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## Experimental study on human physiology during repetitive workload simulated under high temperature and high relative humidity

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**Abstract.** Repetitive workload may cause fatigue and contributed to most cases of workplace related ergonomics injuries in the industries. The purpose of this study is to investigate the physiological responses induced by the repetitive lifting activities based on in the Malaysia construction workers being exposed under high heat and the relative humidity. To achieve the objectives, three male workers participated in this experiments. There were repeated experimental based on the Design of Experiments procedure simulated under environmental temperature (32°C and 25°C) and repetitive lifting task (15 min). The physiological responses measured where the heart rate (HR) and maximum oxygen consumption (VO<sub>2</sub>max). The experiments were conducted in a thermal climate simulation chamber and the parameters were set-up based on the real working environment. The results showed that the subjects highly experiencing fatigue when they were exposed to high temperature at 32°C. These phenomena were determined through their HR and VO<sub>2</sub>max, which were increased gradually under prolonged environment exposure. This study found that the significant heat stress increased the workload intensity in repetitive lifting tasks significantly correlated with the physiological responses of the subjects represented through the HR and VO<sub>2</sub>max. The study concluded the need of management to reconsider the impact of work environmental temperature and relative humidity to their workers especially to those work under tropical climate.

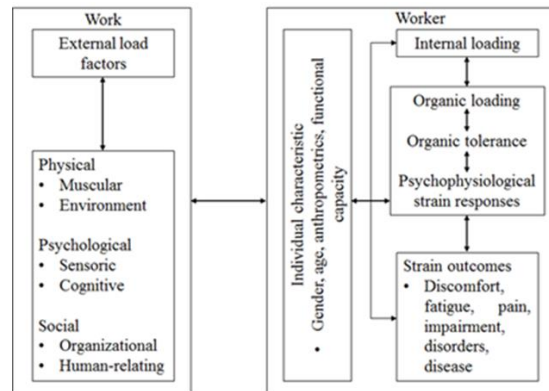


## 1. Introduction

Heart rate (HR) has been widely used as a measure of physical exertion in the construction industry [1–5]. HR is a precise metric based on electrocardiogram (ECG) monitoring. Recent studies in the construction industry have highlighted the potential of HR for understanding physical strain [6,7]. Ahmad Rasdan et al. [8], stated that different heart rate readings have been recorded for different types of tasks at different temperature ranges. Respiration related measures such as oxygen consumption might also provide valuable information related to physical exertion and fatigue development during construction tasks. For instance, the previous study, Wong et al. [5] monitored oxygen consumption in addition to other physiological measures. Similarly, Abdelhamid and Everett [1] compared the oxygen consumption of various construction trade workers against established guidelines. Importantly, respiration related measures have the potential to enhance physical exertion monitoring and modeling for construction tasks, mainly the respiration frequency. Respiration frequency has been recently regarded as “the neglected physiological measure” in relation to physical demands modelling [9]. Recent studies have shown that heart rate and oxygen consumption is more strongly related to physical effort for a range of exercises (continuous or intermittent), and under a variety of experimental conditions that might affect fatigue development such as hypoxia, muscle fatigue, heat exposure and glycogen depletion [9–12]. The strong relation between physical effort and respiration frequency could be described based on the pivotal role of central command. Physical effort which could be defined as the degree of motor effort is regulated by the central command [13]. Similarly, respiration frequency is also regulated by the central command during exercise [14], leading to a strong correlation between the two. Given the importance of the respiration frequency as a marker of physical exertion during exercise, the authors hypothesized that measuring oxygen consumption and HR could significantly improve physical exertion modeling for the construction tasks.

