Safety and Health at Work 9 (2018) 232–235

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org

Original Article

Assessment of Semen Quality among Workers Exposed to Heat Stress: A Cross-Sectional Study in a Steel Industry

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A R T I C L E I N F O

Article history:
Received 9 April 2017
Received in revised form
8 July 2017
Accepted 10 July 2017
Available online 18 July 2017

Keywords:
heat stress
predicted heat strain
semen parameters
steel industry
wet-bulb globe temperature

A B S T R A C T

Background: This study was conducted to investigate the heat stress and semen quality among male workers in a steel industry in Iran and investigate the relationship between heat stress indices and semen parameters.

Methods: The study was conducted on workers exposed ($n = 30$) and unexposed ($n = 14$) to heat in a steel industry. After obtaining a brief biography of the selected employees, scrotal temperature, oral temperature, and environmental parameters were measured, and their semen samples were analyzed according to the procedure recommended by the World Health Organization. The heat stress indices, including wet-bulb globe temperature (WBGT) and predicted heat strain (PHS), in their workplace were calculated according to environmental parameters (ISO 7243:1989 and 7933:2004, respectively).

Results: Time-weighted averages of WBGT and PHS (35.76°C and 491.56 w/m$^{2}\frac{w}{m^2}$, respectively) for the exposed group were higher than threshold limit values. The mean difference of environmental, physiological, and semen parameters (exception: pH of semen), and also WBGT and PHS indices were statistically significant ($p < 0.05$) between the two groups. Mean semen parameters were in the normozoospermic range. WBGT and PHS indices showed significantly "negative" correlation with physiological parameters (scrotal and oral temperature) and most semen parameters (semen volume, sperm morphology, sperm motility, sperm count; $p < 0.05$); moreover, the correlation of WBGT with these parameters was stronger than PHS.

Conclusion: Semen parameters of the studied workers exposed to heat were in the borderline level of normozoospermic range, and their semen parameters were significantly lower than controls. For better assessment of occupational environment concerning physiological and semen parameters in steel industries, WBGT can be a more useful index.

1. Introduction

With the regard to the growing working population, various industries, businesses, and different production processes, and their use of natural and artificial energy, have all resulted in increased global warming, and one of the most common problems faced by employees in their workplace is unfavorable weather conditions and working in hot environments [1,2]. This problem can be observed in various jobs (occupations) performed in both indoor and outdoor work environments, such as those in foundry, glass, and steel industries, bakeries, kitchens, and mines [3,4]. If the human thermal equilibrium is disturbed because of increasing temperature in workplaces, workers may be at risk of heat stress [5,6]. The common complications caused by heat stress are an elevated deep body temperature, tachycardia, and decreased blood pressure, among others [7–9]. In addition, various studies have demonstrated the adverse effects of high temperature and heat stress on semen quality, and subsequently on male fertility. Many studies have shown that the high temperatures can affect the reproductive parameters of humans and animals [8,9]. Scrotal

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2093-7911/$ – see front matter
http://dx.doi.org/10.1016/j.shaw.2017.07.003

temperature must normally be 2.2°C lower than the abdominal temperature to ensure the appropriate formation of sperm cells; in fact, it has been reported that a 1−1.5°C increase in scrotal temperature leads to either impaired sperm production or abnormal sperm morphology [7,8]. Harmful effects of exposure to heat on sperm production (such as oligozoospermia, azoospermia, and teratozoospermia) have been proven. In particular, these abnormalities have been reported among laundry and dry-cleaning workers, cooks, furnace workers, and professional drivers [10–12]. Zhang et al. [13] investigated the effects of scrotal heat stress and revealed that seminal fluid parameters before, during, and after exposure to heat stress showed significant changes, and constant exposure resulted in impaired sperm formation [13]. To date, no field study has been conducted on the effect of occupational exposure to heat stress on semen quality in fertile men in Iran and in the studied industry (steel); therefore, we aimed to assess the heat stress and semen quality among male workers in a steel industry in Iran and investigate the relationship between heat stress indices and semen parameters.

