

Study Progress of Physiological Responses in High Temperature Environment

K Li, G Z Zheng^{*}, W T Bu, Y J Wang and Y Z Lu

School of Energy Power and Mechanical Engineering, North China Electric Power University, Baoding 071003, China

Abstract: Certain workers are exposed to high temperatures for a long time. Heat stress will result in a series of physiological responses, and cause adverse effects on the health and safety of workers. This paper summarizes the physiological changes of cardiovascular system, core temperature, skin temperature, water-electrolyte metabolism, alimentary system, neuroendocrine system, reaction time and thermal fatigue in high temperature environments. It can provide a theoretical guidance for labor safety in high temperature environment.

1. Introduction

According to the relationship between environment temperature and body thermal balance, the living environment higher than 35°C and the production environment higher than 32°C are considered as high temperature environment [1]. The high temperature environment can be divided into natural high temperature environment and industrial high temperature environment. The natural high temperature environment is caused by solar radiation, while the industrial high temperature environment is caused by fuel combustion and mechanical rotation friction [2]. In the context of global warming, the extreme high temperature weather occurs more frequently. When humans are exposed to high temperature environment for a long time, they would suffer from a series of physiological abnormality. When the body thermal balance is destroyed, physical health will be threatened. To better understand the affects of the high temperature on human body, this paper summarizes the related studies of physiological responses in high temperature environment.

2. The physiological responses in high temperature environment

When exposed to high temperatures for a long time, people may suffer from a series of physiological abnormalities. This section introduces the various human body physiological responses of the cardiovascular system, the core temperature, the mean skin temperature, the alimentary system, the neuroendocrine system, the reaction time and the thermal fatigue.

2.1. Cardiovascular system



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

In high temperature environment, the human body temperature is lower than ambient temperature. Human surface skin vascular network is expanded to quicken the blood circulation to dissipate heat, and the blood flowing into internal organs decreased accordingly. In order to maintain the normal activities of human body, human heart rate increases to increase the cardiac output. Zhou [3] found that the skin blood flow increased from 1.4L/min to 2~4L/min or even 6~11L/min while the average heart rate increased by 20%~40% when people were in high temperature environment. Huang et al. [4] applied the method of Meta and compared the electrocardiogram between the high temperature group and the control group. Then they found that the left ventricular high voltage, sinus bradycardia and ST-T segment were significantly affected by high temperature. Therefore, above indexes are sensitive indicators of monitoring the cardiovascular disease of the staff in high temperature. Chen et al. [5] applied the western blotting to measure the heat shock protein 70 antibodies of the experimental group and the control group. They found that the abnormal proportion of hypertension and electrocardiogram in the experimental group was significantly higher than the control group. And they summarized that the incidence of cardiovascular diseases may be related to the high temperature. Zhang and Wu [6] randomly selected some hypertensive patients as a case group and some healthy workers as a control group. Based on physical examination and questionnaire investigation, the chi-square test indicated there may be a certain degree of correlation between high temperature and hypertension.

2.2. Core temperature

The core temperature usually refers to the temperature of the brain, liver and other important internal organs. When people are in a rest state, the core temperature is 37.2°C to 37.6°C [7]. Commonly, the armpit temperature, rectal temperature, tympanic temperature and oral temperature are adopted to represent core temperature. Bai [8] proposed to use the oral temperature to replace the measure of rectal temperature. The core temperature directly affects human metabolic activity. Nybo et al. [9] found that when the core temperature increased by 1.5°C, the basal metabolic rate increased by 23%. After sweating profusely, the blood concentrated, thus the muscle blood flow increased and the dermal blood flow decreased. As the temperature regulation was restricted, and the thermal balance was destroyed, the core temperature began to increase [10]. When the core temperature approach a critical value, it will result in the athletic ability decrease and make people feel tired [11]. Johnson [12] pointed out that when core temperature raises to about 40°C, people felt weary.

2.3. Mean skin temperature

The mean skin temperature can be calculated by the weighted average of several body surface temperatures [13]. In normal condition, the skin temperature is about 33.5°C. In high temperature environment, to maintain the human body heat balance, sweat volume and skin blood flow increases, thereby body heat loss increases. In hot environment, the temperature gradient between skin and environment is reverse. Thus the heat loss by convection and radiation is greatly restricted, and the skin temperature gradually increases. When the skin temperature is close to the core temperature, the human body gradually reaches the physiological limit. In addition, the personal safety would be threatened if there were no protective measures [14]. In artificial climate chamber, Liu et al. [15] simulated the heated process of atmospheric temperature. The temperature was set as 23°C, 28°C, 33°C and 35°C, respectively. By measuring the subject's skin temperature, they found that the mean

skin temperature was 30.51°C, 32.39°C, 34.34°C and 35.09°C, individually. And the local deviation of skin temperature from head to foot decreased. The local deviation of the chest was 0°C, therefore the chest temperature could be approximately considered as the mean skin temperature. Li [13] set environment chamber temperature at 23°C, 30°C, 35°C and 40°C, individually. Subjects were required to read quietly, walk at the speed of 3.5km/h and run at the speed of 5.5km/h in the chamber. By measuring their mean skin temperature, she found that when the environment temperature increased, the rising rate of the mean skin temperature accelerated. When the ambient temperature was 35°C, the mean skin temperature were 36.5°C, 37.5°C and 38°C under different labor intensities respectively.