Physical demands refer to each individual's physical responses to given workloads. Previous research efforts on measuring physical demands have focused on assessing workloads by measuring workers' work elements, such as postures (e.g., back bent and twisting), activity types (e.g., walking, lifting, and carrying), weight and forces, as well as activity duration and frequency [15-17]. Because physical performance is greatly influenced by diverse factors such as individual factors (e.g., age, training, and nutrition) or environmental factors (e.g., temperature, humidity, and noise) [18-20], reliable physical demand measurement should consider not only workloads but also all these factors [18,21]. However, due to many individual and environmental factors affecting physical demands, it is very difficult to take into account all of them. Different effects of workloads on workers' physical capacity exist among workers performing similar tasks in the same work conditions, or among workers performing the same tasks at different workplaces [20,22]. Astrand et al. [18] have also confirmed that “a workload that is fairly easy for one worker can be quite exhausting for another.” If physical demands are measured based on factors affecting physical demands (specifically, work elements) and if this measurement cannot include all the factors, some factors that are particularly important to a certain worker (e.g., high temperature to a worker who is more sensitive to heat stress than others) can be omitted. This can lead to improper interventions (e.g., motivating the worker who is more susceptible to heat stress than others to work faster under hot weather), which can result in his/her safety and/or health issues as well as productivity loss.

Figure 1 presents the muscle work can be considered according to the concept where the two main elements are work and worker. External load (stress, burden, demand, exertion, effort, cost) factors at work may be physical, psychological and social in nature. Physical factors include muscle work and environmental exposures. During a job performance load factors are transmitted various cardiorespiratory, musculoskeletal or neural loads through internal loading process. Organic load results in psychophysiological strain responses and strain outcomes, which depend on individual characteristics and organic tolerances of a worker. The most important individual characteristic relating to muscle work are gender, age, anthropometrics and functional capacity.



**Figure 1.** Conceptual model for the relationship of workload and individual strain response and outcomes. Modified from the stress-strain concept by Rutenfranz [23] and model by CoBaSSaE [24].

Muscle work in occupational activities can be roughly categorized as heavy dynamic work, manual materials handling, static postural work and repetitive work (Figure 2). Heavy dynamic work with large muscle groups consists mainly of activities requiring the moving of a worker’s own body mass, and his or her physiological strain responses and strain outcomes are mostly cardiorespiratory (overall) in nature. The load of heavy dynamic work increases in relation to moving speed, distance, the degree of ascent at the covered distance, and the amount of a worker’s own body mass as well as the additional mass of personal protective equipment which must be worn in many heavy physical task. Manual materials handling involves mixed dynamic and static muscle work with large muscle groups. The ordinary activities of manual materials handling are lifting, carrying, pulling and pushing of external loads of various weights and sizes. Muscle work of manual materials handling equally effects the cardiorespiratory and musculoskeletal system. Static postural and repetitive types of muscle work predominantly produce musculoskeletal (local) strain response and strain outcomes (Figure 2).

Workload ❖ size of active muscle mass	Worker’s individual characteristics and organic tolerances	Strain responses on the worker
<ul style="list-style-type: none"> <li>• Heavy dynamic work ❖ Large</li> </ul>	<ul style="list-style-type: none"> <li>• Gender</li> <li>• Age</li> <li>• Anthropometrics</li> <li>• Functional capacity</li> <li>• Health</li> </ul>	<ul style="list-style-type: none"> <li>• Cardiorespiratory (overall)</li> </ul>
<ul style="list-style-type: none"> <li>• Manual materials handling ❖ Large</li> </ul>		<ul style="list-style-type: none"> <li>• Musculoskeletal (local)</li> </ul>
<ul style="list-style-type: none"> <li>• Static postural work ❖ Large-small</li> </ul>		
<ul style="list-style-type: none"> <li>• Repetitive work ❖ Small</li> </ul>		

**Figure 2.** The effects of different types of physical workload on the cardiorespiratory and musculoskeletal strain responses. The individual characteristics and organic tolerances are considered as intervening factors influencing strain due to physical workload. Adapted from the model by Louhevaara [25].

In this regard, physical demand measurement based on workers' physiological response such as oxygen consumption and HR can be an alternative means to understand the impact of all the factors in worker’s physical demands because all these influences on the human body are represented in physiological signals. For instance, HR used in this research is affected by not only workloads but also

all the individual and environmental factors [26,27]. The purpose of this study to investigate the behavior of the physiological responses induced by the lifting process in the Malaysia construction workers to the heat.