2. Material and methods

The studied industry has 16,000 staff members, employed directly and indirectly in various jobs and positions. A total of 261 employees were employed in pelletizing, casting, hot rolling, and iron-making units. Participants for this study were selected among fertile workers (identified as those having at least one child) employed in a steel industry in Iran after obtaining approval from the Research Ethics Committee of Tehran University of Medical Sciences. For this purpose, a detailed medical history of all possible participants was obtained and then those having at least one child, not smoking [14], not placing a laptop on their legs [15], with no long-term sitting [16], with lack of varicocele [17], not using bodybuilding supplements [18], with no history of orchitis and chemotherapy/radiotherapy [19], and not using antioxidant medications [20], such as selenium, vitamins B, C, and E, were included in the study. Finally, after reviewing the medical history of 220 workers exposed to heat and 41 employees of the administrative division, 30 workers who had been exposed to heat stress for approximately 4 hours daily and fulfilling the aforementioned criteria were enrolled into the exposed group; among the employees administrative division, 14 were enrolled into the unexposed group. A signed informed consent was obtained from all participants. Prior to this study, all participants were informed about the investigations and were requested to refrain from sexual intercourse for at least 3 days before sampling.

The scrotal and oral temperature of all participants were measured using digital thermometers (Beurer GmbH FT 15/1, Ulm, Germany and AccuMed MT 101, Houston, Texas, USA, respectively). Participants were asked to provide semen samples for analysis and because time since last sexual activity is one of the factors associated with changes in semen quality, they were requested to refrain from sexual activity for 3 days before sampling. Because it was not possible to collect semen samples directly in the laboratory, participants collected the samples at home and stored them in accordance with the storage conditions mentioned on the cover of the sample containers. For the purpose of sampling, specialized plastic containers were used and the samples were stored until further analysis at near body temperature (37°C). In accordance with the World Health Organization (WHO) laboratory manual, the time from sample collection to delivery to the laboratory took less than 1 hour, and the time of review, preparation, and analysis of samples took less than 3 hours. After analysis, samples were immediately transferred to the laboratory and analyzed according to the WHO laboratory manual for the examination and processing of human semen [21]. Seminal parameters, including the volume of semen, motility of sperm, pH of semen, style of motility, number of sperm with normal shape, and number of live sperm were measured. Semen volume was calculated using the weighting method. To obtain the pH of semen, a special pH meter (Hanna Instruments HI98103, Michigan, USA) was used. Sperm motility was evaluated using a microscope in the laboratory. To examine the number of sperm in each ejaculate, a WHO's approved method (Neobar slide) was used. Determination of sperm morphology included the following steps: preparing a smear of semen on a slide (with feathering method); air drying, fixing, and staining the slide; mounting the slide with a coverslip if it is to be kept for a long period; and then examining the slide with bright-field optics.

The wet-bulb globe temperature (WBGT) meter (Casella Microtherm Monitor, Charlotte, North Carolina, USA) was used to measure environmental parameters such as the dry temperature, relative humidity, black globe temperature, and natural wet-bulb temperature. The air velocity was measured using the hotwire thermo-anemometer (KIMO VT50, Edenbridge, UK).

Heat stress indices WBGT and predicted heat strain (PHS) were measured and calculated based on International Organization for Standardization (ISO) Standards 7243:1989 and 7933:2004, respectively [22,23]. WBGT was measured at three heights of the body (ankle, abdomen, and head) in participants working in hot rolling, in the foundries iron and steel-making units, and then mean WBGT and $WBGT_{TWA}$ (time-weighted average) were calculated [4]. It should be noted that this study was performed in the warm season (i.e., the summer) in 2015.

Data were analyzed using SPSS version 22 (SPSS Inc., Chicago, IL, USA). The Kolmogorov−Smirnov statistical test was performed to check the degree of normality in the data. Pearson correlation coefficient test and independent t test were used for data analysis. A p level = 0.05 was set as significant for all statistical analyses.