2.4. Water-electrolyte metabolism

Under the high temperature environment, sweat is accelerated to regulate body temperature. The sweat contains water, NaCl, inorganic salts and water-soluble vitamin C, B, etc. With the lack of timely supplement, the loss of the inorganic salt will result in the imbalance of water and salt. In normal condition, when the body fluid loses more than 1%, it can be regard as dehydration. Naghii [16] indicates that when the loss of water exceeds 2% of the body weight, the body athletic ability decreases. Therefore, 2% of the body weight is considered as the safe bottom line for body water loss. The body physiological responses in different water losses are shown in Table 1 [17].

Table 1. The body physiological responses in different water losses.

The loss of weight (%)	The loss of water (L)	Symptom
1	0.75	Slight (When the loss of weight is 1.5%, it can be considered as dehydration).
2	1.5	Body reaches endurance limit, and people starts feeling thirsty.
3	2.25	Body physical power begins to decline, and people feels moderately uncomfortable.
4	3	Body suffers from jerkiness and headache, and people feel extremely uncomfortable.
5~6	3.5~4	Body suffers from nausea and dizziness, and people are exhausted.
7	>5	Body loses consciousness.

2.5. Alimentary system

In high temperature environment, human body need to lose more heat, and it results in the heat stress. Firstly, the blood capillary and skin vascular become expansive, thus the amount of blood flowing into the alimentary canal decreases, and it causes the gastrointestinal dysfunction. Secondly, the profuse sweating leads to the loss of NaCl and other mineral salts. As the Cl ion reduces, the gastric acid decreases. And the gastric juice is diluted as a result of large water drink, thus it leads to poor appetite and other gastrointestinal diseases. In addition, as gastric emptying accelerates, the food cannot be adequately digested [18]. Zou [19] chose some bank staffs without a history of diabetes as the control group, and some steel workers as the observation group. The hemoglobin and blood glucose in whole

blood were measured, and it was indicated that the differences of hemoglobin and blood glucose between the control group and the observation group were significant, and the average level of the observation group was higher than that of the control group. It summarized that the high temperature working environment could cause the increase of hemoglobin and blood glucose. Wang et al. [20] compared the physical conditions of the workers between a high temperature group and a control group. They found that the fasting blood glucose level of the worker was also influenced by the work type, work age, body mass index and blood pressure.

2.6. Neuroendocrine system

Under the high temperature environment, the excitability of human sympathetico-adrenomedullary system increases. Then the renin angiotensin II, antidiuretic hormone and aldosterone concentrations significantly increase, therefore the body oxygen consumption and heat production increase. Knochel et al. [21] let subjects have a sauna, and they found that their renin, angiotensin II and aldosterone all increased. However, due to the negative induction, the central nervous system function was depressed. Therefore, the body temperature regulation function weakened, and the impulse frequency of nervous system decreased. In addition, as the excitability of neuromuscular descends, the accuracy and coordination of action reduce and accidents easily occur. Sun et al. [22] selected two groups of workers from a steel tube plant. One group of them was exposed to high temperature, and the other group was exposed to non high temperature for comparison. The field investigation indicated that the incidence of neurasthenia syndrome in the high temperature group was significantly higher than the control group. And the incidence increased as the increase of the work age.

2.7. Reaction time

Reaction time can be divided into the simple reaction time and the complex reaction time [23]. The simple reaction time refers to the fastest average time the brain responds to a certain stimulus. It can be defined as the time from being stimulated and starting action. The complex reaction is the latency between a variable stimulus and a respectively variable response. It refers to the response of the body to several stimuli at the same time. The shorter the reaction of the brain, the less the accidents the workers suffer from. The factors influence the reaction time are age, sex, noise, fatigue, illness and intelligence, etc [24, 25]. Xu and Chen [26] indicated that the heat stress would shorten the simple reaction time, while it would increase the complex reaction time. And the severer the heat stress is, the more obvious the effect is. Ma et al. [1] simulated the high temperature and high humidity environment in a chamber. The simple reaction time of the subjects were measured in different working conditions and working intensities. The results indicated that changing the work type and adjusting the work intensity in definite time are beneficial to decrease the reaction time. Cheng et al. [27] measured the indexes of physiological, psychological and action stability in different temperatures and different work intensities. The results showed that in the fatigue condition, the attention, reactivity, action stability all reduced at different degrees. And the high temperature caused the body fatigue while it causes the increase of the error ratio of the action.