## 2. Methodology

A heat exposure experiment was conducted in the climate chamber. A climate chamber was used to simulate a working environment, and three subjects were chosen in these experiments. Experimental observations of subjects' physiological indices of HR and VO<sub>2</sub>max were compared in the different temperature and similar relative humidity.

### 2.1. Subjects

Three healthy subjects participated in the study, as illustrated in Table 1. The physical characteristics of the participants were as follows (mean  $\pm$  SE): age  $23.0 \pm 8.3$  years old; height  $169.8 \pm 5.2$  cm and body weight  $61.7 \pm 12.7$  kg. Exclusion criteria included: the history of diagnosed major health problem including diabetes, hypertension, cardiovascular disease and regular medication intake. Ismail et al. [28] use six subjects to identify the effect of temperature, humidity and illumination on the productivity at the automotive industry. Meanwhile, Umer et al. [29] used ten students and staff to explored the use of multiple physiological measures (cardiorespiratory and thermoregulatory) to model physical exertion during manual material handling tasks. Nguyen et al. [30] study the performance of walking, standing, sitting and lying of three subjects. While Hofer et al. [31] only use two subjects to study the effect of the temperature and relative humidity on the skier. So, a number between two and six which is three subjects, is chosen. All subjects were volunteers. Subjects' demographic, such as age, height, weight and sex, were recorded for analysis. The subjects were clearly informed of the purposes and the procedures of the study before starting any tasks. Written consent was obtained from all participants prior to the study. The study was fully approved by the Ethical Committee of NIOSH Malaysia.

**Table 1.** Demographic subjects.

Subjects	Sex	Age (years)	Body weight (kg)	Height (cm)	A <sub>DU</sub> (cm <sup>2</sup> )	BMI
A	Male	24	76.3	168.5	1.87	26.9
B	Male	24	53.4	165.3	1.58	19.5
C	Male	20	55.4	175.5	1.68	18.2
Mean		23	61.7	169.8	1.71	21.5
Std. Dev.		2.31	12.68	5.22	0.15	4.70

### 2.2. Experimental designs

The experiments were conducted in a climate chamber, as shown in Fig. 3 with measurements of 4.1 m (L)  $\times$  4.1 m (W)  $\times$  2.5 (H). The purpose climate chamber in this study to ensured that the indoor thermal environment was less affected by external environments. The controlled range and accuracy of the air temperature in the chamber were -40 to 80 °C within  $\pm 0.3$  °C; the relative humidity (RH) ranged from 10 to 95% within  $\pm 5\%$ . To create the thermal environments in the climate chamber, the air temperature levels (32 °C and 25 °C) were selected in this study. Considering a combination of RH and air temperatures would create significant physiology responses on the human body. In this experiments the relative humidity was maintained at 70%. These environmental temperatures are selected in this study because they are very realistic temperatures, which found in many parts of the Malaysia regions.



**Figure 3.** Climate chamber.

Table 2 demonstrated the experimental conditions and the measured physical parameters during the test. It is showed that the thermal environments were well controlled during the experiments to meet the design requirement.

Table2. The designed and measured environmental parameters (mean  $\pm$  SD).

Designed conditions		Experimental conditions	
$T_{\text{air}}/\text{RH}$	$T_{\text{air}} (^{\circ}\text{C})$	$T_{\text{glob}} (^{\circ}\text{C})$	RH (%)
32 $^{\circ}\text{C}/70\%$	$32.4 \pm 0.2$	$32.3 \pm 0.3$	$70.3 \pm 2.1$
25 $^{\circ}\text{C}/70\%$	$25.6 \pm 0.2$	$25.4 \pm 0.1$	$71.2 \pm 0.9$

