperature and heart rate) with HSSI was better in comparison to WBGT [5]. In the present study, WBGT had a better correlation with the physiological parameters in comparison to HSSI. The results of Dehghan et al., study were not confirmed in present study. WBGT was the most reliable index to investigate heat stress at workplaces [23], which is in line with our findings.

Acute exposure to heat may cause significant changes in thyroid hormones and serum triiodothyronine [28] and there was a significant relation between WBGT index and T3 hormone of the exposed workers. Although such studies may lead to new markers to be considered in further studies but their measurement is not as easy as core temperature and heart rate.

CONCLUSION

WBGT had a strong correlation with physiological parameters (core body temperature and heart rate), while HSSI shows a weak correlation. Therefore, to assess workers heat stress in the steel industry HSSI is not recommended. However, it is still advised that further studies need to be conducted in this field.

ACKNOWLEDGMENT

This study was part of an MSc thesis supported by Kerman University of Medical Sciences, Kerman, Iran. The authors declare that there is no conflict of interests.

REFERENCES

1. Dehghan H, Mortazavi SB, Jafari MJ, Maracy MR. Comparision betwen cardiac strain of normal weight and overweight workers in hot and humid weather of the south of Iran. *Health System Research* 2012; 8(5): 866-75.
2. Golbabaei F, Omidvari M. *Man and thermal environment.* Tehran: Tehran University Press; 2008.
3. Kjellstrom T, Lemke B, editors. *Loss of worker productivity due to projected climate change.* IOP Conference Series: Earth and Environmental Science; 2009: IOP Publishing.

4. Epstein Y, Moran DS. Thermal comfort and the heat stress indices. *Industrial Health* 2006;44(3): 388-98.
5. Dehghan H. *The design of screening method for primary evaluation of thermal risk based on observation and subjective feeling workers under field conditions in center and south parts of Iran, PhD thesis*, Tarbiat Modares University, Tehran, Iran, 2012.
6. ASHREA. *Fundamental hand book physiological principal for comfort and health*. ASHREH; 1985.
7. Brake R, Bates G. A valid method for comparing rational and empirical heat stress indices. *Ann Occup Hyg* 2002; 46(2):165-74.
8. Dehghan H, Mortazavi SB, Jafari MJ, Maraci MR, Khavanin A. Construction and validation of a heat strain score index with structural equation modeling. *Health Sys Res* 2011; 7(2): 1-18.
9. Parsons K. Heat stress standard ISO 7243 and its global application. *Indus Health* 2006; 44(3):368-79.
10. NIOSH. *Criteria for a recommended standard: Occupational exposure to hot environments* (Revised Criteria 1986). Washington DC, USA, April 1986.
11. Moran DS, Shitzer A, Pandolf KB. A physiological strain index to evaluate heat stress. *Am J Physiol-Regulatory, Integ Compar Physiol* 1998;275(1):R129-R34.
12. Moran D, Shapiro Y, Epstein Y, Matthew W, Pandolf K. *A modified discomfort index (MDI) as an alternative to the wet bulb globe temperature (WBGT).* Environmental Ergonomics VIII, Hodgdon JA, Heaney JH, Buono MJ (Eds). 1998:77-80.
13. ISO 10551. *Ergonomics of the thermal environment— Assessment of the influence of the thermal environment using subjective judgement scales*. International Standards Organisation. Geneva2004.
14. Malchaire J, Gebhardt HJ, Piette A. Strategy for Evaluation and Prevention of Risk Due to Work in Thermal Environments. *Ann occup Hyg* 1999; 43(5): 367-376.
15. Falahati M, Alimohammadi I, Farshad A, Zokaii M, Sardar A. Evaluating the reliability of WBGT and P4SR by comparison to core body temperature. *Iran Occup Health* 2012;9(3): 22-31.
16. Hostler D, Gallagher Jr M, Goss FL, Seitz JR, Reis SE, Robertson RJ, et al. The effect of hyperhydration on physiological and perceived strain during treadmill exercise in personal protective equipment. *European J Appl Physiol* 2009;105(4):607-13.
17. Morioka I, Miyai N, Miyashita K. Hot environment and health problems of outdoor workers at a construction site. *Industrial Health* 2006;44(3):474-80.
18. Naghibi A. *Evaluation of thermal stress on lead and zinc mine and the determine model for predicting the amount of workers tolerating*. Tehran, IRAN: Tehran University; 1996.
19. Haji Azimi E, Khavanin A, Aghajani M, Soleymanian A. Heat stress measurement according to WBGT index in smelters. *J Mil Med* 2011;13(2):59-64.
20. Iguchi M, Littmann AE, Chang S-H, Wester LA, Knipper JS, Shields RK. Heat stress and cardiovascular, hormonal, and heat shock proteins in humans. *J Athletic Training* 2012;47(2):184.
21. Aliabadi M, Jahangiri M, Arrassi M, Jalali M. Evaluation of heat stress based on WBGT index and its relationship with physiological parameter of sublingual temperature in bakeries of Arak city. *Occup Med Quarterly J* 2014;6(1):48-56.
22. Jafari MJ, Hoorfarasat G, Salehpour S, Khodakarim S, Haydarnezhad N. Comparison of Correlation between Wet Bulb Globe Temperature, Physiological Strain Index and Physiological Strain Index Based on Heart Rate with Heart Rate and Tympanic Temperature on Workers in a Glass Factory. *J Saf Promot Injury Preven* 2014;2(1):55-64.
23. Golbabaie F, Monazam Esmaieli MR, Hemmatjou R, Yaaghoub P, Reza G, Hosseini M. Comparing the Heat Stress (DI, WBGT, SW) Indices and the Men Physiological Parameters in Hot and Humid Environment. *Iran J Health Environ* 2012;5(2):245-52.
24. Motamedzade M, Azari MR. Heat stress evaluation using environmental and biological monitoring. *Pak J Biol Sci* 2006;9(3):457-9.
25. Dehghan H, Mortazavi SB, Jafari MJ, Maracy MR. Evaluation of wet bulb globe temperature index for estimation of heat strain in hot/humid conditions in the Persian Gulf. *J Res Med Sci* 2012;17(12):1108.
26. Falahati M, Alimohamadi I, Farshad A, Zokaie M, Sardar A. Evaluation and Validation of Heat Stress Indices in Iranian Oil Terminals. *Int J Occup Hyg* 2012;4(2):73-7.
27. Hoorfarasat G, Jafari MJ, Omidi L, Salehpour S, Khodakarim S, Haydarnezhad N. Correlation between heat strain score index and WBGT index with physiological parameters in a glass manufacturing plant. *Int J Occup Hyg* 2015; 7(4): 202-208.
28. Jafari MJ, Norloei S, Omidi L, Khodakarim S, Bashash D, Abdollahi MB. Effects of heat stress on concentrations of thyroid hormones of workers in a foundry industry. *Occup Med Quarter J* 2016; 7(3): 69-79.