2.8. Thermal fatigue

The high temperature environments usually cause the mental and physiological fatigue of workers.

The cardiovascular load index is defined to estimate the fatigue degree of human body by measuring the human heart rate changes. Xing et al. [28] measured the working intensity and heart rate of the underground workers and proposed that the working hours of the miners should be lower than 8 hours. Hao et al. [29] selected some healthy college students as subjects. Subjects doing exercise in high temperature condition was set as the control group, and subjects doing exercise in normal temperature condition was set as the observation group. The body temperature, heart rate, blood pressure, superoxide dismutase (SOD) and malonaldehyde (MDA) contents in blood serum after exercise were measured. The results indicated that doing exercise in the high temperature environment would cause the fatigue and injury degree of the body cell increased, namely the SOD and MDA increased.

3. Conclusion

When exposed to high temperatures for a long time, people may suffer from a series of physiological abnormalities. This paper summarizes the various human body physiological responses of the cardiovascular system, the core temperature, the mean skin temperature, the water-electrolyte metabolism, the alimentary system, the neuroendocrine system, the reaction time and the thermal fatigue. It can provide a theoretical guidance for labor safety in high temperature environment.

Acknowledgements

This research has been supported by National Natural Science Foundation of China (Grant No. 51408220).

Reference

- [1] Ma H, Yuan X X and Zhang C 2014 *Journal of North China Institute of Science and Technology* **11** (6) 68-72.
- [2] Liu Y H 2006 *Journal of Liaoning Teachers College* **8**(2) 66-67.
- [3] Zhou Z Z 2011 *Neijiang Technology* **3** 29-30.
- [4] Huang L Z, Yang T. F, Huang J J, et al. 2011 *Chinese Journal of Evidence- Based Medicine* **11** (2) 174-180.
- [5] Chen Z P, Su W G, and Wang S M 2010 *Chinese Medical Journal of Metallurgical Industry* **27** (5) 521-523.
- [6] Zhang Q, and Wu J B 2014 *Chinese Health Industry* **16** 126-127.
- [7] Ruttly G N. <http://link.springer.com/book/10.1007/978-0-85729-519-1>.
- [8] Bai YK. 2015 *Xi'an Technology University*.
- [9] Nybo L, Moller K, Volianitis S, Nielsen B, and Secher NH 2002 *J. Appl Physiol* **93**(1) 58-64.
- [10] Peng ZH 2016 *Liaoning Sport Science and Technology* **38** (1) 191-193.
- [11] Nybo L 2008 *J Appl Physiol* **104**(3) 871-878.
- [12] Johnson J M 2010 *Med Sci Sports*. **20** (13) 29-39.
- [13] Li N 2011 *Tianjin University*.
- [14] Li G J 2008. *Tianjin University*.
- [15] Liu YF, Zhou X and Wang LJ 2014 *Journal of Environment and Health* **31**(1) 68-70.
- [16] Naghii M R 2000 *Nutr Health* **14** (2) 127-132

- [17] Guyton A C and Hall J E 2006 *Elsevier Saunders*.
- [18] Huang S H and Shen Y Q 2016 *Chinese Journal of Medical Science* **6(4)** 221-228.
- [19] Zou P. 2014 *Journal of Sichuan Metallurgy* **36 (3)** 66-67.
- [20] Wang J, Sun J, Wang C X and Chen CG 2014 *Prevntive Medicine Tribune* **20(9)** 675-676.
- [21] Knochel JP, Dotin LN and Hamburger RJ 1972 *Journal of Clinical Investigation t* **51(2)** 242-255
- [22] Sun P, Yang Y L and Wang R Y 2004 *Modern Preventive Medicine* **31 (1)** 21-23.
- [23] Wang B 2003 *Journal of Capital Institute of Physical Education* **15 (4)** 110-113.
- [24] Li K D 2005 *China Mining News* **5 (12)** 25-26.
- [25] Chen R and Tang TB 2002 *Chinese Journal of School Health* **23 (3)** 277-278.
- [26] Xu XD and Chen XR 1994 *Chinese Journal of Safety Science* **4 (2)** 42-45.
- [27] Cheng C, Zhang Q, Xu AM and Ding Z 2014 *Journal of North China Institute of Science and Technology* **11(6)** 79-82.
- [28] Xing J J, Liu W D and Wang XL 1998 *Labor Protection Science and Technology* **18 (4)** 54-57.
- [29] Hao Z J, Liu H P, Li GH and Sun Y N 2013 *Journal of Ningxia Medical College* **35 (3)** 199-200.