### 2.3. Measurements

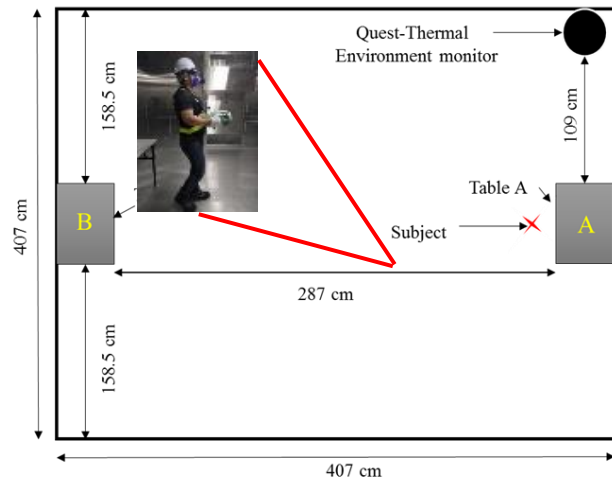
The study is conducted in two different designed conditions (32  $^{\circ}\text{C}/70\%$  and 25  $^{\circ}\text{C}/70\%$ ). Considering that in real situations the activity levels and work intensity of workers change over time. It simulates the manual handling work at construction industry. In the construction industry, the workers are demanded to lift a workload manually. Fang et al. [32] suggested that the weight of manual handling is reasonably set at 15 kg for construction workers, and a sandbag would be much less harmful when unexpectedly dropped down. Based on the guideline from DOSH Malaysia [33], for a male worker who lifts an object near to the body from the elbow height, the maximum weight is 20 kg. However, when the tasks are repeated one to twice per minute, the maximum weight must be reduced to 30%, which is 14 kg [33]. Therefore, in this study, the weight of the sandbag used is 10 kg to follow the guideline with much lower weight than the maximum.

Table 3 shows the manual material lifting tasks comprised of carrying a sandbag of 10 kg along a path of 2.9 m (Figure 4). There are four steps of the task done by the subject. This operation is repeated again and again manually for 15 minutes [34]. Total time for completing one single round is 30 s. Additionally, the sand bag had to be lifted and placed at the height of 1 m to minimize repetitive bending, which could lead to low back discomfort at a rate higher than that of because of whole-body exertion.

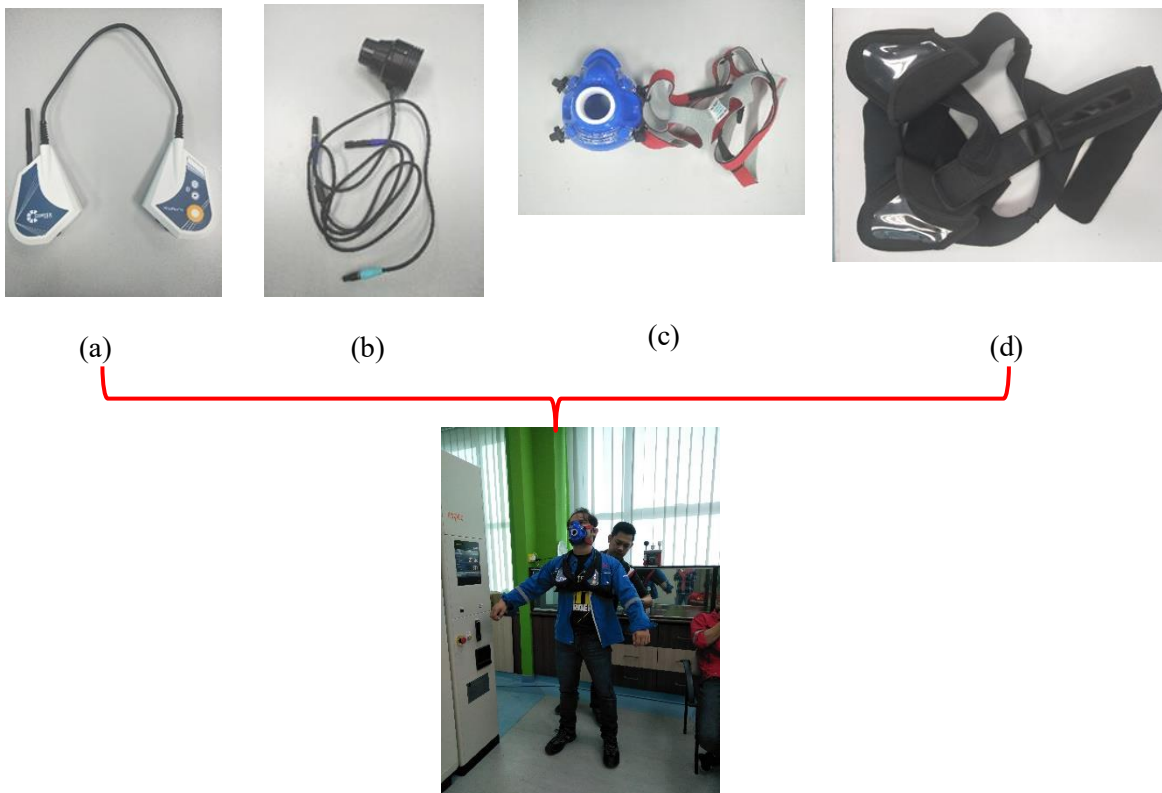
Physiological parameters such as heart rate (Polar) and oxygen consumption ( $\text{VO}_2$ ) were continuously measured every 5 s by a Cortex MetaMax 3B (Figure 5). Before the experiment, the calibration of gas and volume were carried out of each subjects. The subjects were then asked to wear a face mask and portable unit.