3. Results

Demographic data of studied populations (exposed and unexposed) are presented in Table 1. The mean (standard deviation) age was 33.2 (6.75) years and 32.07 (7.16) years for the participants in

Table 1
Demographic data of the study population

Group	Exposed group (n = 30)				Non-exposed group (n = 14)			
Individual parameters	Maximum	Minimum	Mean	SD	Maximum	Minimum	Mean	SD
Worker age (y)	45	21	33.2	6.75	50	25	32.07	7.16
Length of marriage (y)	16	2	7.27	4.64	17	2	6.93	4.71
Spouse's age (y)	45	20	30.77	7.98	45	22	29.07	6.43
No. of children	4	1	2.27	1.05	3	2	2.14	0.363
Employment duration (y)	21	1	12.23	7.59	21	2	8.29	6.54
Daily exposure to heat at work (h)	6	5	5.67	0.48	0	0	0	0

SD, standard deviation.

the exposed and unexposed groups, respectively. The mean value of heat exposure was 5.67 hours/d at the workplace for the exposed group (Table 1).

Table 2 presents the measurement results of environmental parameters (air temperature, black globe temperature, natural wet-bulb temperature, relative humidity, and air velocity), heat stress indices (WBGT and PHS), as well as physiological parameters (scrotal and oral temperature) and seminal parameters (semen volume, pH of semen, sperm morphology, sperm motility, and sperm count) in both groups. Significant mean difference was observed for the studied parameters between the two groups ($p < 0.05$), except for pH of semen ($p = 0.051$). Environmental parameters (except for relative humidity), physiological parameters, and heat stress indices were significantly higher for the exposed group than for the unexposed group. Regarding semen parameters, all were higher in the unexposed group than those in the exposed group.

The results of the correlation test between heat stress indices and seminal and physiological parameters in the exposed group are presented in Table 3. There is a significant positive correlation between heat stress indices and physiological parameters ($p < 0.03$), and the correlation coefficient for scrotal temperature is larger than oral temperature. All semen parameters (except for pH) showed a negative correlation with WBGT ($p < 0.04$) and a stronger relationship was noted between WBGT and seminal and physiological parameters in comparison with PHS.

4. Discussion

The steel industry is one of the most important economic industries in both developed and developing countries, involving a large population of employees. Workers engaged in this industry are more likely to be exposed to excessive heat stress and its adverse effects [24]. In this study, it was found that participants in the exposed group had higher heat stress values than the threshold limit values recommended by the American Conference of Governmental Industrial Hygienists [25]. As in other similar studies, the heat stress value among employees in the steel industry was higher than the standard level [26,27], and they are more susceptible to adverse effects of heat exposure [28]. Because

Table 2
Measurement results of environmental and physiological parameters, heat stress indices, and semen parameters

Group parameters	Exposed group [Mean (SD)]	Non-exposed group [Mean (SD)]	p
T_a (°C)	44.24 (6.1)	27 (0.6)	0.001
T_g (°C)	52.24 (5.9)	27.58 (0.5)	0.001
T_w (°C)	28.7 (1.37)	17.75 (0.5)	0.001
RH (%)	15.61 (9.19)	44.1 (0.6)	0.001
V (m/s)	0.16 (0.09)	0.08 (0.03)	0.004
$WBGT_{TWA}$ (°C)	35.76 (2.52)	20.7 (0.36)	0.002
PHS_{TWA} (W/m^2)	491.56 (18.75)	80.51 (3.1)	0.001
Scrotal temperature (°C)	35.85 (1.26)	34.79 (0.41)	0.004
Oral temperature (°C)	37.23 (0.49)	36.8 (0.57)	0.004
Semen volume (mL)	2.1 (0.31)	3.45 (0.25)	0.003
pH of semen	7.5 (0.35)	7.6 (0.4)	0.051
Sperm morphology (%)	6.4 (3.3)	10.54 (2.3)	0.035
Sperm motility (%)	47.3 (11.6)	68.7 (10.22)	0.001
Sperm count (million/mL)	40.1 (15.4)	91.54 (9.41)	0.001

PHS_{TWA}, predicted heat strain time-weighted average; SD, standard deviation; T_a, air temperature; T_g, black globe temperature; T_w, natural wet-bulb temperature; RH, relative humidity; V, air velocity; $WBGT_{TWA}$, wet-bulb globe temperature time-weighted average.

