original article

The evaluation of heat stress through monitoring environmental factors and physiological responses in melting and casting industries workers

Habibollah Dehghan, Seyed Bagher Mortazavi, Mohammad Javad Jafari[1], Mohammad Reza Maracy[2], Mahdi Jahangiri[3]

Department of Occupational Health Engineering, Faculty of Medical Sciences, University of Tarbiat Modares, Tehran, Iran, [1]Department of Occupational Health Engineering, School of Public Health, Shahid Beheshti University of Medical Sciences, Tehran, Iran, [2]Environmental Research Center, Isfahan University of Medical Sciences, Isfahan, Iran, [3]Department of Occupational Health Engineering, School of Public Health, Shiraz University of Medical Sciences, Shiraz, Iran

Address for correspondence:
Dr. Seyed Bagher Mortazavi,
Department of Occupational Health Engineering, Faculty of Medical Sciences, University of Tarbiat Modares, Tehran, Iran.
E-mail: mortazav@modares.ac.ir

ABSTRACT

Aims: Evaluation of heat stress in workers exposed to hot/dry conditions of melting and casting industry is imperative for management of heat stress. This study aims to compare results of heat strain evaluation by monitoring environmental factors and physiological responses.

Materials and Methods: This is a cross-sectional study that was conducted on 51 workers of a large melting and casting company in 2010. Wet Bulb Globe Temperature (WBGT) index, heart rate and ear canal temperature were measured by WBGT meter, heart rate monitor and personal heat stress monitor, respectively. Physical activity intensity was assessed based on the ratings of perceived exertion (RPE). Data were analyzed using descriptive statistics and Pearson correlation test.

Results: WBGT index in 64.7% of workstations exceeded 30°C and in 41.2% was over 32°C. The value of WBGT index in 69% of work stations exceeded the threshold limit of the ACGIH standard. The physiological strain index (PSI) in 31% of worker was higher than 5, although its mean measured at 3.8 (1.8). Increase in the ear canal temperature in 64.7% of cases (33 persons) was over 1°C. Correlation between WBGT index with ear canal temperature and PSI index, adjusted body mass index and age, was 0.67 and 0.69 ($P < 0.0001$).

Conclusion: In hot/dry conditions of melting and casting processes, despite moderate correlation between WBGT index with ear canal temperature and PSI index, work-rest cycles of WBGT index is not applicable for many of the workstations. Therefore, heat stress evaluation based on physiological variables probably has higher validity and is more appropriate.

Key words: Ear canal temperature, heart rate, heat stress, hot/dry conditions, WBGT index, PSI index

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INTRODUCTION

Workplace conditions in some of the melting and casting industries in developing countries, for lack of automation and perform of physical hard work, are so serve that production line workers exposure to extreme heat.[1] Prolonged work under these conditions causes heat strain. Sustained

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heat strain in the expose to hot conditions, doing heavy physical work, the use of the personal protective clothes and equipments form insulation against water vapor and heat, resulting in heat exhaustion.[2-4] Heat stroke,[5,6] muscular cramp,[7] increased human error, reduced mental and physical activities,[8-10] increased accidents at work and ultimately reduced productivity.[11-14]

In the melting and casting processes, particularly during the hot months of the year, since atmosphere is warmer together with the heat radiated from molten material and hot surfaces of the cast, heat stress becomes one of the most important physical harmful agents in such environments. Therefore, dealing with heat stress in workers of these industrial units is mandatory and prevention of heat-related illnesses and maintaining workforce efficiency, necessitates continual measurement and evaluation of heat stress for the purpose of its proper management.

In the past century, for the evaluation of heat stress in hot environments, a number of indices were introduced, but only a few of them were used worldwide. WBGT index (Wet Bulb Globe Temperature) has been one of the best known and most widely used of all thermal indices which contained important environmental factors such as dry bulb temperature, wet bulb temperature and globe temperature in its equation.[15-17] In the calculation of this index, non-environmental factors are not accounted for, but factors such as clothing, level of metabolism and acclimatization are used in the description of this index. Often in the evaluation of the level of metabolism for use in the description of the WBGT index, large variations are observed, causing oscillation in the results obtained for the index.[14,15,18] Also, because of the self-pacing phenomenon in very hot conditions,[19] WBGT index tends to overestimate level of heat stress in personnel exposed to heat in many hot countries such as China, India, Thailand, and Dubai.[20,21] Moran *et al*. introduced Physiological Strain Index (PSI) for the evaluation of the heat strain in 1998. This index is calculated using Equation (1) in which variation in rectal temperature (T_c) and heart rate (HR) are compared under rest and work conditions. Tr, Tw, HRr, HRw stand for deep body temperature and heart rate in rest and work periods, respectively.