**Table 3.** The manual material lifting task.

Step	Task
1	Lifting the bag
2	Walk and carry the bag to the second table
3	Drop the bag.
4	Lifting the bag
5	Walk and carry the bag to the initial table



**Figure 4.** Manual material handling experiment.

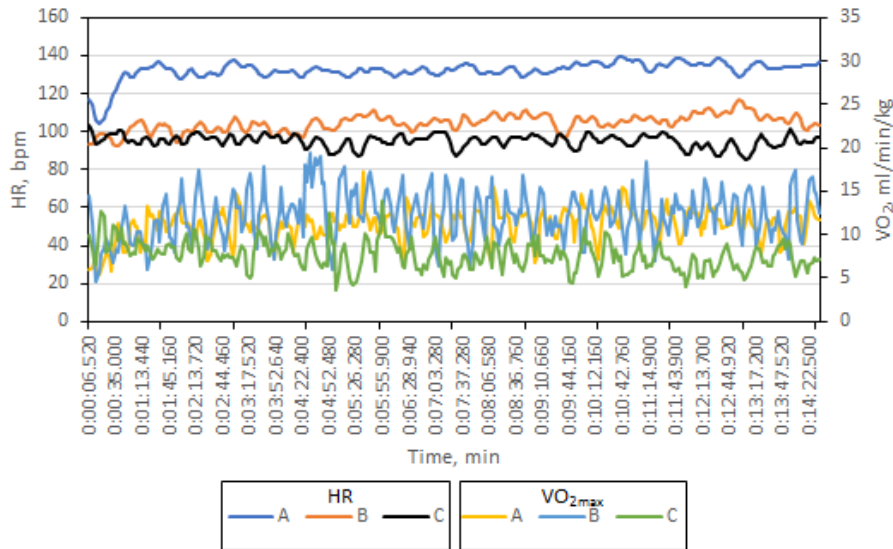


**Figure 5.** The Cortex MetaMax 3B from Cortex Medical.

**3. Results and Discussion**

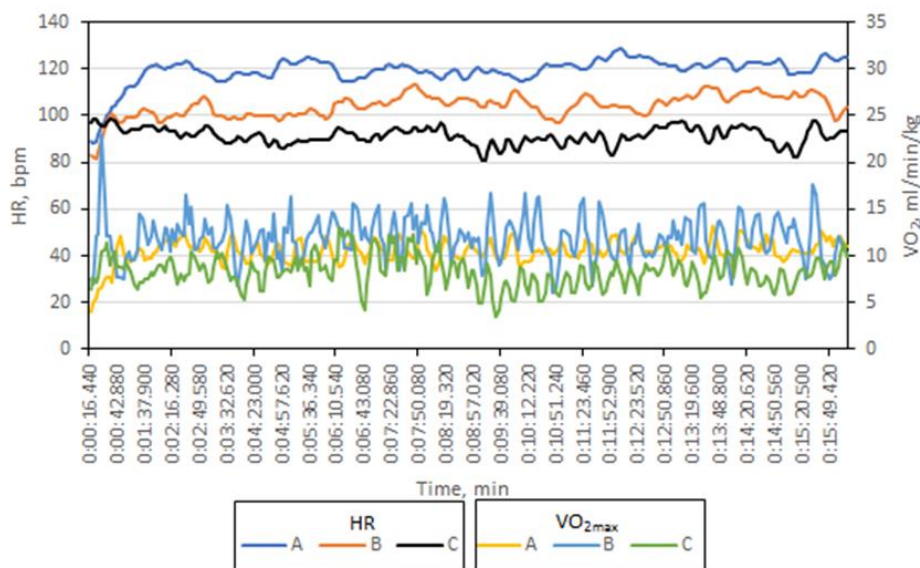
Figure 6 shows measured HR and VO<sub>2</sub>max patterns from three subjects during their task. The trend of HR change in three subjects' is similar. The signal in Figure 6 reflects the thermoregulatory changes that occur during lifting and drop work. Once the subject starts lifting heavyweight (box 10 kg), a gradual increase in the heart rate signal is observed. The decrease in the heart rate signal is observed when the subject drops the box and follows by increasing heart rate signal again when the subject lifting and carry the box to another table (287 cm distance from table A to table B). Mean HR and VO<sub>2</sub>max for subject A is 133 bpm; 11 ml/min/kg, meanwhile subject B is 106 bpm; 12 ml/min/kg and

subject C is 95 bpm; 8 ml/min/kg. The signal heart rate for subject A is highest than subject B, followed by subject C.



**Figure 6.** Physiological responses during work task for subject A, B and C under condition at 32 °C/70%.

Figure 7 shows measured HR and VO<sub>2</sub>max patterns from three subjects during their task. The trend of HR change in three subjects' is similar. The signal in Figure 7 reflects the thermoregulatory changes that occur during lifting and drop work. Once the subject starts lifting heavyweight (sand bag 10 kg), a gradual increase in the heart rate signal is observed. The decrease in the heart rate signal is observed when the subject drops the box and follows by increasing heart rate signal again when the subject lifting and carry the box to another table (287 cm distance from table A to table B). Mean HR and VO<sub>2</sub>max for subject A is 120 bpm; 11 ml/min/kg, meanwhile subject B is 105 bpm; 12 ml/min/kg and subject C is 91 bpm; 8 ml/min/kg. The signal heart rate for subject A is highest than subject B, followed by subject C.





