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Determining an optimal recovery time after exercising to exhaustion in a controlled climatic environment: Application to construction works

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A B S T R A C T

This study aims to determine an optimal recovery time after a participant has exercised to exhaustion in a controlled climatic condition. Ten males and four females volunteers were examined under hot (30°C) and humid (75% relative humidity) environment in a climatic chamber to simulate typical summer outdoor working conditions of construction workers in Hong Kong. The participants (age 31.3 ± 9.3 years; height 168.5 ± 9.8 cm; weight 62.5 ± 7.1 kg; and percentage body fat 22.9 ± 7.2%) performed graded upper body exercise at a target cadence of 70 rotation per minute (RPM) until exhaustion and were recovered inside the climatic chamber until their physiological conditions returned to the pre-exercise level or lower. Physiological Strain Index (PSI) was used as a yardstick to determine the rate of recovery. The physiological conditions of the participants were monitored by recording their ear temperature (to estimate core temperature), heart rate, oxygen consumption, respiratory exchange ratio and Ratings of Perceived Exertion (RPE). It was found that on average a participant could achieve 97% energetic recovery in 40 min; 90% in 35 min; 82% in 30 min; 75% in 25 min; 68% in 20 min; 60% in 15 min; 53% in 10 min; and 46% in 5 min. Linear regression results showed that recovery time is a significant independent variable to determine the rate of recovery ($R^2 = 0.95$, $P < 0.05$). Depending on the level of recovery, an optimal recovery time after exhaustion in a hot and humid environment can be determined based on these findings.

1. Introduction

Physical work in a hot and humid environment imposes considerable physical strain on workers, with significant associated health risks, reduced productivity and certain safety problems [1]. Many countries located in the subtropical climatic zone suffer from high temperature, high humidity, and occasionally coupled with low wind speed in summer. Heat stress can cause more health problems and deaths to humans as compared with extreme cold [2]. The risk of subjecting workers to heat stress when working outdoors has been increased. In view of this, the American College of Sports Medicine has published position stand papers for recommendations preventing heat illness in hot weather [3]. In addition, some countries and regions such as Hong Kong announce very hot weather warnings to the public so that appropriate preventive measures against heat stroke can be taken accordingly.

The construction industry is found to be more susceptible to heat stress than other industries [4]. Construction workers are subjected to heat stress not only from outdoor physical work but also in confined spaces which could be even worse due to poor air ventilation. Rebar work is one of the most labor-intensive and long duration tasks in construction [5,6]. It was reported that 10 percent of rebar workers have suffered heat stroke [7] and a number of fatality cases of rebar workers related to heat stroke were reported in local newspapers [8,9]. The Hong Kong government and the industry have expressed concerns of working in hot weather and promulgated a series of fundamental practice notes and guidelines on working in hot weather [10–12]. Prevention measures on work arrangement, work-break cycle, cool down facilities were advocated to protect site personnel working in hot weather. The purpose of work–rest scheduling is to balance productivity demands with safety concerns and the physical workload of the personnel [13]. A proper design of a work–rest schedule is an effective means in improving a worker's comfort, health, and productivity [14]. Earlier research work has computed the maximum duration (Heat Tolerance Time) that a rebar worker could work continuously without jeopardizing his health [15]. Naturally workers should be allowed

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to take a rest when such a threshold is reached. However, how long the workers should be allowed to recover in hot weather after working to exhaustion remains to be a question yet to be answered. The main purpose of the current study is to determine the optimal recovery time after exercising to exhaustion in a controlled climatic environment similar to that of a construction worker. Heat stress evaluation can generally be monitored through physiological parameters [1]. However, limited studies were conducted to find out the physiological values at extreme hot environments. Nag et al. [16] evaluated the human tolerance limits according to physiological and psychophysical reactions. Lu and Zhu [1] evaluated heat tolerance ability and gave reference values of physiological variables at heat exposure. Zhao et al. [17] established a mathematical model reflecting the relationship between the heat tolerance time and thermal environment in conditions of heavy, medium and light physical labor intensity. Steady-state lower body exercises such as cycling, walking, and running were conducted in previous studies to measure heat tolerance ability. However, graded exercise is regarded as a better means to measure a participant's maximal aerobic capacity [18]. Since rebar work involves mainly strenuous arm exercise and is a highly demanding task, graded upper body exercise was designed to compute the amount of recovery time after a participant has exercised to exhaustion in a controlled climatic environment.

