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Human heat acclimatization in extremely hot environments: A review

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Abstract

During the past decades, physiological responses of the human body in extremely hot environments have been studied. Most research has focused on the human heat tolerance, and assessment of the heat stress. In this context, parameters of environments and physiological parameters were introduced, and important heat stress indexes were explained. This article aims to summarize the progress in the literature concerning heat stress indexes and heat acclimatization. The research priorities should shift to the relationship between human heat acclimatization and the indoor thermal environments. This paper will hopefully aid the understanding of human heat acclimatization in extremely hot environments and guide the future research.

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Keywords: Extremely hot environment; Human heat tolerance; Heat stress index; Heat acclimatization

1. Introduction

Extremely hot environments are ubiquitous in various workplaces, such as steel mills, deep mines, glass workshops, military facilities and military field operations. Heat-related disorders, decreases in productivity and security risks are common phenomena when people work in extremely hot environments. The heat damage to workers and latent threat to operation security by extremely heat environments need urgent solutions. The human heat tolerance in extremely hot environments has drawn researchers' attention for more than 50 years. During this time, numerous studies have been carried out. Over the past few decades, a paradigm shift has taken place in the research field of dynamic acception of human body for extremely hot environments.

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In the 1980s, physiological responses of the human body under extremely hot environment have been studied. Physiological indexes were respectively measured in different environmental parameters. McLean et al. [1] studied the heat exchange between the human body and environments. Moreover, the mechanism of evaporative heat dissipation and radiant heat loss has been shown. With the understanding that it was necessary to control the environments and guarantee workers' health and safety, research emphases gradually shifted to heat stress on working man. Suzuki [2] conducted a field experiment to study physical performance and cardio-circulatory responses to hot environments during sub-maximal upright cycling. The results showed that the tolerance time of respondents for 0℃, 20℃ and 40℃ were 91min, 87min and 19min, respectively. Obviously, it can be seen that the heat stress can make changes on cardiovascular system, respiratory system, energy metabolism rate, temperature regulation system, body fatigue and work efficiency.

However, researchers realized that some heat stress indexes should be developed to quantitatively describe the effects of different hot environments. The wet bulb globe temperature (WBGT) [3] index is by far the most widely used heat stress index and adopted as an international standard. The WBGT consists of weighting of dry bulb temperature, wet bulb temperature and black-globe temperature. Relative humidity and solar radiation were subsequently added to the more comprehensive version of WBGT, it was called the environmental stress index (ESI) [4]. In addition, the temperature-humidity index (THI) [5], is the combination of dry bulb temperature and relative humidity. Recently, a new index, the equivalent temperature (ET) [6], was defined based on the Cox regression results.

In order to prevent security risks and heat-related disorders, the concept of heat acclimatization was proposed. Heat acclimatization, i.e., the protective physiological responses of the human body under a repeated thermal stimulus, is beneficial for adapting to hot environments and can improve the body's heat tolerance capability [7]. The existing control theories and standards of extremely hot environment don't have consideration of the heat acclimatization, ignore the dynamic acception of human body for environments around. The future research direction of human heat tolerance under extremely heat environments should focus on heat acclimatization of human body.

2. Parameters of the extremely hot environment

The environment parameters can change dynamically not only in terms of time but also spatially, and the physiological responses of the human body is a complex process. In order to obtain a detailed understanding of heat stress assessments, it is necessary to examine the effects of different environment parameters and their impact on the human body. Numerous research efforts have attempted to determine the parameters that can influence heat tolerance of the human body. For example, many studies have focus on the temperature, aiming to determine durations limit of exposure at different temperatures [8]. Relative humidity has also drawn significant attention and was embodied in the function of the heat acclimatization training [9].

2.1. Temperature

To accurately describe the environment temperature, several typical kinds of temperature have been proposed. Each kind of environments has different dominant factor (shown in Table1).

Table 1. Application of different kinds of temperature.

Application of different kinds of temperature	Application
Dry-bulb temperature	Used to assess thermal comfort environments
Wet-bulb temperature	Used to assess humid environments
Black globe temperature	Used to assess radiation environments
Wet bulb globe temperature	Used to assess the heat stress from hot environments
Mean radiant temperature	Used to assess effects of radiation from internal surfaces