**Figure 7.** Physiological responses during work task for subject A, B and C under condition at 25 °C/70%.

As analyzed in Figure 6 and 7, the exposure time would also have significant effect on human heat stress. More importantly, the permitted exposure time for workers is significantly affected work intensities. According to Yao et al. [35], if the HR is maintained below 110bpm, the permitted working time for the human body can be up to 100 min under the designed condition. However, when the heart rate exceeds 110bpm, the working time of 100 min fails to guarantee human health and safety.

Heart rate is a general indicator of stress on the body [36]. Heart rate is the safest index because it is the earliest response of physiological strain [37]. Earlier research reported that the average heart rates for performing heavy work in a hot and humid environment were in the range of 120-160 bpm [37,38]. The findings revealed the heart rate limits are in agreement with most of previous research studies especially to the subject A. Subject A exhibited greater heart rate differences than Subject B, and C. Previous study stated that there is a significant relation between VO<sub>2</sub> max, HR and age, BMI [39]. In this study, the higher BMI reflect to subject A.

#### 4. Conclusions

The findings indicated that there was significant impact of human physiology especially to the heart rate (HR) and maximum oxygen consumption (VO<sub>2</sub>max) when the human undergo with repetitive lifting activities at high temperature and high relative humidity. As overall this study found that heat stress increases the workload intensity in lifting tasks influencing the physiological responses of the workers represented in heart rate and VO<sub>2</sub>max. The study findings presented the necessity of considering environmental work temperature to avoid workers fatigue.

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