This index compares changes of rectal temperature (T_{re}) and heart rate (HR) at two rest and work states according to Equation 1:

$$PSI = 5(T_{re\ t} - T_{re0}) \cdot (39.5 - T_{re0})^{-1} + 5(HR_t - HR_0) \cdot (180 - HR_0)^{-1} \quad (1)$$

where $T_{re\ t}$ and HR_t are simultaneous measurements taken at any time during the exposure and T_{re0} and HR_0 are the initial measurements. Numerical values of this index range 0-10, in which 0 indicates lack of thermal stress and 10 shows its maximum value.[22] Validity of this index for men and women under various conditions of work has been studied. This physiological index evaluates level of heat stress resulting from environmental factors, clothing, level of activity and personal particulars such as sex, age, etc.[23-25]

In the evaluation of thermal stress under dry/hot conditions, question arises as to the usefulness of the cycles of work-rest of WBGT index based on the ACGIH Standard, which at present time is widely used for the evaluation of thermal stress in the environments of melting and casting processes, and whether WBGT index is an appropriate index for the physiological heat strain estimation in the dry/hot conditions of these industrial processes. To answer this question, WBGT and PSI indices in the workers exposed to heat were measured simultaneously. Effectiveness of the usage of WBGT index for evaluating heat stress in dry/hot conditions was assessed through comparison of the results of monitoring environmental factors and physiological responses.

MATERIALS AND METHODS

This cross-sectional study was performed on 51 workers of a melting and casting company in central Iran during June and July 2010. Permit for this study was obtained from the medical ethics committee of the school of medical sciences of the University of Tarbiat Modares. These workers were selected randomly on the basis of the required criteria for this study (no cardiovascular, respiratory and infectious diseases, diabetes and hyperthyroidism and did not take cardiovascular medicine and minimum 2 weeks presence at workplace), and being exposed to important factors that cause thermal stress.

On the day of the experiment, after taking measurements of weight, height and recording any previous heat-related illnesses they may have had, workers were attached to a heart rate monitoring device (Polar Electro RS100, Finland).[26] This device uses a sensor stuck to the chest and a receiver similar to a wrist watch strapped around the person's wrist. Also a portable Personal Heat Stress Monitor (Questemp ii), to measure deep body temperature was used via the ear of the person.[27-29] This device contains a temperature sensor which is placed inside the outer ear and a processing system and monitor attached to the persons belt. To reduce atmospheric effects on the measured temperature, the sensor is completely insulated.[30] After 30 minutes of rest in the cool room (WBGT = 23.6 + 1.4), heart rate and ear canal temperature were measured and the mean heart rate and ear canal temperature under rest conditions were recorded.[31] Then without disconnecting measuring devices, the workers were asked to return to their workstations and start work. After beginning of work, measurements of heart rate and ear canal temperature at intervals of 20, 40, and 60 minutes were recorded.[26] At the same time as measuring heart rate and ear canal temperature, dry bulb temperature, wet bulb temperature, globe temperature and WBGT index during work and rest, using WBGT meter (Cassella model) based on ISO7243 Standard were also measured.[15,16] Also in this study, to estimate level of workers physical activity, the Persian version of the perceived exertion rate of Stone-Parfitt[32,33] was used.

These experiments were carried out indoors, at 9-12 pm. At the end of the measurements, PSI index and difference between ear canal Temperature in rest and work state (ΔT) were calculated. Based on the American Conferences Governmental industrial Hygienists (ACGIH) TLVs for the year 2006, values of the WBGT index on three levels of light work, medium work and heavy work were classified. Distribution of the PSI index, heart rate, ear canal temperature and ΔT in different levels of WBGT index were established by using SPSS-18 software.