Table 3
The correlation between heat stress indices and semen and physiological parameters

Heat stress indices	WBGT		PHS	
Parameters	r	p	r	p
Scrotal temperature (°C)	0.506	<0.001	0.414	<0.001
Oral temperature (°C)	0.334	<0.001	0.142	0.026
Semen volume (mL)	−0.696	<0.001	−0.454	0.024
pH of semen	0.110	0.065	0.433	0.121
Sperm morphology (%)	−0.574	0.036	−0.512	0.043
Sperm motility (%)	−0.754	<0.001	0.231	0.051
Sperm count (million/mL)	−0.647	0.0045	−0.612	0.001

PHS, predicted heat strain; $WBGT_{TWA}$, wet-bulb globe temperature.

indices WBGT and PHS are verified by the ISO for evaluating the heat stress in occupational environments, and a significant relationship between these indices and physiologic parameters has been reported [3,29], we used these indices to determine the relationship between seminal parameters and heat stress.

Our findings show that heat stress in the exposed group is extremely higher than the ISO and American Conference of Governmental Industrial Hygienists threshold limits, and also there is a significant association between most of the seminal parameters and the heat stress indices. Momen et al. [9] reported that values of semen parameters of those exposed to high environmental temperature were less than those of controls; however, mean difference in their study was not statistically significant. Similarly, in our study, semen parameters are within the normozoospermic levels. These results demonstrated that heat stress in the studied industry (steel) may affect the seminal parameters, and subsequently fertility among the workers, because a significant mean difference was observed for physiological parameters (scrotal and oral temperatures) and most semen parameters between the two groups; additionally, some studies have confirmed that high scrotal temperature leads to changes in seminal parameters as well as increased infertility in both human and animal models [30,31]. Thonneau et al. [32] introduced heat exposure as a risk factor in men's infertility and indicated that abnormal conditions, together with an impaired testicular arterial system, may lead to chronic impairments in temperature regulatory systems, followed by tremendous changes in sperm function, as had been reported in animal models [32]. Namiki et al. [33] found that short-term exposure to high temperature may not lead to disruption of Leydig cells' function [33]; however, in our case, employees have long-term heat exposure, and disruption of Leydig cells' function may have occurred.

The major cause of infertility may be the excessively high temperature of testicles, resulting in their inability to produce mature sperm. Sheiner et al. [31] in a literature review studied the effect of occupational exposures on male fertility and concluded that the physical exposures including radiation (both ionized and microwaves) and heat were shown to deteriorate sperm parameters [31]. Garolla et al. [34] reported significant changes in spermatogenesis among swimmers following sauna exposure.

Many studies have been performed to evaluate the heat load of occupational environments using heat strain indices, such as body temperature and physiological parameters [35,36]. In most studies, WBGT [5,37,38] and PHS [39] have been reported as the most effective indices for assessing occupational heat stress. The novelty of this study was to investigate whether there is any relationship between seminal parameters and heat stress indices, which has not been previously studied. Indeed, our results uncovered a significant relationship between these two indices and all seminal parameters except pH, as well as between these indices and physiological parameters. In addition, some studies have suggested the WBGT as the most useful index [40] (because of a stronger significant association with physiological parameters) to evaluate occupational environment not only in the steel industry but also in other similar industries. According to the study results, WBGT appears to be an effective index for evaluating heat stress of individuals with regard to physiological and fertility-related parameters.

A significant decrease was found in the seminal parameters as these indices rose; however, some studies have reported that only increased scrotal temperature is significantly associated with the semen parameters [30].

In conclusion, semen parameters of fertile workers exposed to heat were in the borderline level of normozoospermic range, and their semen parameters were significantly lower than the controls. For better assessment of occupational environment concerning physiological and semen parameters in steel industries, WBGT can be a more useful index.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

This study has been funded and supported by Tehran University of Medical Sciences (TUMS; (Grant No. 92-10-01-130/2001). We express our gratitude to the management committee of the steel industry studied and thank all study participants.

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