Recovery can play a considerable role to the well-being of rebar workers as well as in their productivity [19]. Sufficient rest can prevent the accumulation of fatigue and a loss of productivity. A lack of recovery can interfere with their productivity and also induce emotional, cognitive and behavioral disturbances [19], which can subsequently lead to heat syndromes especially in a hot and humid environment. Hence, proper attention should be given to monitor physical and physiological stress and recovery. To ensure the health and safety of personnel working in hot weather, research on human heat tolerance and recovery at heat exposure is urgently needed. In view of this, experimental study allowing participant to perform upper body exercise until exhaustion inside an electronically controlled climatic chamber will be useful to determine an optimal recovery time. Findings of this study will help the industry to determine a better work-and-recovery pattern to safeguard rebar workers' health and safety when working in a hot and humid environment.

2. Materials and methods

2.1. Participants

A total of 14 volunteers participated in this research study, including 10 males and 4 females. Exclusion criteria included: flu in the week prior to participation, and history of diagnosed major health problems including diabetes, hypertension, cardiovascular disease, neurological problem and regular medication intake. All participants were dressed in short-sleeved cotton shirts, long trousers, socks and shoes. The clothing thermal resistance was about 0.5 clo. Table 1 provides the demographic details of the participants.

Participants were clearly informed of the purposes and the procedures of the study before commencement of any tests. Written consent was obtained from all participants prior to the study. Participants could withdraw at any time without penalty. Data collected from the study was password-protected and kept centrally in a stand-alone server and was used for this study only. Only authorized research personnel would have access to the data and the raw data would be destroyed after analysis. The study was conducted according to the Declaration of Helsinki and the protocol was fully approved by the Research Ethics Committee of the authors' host institution.

Table 1
Demographic data of the participants ($N = 14$).

	Male	Female	Pooled
Sample size	10	4	14
Age (y)	33.0 ± 9.9	26.5 ± 1.3	31.3 ± 9.3
Height (cm)	170.8 ± 6.6	160.5 ± 4.1	168.5 ± 9.8
Weight (kg)	64.7 ± 5.6	55.0 ± 3.8	62.5 ± 7.1
Smoking habit	0.2 ± 0.4	0.0 ± 0.0	0.1 ± 0.3
Alcohol drinking habit	1.2 ± 1.0	0.9 ± 0.7	1.0 ± 1.0
Sleeping hours (h)	7.3 ± 0.6	7.1 ± 0.7	7.2 ± 0.7

Smoking habit and alcohol drinking habit are measured in a scale from 0 (no consumption) to 5 (20 cigarettes or more per day for smoking habit; 2 or more prescribed quantities per day for alcohol drinking habit). Details of these measurements are delineated in Figs. 1 and 2 respectively.

2.2. Chamber

A chamber with 3 m × 2.5 m × 2.2 m (length × width × height) was built to simulate the outdoor hot and humid environments. Supply air outlets with different types and sizes were installed on the ceiling and the side wall to form different airflow organizations. Return air outlets were installed on the lower part of the chamber. The heat source was provided by two heat pump unit air conditioners and a reserve electric heater. The humidity source was provided by an electrode steam humidifier fixed in the air supply system. The envelopes of the chamber were insulated by thermal insulation materials. In order to maintain the actual pre-determined temperature and humidity in a stable condition, the electric heater and the electrode steam humidifier would be regulated. The meteorological condition inside the climatic chamber was set at 30 °C temperature and 75% relative humidity to simulate the average meteorological condition of thirty-three days of "very hot weather warning" issued by the Hong Kong Observatory in 2010 [20].

2.3. Parameters and instruments

A series of physiological parameters such as energy expenditure, breath frequency, METs, minute ventilation, heart rate, oxygen uptake, and respiratory exchange ratio were monitored by a metabolic cart during experimentation. These parameters responded closely to the metabolic heat load arising from the combined effects of exercise and the environment [21].

Fatigue is a common psychological–physiological phenomenon [22]. In order to evaluate the feeling of fatigue during exercise, ratings of perceived exertion (RPE) scale were used which has been considered as a practical and cost-effective approach to quantifying the psychological–physiological effects. The RPE, defined as the intensity of subjective effort, stress, or discomfort felt during physical activity, has been shown to be a simple and valid method for regulating exercise intensity [23–26]. The scales use both verbal anchors and numbers that have been reported to possess both categorical and interval properties [27]. The Borg CR10 Scale (a 10-point single-item scale) was employed in this study, with anchors ranging from 1 'very very easy' to 10 'maximal exertion' [28].

In order to estimate the level of strain and to initiate appropriate actions at an early stage, Moran et al. [29] introduced a Physiological Strain Index (PSI), which is based on heart rate and core temperature records in humans, to describe heat strain in quantitative terms during continuous exercise [30]. PSI is therefore applied in this study to measure how rest breaks influence the recovery of the heat strain process. PSI has been shown to effectively differentiate the heat strain associated with different climatic conditions, hydration levels, types of clothing including protective clothing, different exercise intensities, gender and the effects of aging [31–33]. It is an algorithm combining data from the heart rate