RESULTS

This cross-sectional study was conducted on 51 unskilled and semi-skilled workers of a large melting and casting company in 2010. Mean (standard deviation) age 32.1 (4.8) years, height 176 (6.0) cm, weight 77.7 (10.4) kg and body mass index 25.0 (3.1) kg/m^2 and 11.8% of these workers (6 persons) having had heat strokes previously.

Mean (standard deviation) dry bulb temperature, wet bulb temperature, globe temperature and relative humidity were 41.8°C (6.1), 24.8°C (3.2), 45.8°C (7.8), and 25% (4.2), respectively. The values of WBGT index in 64.7% of the workstations were over 30°C and in 41.2% was over 32°C [Table 1]. Mean WBGT index in 51 workstations was 30.7°C (4.2) and varied over 22.0-40.8°C range. Mean WBGT index at time intervals of 20, 40 and 60 minutes measured; 30.7°C (4.8), 30.7°C (4.4) and 31.2°C (4.5), respectively. The value of WBGT with respect to physical activity, in 69% (35 cases) of workstations exceeded standard threshold of ACGIH for continuous work and acclimatized.

Physical activity of the workers based on the Rating Perceived Exertion of Stone-Parfitt were 39% of the cases light, 31% of cases medium, and 30% of cases heavy.

The physiological strain index (PSI) in 31.4% of workers was over 5 [Table 2], although its mean (standard deviation) was 3.8 (1.8) within 0.6-9.0 range. Mean value of the PSI index in time intervals of 20, 40, and 60 minutes, after being exposed to the heat, measured as 3.4 (1.9), 3.9 (1.9) and 4.2 (1.9), respectively. Mean physiological stress in workers in all three time intervals was in the range of low to medium.

Mean (standard deviation) heart rate during at rest and work period were obtained 76 (7.5) and 111 (22.7) beat/min. Mean heart beat during light, medium, and heavy work were 91 (11.8), 114.3 (16.9), and 133.5 (15.0), respectively.

Mean (standard deviation) ear canal temperature at rest and work obtained were 36.3°C (0.6), and 37.0°C (0.8), respectively. Mean ear canal temperature during light, medium, and heavy work were 37.6C (0.5), 38.2C (0.6), and 38.0C (0.7), respectively. Values of the ear canal temperature difference at rest and work (ΔT) in 61% of cases (31 persons) exceeded 1°C. Correlation between WBGT index with ear canal temperature and PSI index, adjusted with body mass index and age, were 0.67 and 0.69, respectively. ($P < 0.0001$).

DISCUSSIONS

The value of the WBGT index, with respect to physical activity level, in 69% of the cases exceeded the standard threshold limit of ACGIH for Acclimatizing Workers and continuous work. Thus, based on ACGIH standard, workplace heat was stressful in 69% of the people in the study, but based on physiological responses, intensity of heat strain was over the value 5 only in 31% of workers. Comparison of results obtained for environmental conditions (WBGT index) and physiological responses (PSI index), based on increasing values of WBGT index [Table 3] reveals that: with uniform increase in WBGT index, PSI index in all three levels of physical activity, increases with relative regularity, but values of physiological strain in 86% of workers [Table 2], range between Low to Medium (less than 6). In a similar study by Mr. Moatamedzadeh *et al*. on assessing heat stress in workers in a warm and humid coastal region south of Iran, found that in spite of the fact that all the workers were exposed to

Table 1: Distribution of worker's group in term of WBGT[1] values

WBGT values (°C)	Frequency	Relative frequency (%)	Cumulative frequency (%)
<25.9	10	19.6	19.6
26.0-27.9	4	7.8	27.5
28.0-29.9	5	9.8	37.3
30.0-31.9	11	21.6	58.8
32.0-33.9	8	15.7	74.5
34.0-35.9	10	19.6	94.1
<36	3	5.9	100

WBGT: Wet bulb globe temperature

Table 2: Distribution of worker's group in term of PSI[1] values

PSI values	Frequency	Relative frequency (%)	Cumulative frequency (%)
<0.9	3	5.9	5.9
1.0-1.9	6	11.8	17.6
2.0-2.9	8	15.7	33.3
3.0-3.9	12	23.5	56.9
4.0-4.9	16	11.8	68.6
5.0-5.9	9	17.6	86.3
6.0-6.9	5	9.8	96.1
7.0-7.9	1	2	98.0
<8.0	1	2	100

PSI: Physiological strain index

Table 3: PSI[1] values in term of work load and WBGT[2] values

WBGT values (°C)	Mean (standard deviation) PSI values			
	Total activities *N*=51	Light work *N*=20	Medium work *N*=16	Heavy work *N*=15
>27.5 *N*=14	2.2 (1.3)	1.7 (0.9)	3.0 (1.6)	-
27.6-30.7 *N*=9	3.5 (1.8)	2.3 (0.8)	3.4 (1.1)	4.8 (1.9)
30.8-33.7 *N*=15	4.1 (1.7)	2.8 (0.9)	5.0 (1.7)	5.0 (1.4)
<33.8 *N*=13	5.3 (1.1)	3.8 (0.8)	5.5 (0.8)	5.7 (1.1)

PSI: Physiological strain index, WBGT: Wet bulb globe temperature

the conditions exceeding ACGIH standard, based on given biological values (heart beat and oral temperature) only 16.25% showed signs of thermal stress.[34]

WBGT index is an empirical index which contains, in its calculation, important environmental factors, and other non-environmental factors, important in producing thermal stress such as physical activity, type of work clothes, and acclimatization to heat, are used in the interpretation of results of this index. In this study, one of the reasons for reduction in heat strain based on PSI in comparison with heat stress based on WBGT index is probably, occurrence of the phenomenon of self-pacing in the level of activity which is taken up by people to reduce heat strain.[35] Self-pacing of physical activity is a preventive behavior that occurs when people are exposed to extreme temperature [19] and the role it plays in reducing occurrence of thermal stress has been shown in several studies.[11,21,36-38] Donoghue *et al*. have recognized training to self-pace activity or rest when working under harsh conditions as necessary procedures to reduce heat exhaustion in deep mining workers.[35-37] Brake *et al*. in their research on level of fatigue in mine workers exposed to heat stress environment (WBGT = 30.8) found that, self-pacing of activity level by workers was very probable.[39] Soule *et al*. found that in environmental conditions where wet temperature exceeds 33.5°C and deep body temperature increases, self-pacing of work activity occurs.[40] Mairiux *et al*. concluded that self-pacing via a work-rest cycle by workers exposed to heat is an effective device against physiological strain.[38] Miller *et al*. observed that when self-pacing, mean heart beat, seldom goes over 110-115 beat/min.[41] Also, Rastogi *et al*. studying correlation between globe temperature and heart rate in workers of a glass factory reached the conclusion that globe temperature alone cannot assess heat strain.[30] In a similar study, Bate *et al*. working on physiological response of construction workers in United Arab Emirates concluded that maintaining bodily fluids level and self-pacing of work enabled workers to do their work in the summer without occurrence of extreme physiological response,[21] which is in agreement with the results of this study.

Therefore, in this study, taking into account periods of rest in a cool place and allowing personnel to self-pace, despite environmental conditions of workplace being stressful, level of physiological responses of workers was lower than the level of heat stress based on WBGT index. It appears that in extreme dry/hot environment of melting and casting processes, as dry and radiant temperatures are higher (41.8°C and 45.8°C, respectively) than skin temperature (35°C), body absorbs heat when exposed to hot air and radiant heat,[42] thence, heat loss mechanisms through radiation and convection are not sufficiently effective and the only way to heat loss is through evaporation of sweat from the skin surface. Due to low relative humidity (25% in this study), efficiency of heat losing through evaporation of sweat is desirable, That is why, despite stressfulness of the environmental conditions based on WBGT index values, in a considerable number of workstations (mainly in light and medium work), PSI index which is a physiological body response indicator is limited to the low to medium range, so that only 12% of people under this condition had previous heat stroke records.

CONCLUSIONS

In extreme dry/hot conditions of the melting and casting processes, work-rest regimes of WBGT index in many work stations tend not to be useful and despite moderate correlation between WBGT index and PSI index, since evaporation of sweat from skin is an effective mechanism, heart rate and ear canal temperature are within an acceptable range. Therefore, evaluation of heat stress under these conditions based on physiological responses is probably of higher validity compared with WBGT index and its usage for the upkeep of workers efficiency and maintenance of work-rest cycle is more acceptable for the industrial health and safety officer as well as the employers.

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