https://doi.org/10.1016/j.apergo.2014.06.002

Title: Comparing the physiological and perceptual responses of construction workers (bar benders and bar fixers) in a hot environment

Running title: bar benders and fixers in a hot environment

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Funding
This project is funded by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (RGC Project No. PolyU510409).
Competing interests: none declared
Patient consent: obtained
Ethics approval: This study was conducted with the approval of the Human Subjects Ethics Application Review System of The Hong Kong Polytechnic University.

Highlights

- We found that, in a hot environment, physical workload (in terms of energy expenditure) of rebar work is: overall rebar work (2.57Kcal/min), bar bending (2.26Kcal/min) and bar fixing (2.67Kcal/min).
- Bar fixing induced significantly higher physiological responses in heart rate, percentage of maximal heart rate, oxygen consumption, energy expenditure as compared to bar bending.
- Perceptual response was also higher in bar fixing as compared to bar bending, but such difference was not statistically significant.

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Abstract

This study aimed to (1) quantify the respective physical workloads of bar bending and fixing; and (2) compare the physiological and perceptual responses between bar benders and bar fixers. Field studies were conducted during the summer in Hong Kong from July 2011 to August 2011 over six construction sites. Synchronized physiological, perceptual, and environmental parameters were measured from construction rebar workers. The average duration of the 39 field measurements was 151.1 ± 22.4 min under hot environment (WBGT = 31.4 ± 2.2 °C), during which physiological, perceptual and environmental parameters were synchronized. Energy expenditure of overall rebar work, bar bending, and bar fixing were 2.57, 2.26 and 2.67 Kcal/min (179, 158 and 186 W), respectively. Bar fixing induced significantly higher physiological responses in heart rate (113.6 vs. 102.3 beat/min, $p < 0.05$), oxygen consumption (9.53 vs. 7.14 ml/min/kg, $p < 0.05$), and energy expenditure (2.67 vs. 2.26 Kcal/min, $p < 0.05$) (186 vs. 158 W, $p < 0.05$) as compared to bar bending. Perceptual response was higher in bar fixing but such difference was not statistically significant. Findings of this study enable the calculation of daily energy expenditure of rebar work.

Keywords: construction work, oxygen consumption, heat stress.

1. Introduction

Rebar work (or steel fixer) is one of the most physical demanding, labor-intensive and long duration tasks in construction (Balasubramanian and Prasad, 2007; Chang et al., 2009; Jarkas, 2010). In general, rebar workers cut steel bars and assemble the reinforcing bars or mesh by welding or clipping into the predetermined locations before the completion of formwork erection and concreting. In consideration of this, it has been reported that rebar workers spend 30% of their work time performing bar bending and 70% of work time performing bar fixing (Chan et al., 2012). Specifically, bar bending involves cutting and bending the reinforcement bars into the required length and shape. It is often done at a bar bending yard on-site. Bar fixing, on the other hand, involves putting the tailored reinforcement bars in the right position, in the right layer, and at the right spacing. In a typical high-rise construction site, once the reinforcement bars are cut and bent to the right shape, they will be hoisted up to the construction level and stored at a central location before being moved to the designated location where no shelter will be provided. Steel fixers will therefore need to take delivery of the reinforcement bars at the construction level, and store them up temporarily for subsequent use. Following that, they will move the bars manually to the designated location; erect and fix them into the right position. Since the reinforcement bars are heavy and are highly conducive to heat, bar fixing is perceived as a much more physically demanding job when compared with bar bending.

Rebar workers usually work at the confined space at the top floor of the construction site making them very vulnerable to heat stress when working in a hot environment. Previous study conducted at the United Arab Emirates construction area reported environmental heat as Wet Bulb Globe Temperature (WBGT: 26.1 to 28.6 °C) and Thermal Work Limit (TWL: 189.3 to 237.7 W/m^2) (Bates and Schneider, 2008). Under a full solar load, the body experiences radiative heat gains from the sun and the nearby hot surfaces. In addition, natural convective heat losses cease when air temperature approximates skin temperature, i.e. 31-33

°C (Taylor, 2006). In such a hot environment, the primary heat dissipation is the evaporation of sweat (Taylor, 2006). When heat dissipation is insufficient, heat stress may have a serious negative effect on the health and safety of workers (Fogleman et al., 2005). The incidence of heat stress in the construction industry has been alarming and caused a number of verifiable reported deaths which suggest that heat stress was the probable causal factor (Bonauto et al., 2007; Chan et al., 2012; Chang et al., 2009). These incidents have drawn the attention of the government, statutory bodies and the industry to investigate the health and safety problem of working in hot weather.

Heart rate, oxygen consumption, energy expenditure and perceived fatigue have been used in previous studies to quantify the intensity of physical works in a hot environment (Bates and Schneider, 2008; Li et al., 2009; Maiti, 2008; Rodgers, 1986; Soer et al., 2014). The World Health Organization has recommended that an average heart rate over the duration of a working shift should not exceed 110 beat/min (WHO, 1969). Previous studies have examined the physical workload of electric arc melting workers and continuous casting workers in hot environment (Chen et al., 2003), and the manual lifting and lowering tasks of construction workers (Li et al., 2009). Surprisingly, rebar work, which is one of the most physical demanding and long duration tasks in construction (Balasubramanian and Prasad, 2007; Chang et al., 2009; Jarkas, 2010), receive little concern. It is believed that prolonged rebar work in a hot environment may result in fatigue and heat-related illness. However, to the best of our knowledge, there is no previous study quantifying the respective physical workloads of bar bending and fixing under hot environment. Specifically, simultaneous collections of environmental, physiological and perceptual parameters are needed in order to better understand the topic.

Therefore, the purpose of this study was (a) to quantify the respective physical workload of bar bending and fixing; and (b) to compare the physiological and perceptual responses between bar benders and bar fixers when they work in a hot environment. Results of this study will facilitate the design of construction work procedure and work-rest schedule to adjust the physical workload of workers to prevent overstrain, fatigue, disorders and injuries (Hsie et al., 2009). In addition, this study will provide information for nutrition replenishment and recovery strategies for rebar workers. By doing so, the health and safety of the workers will be enhanced.

2. Methods

2.1 Participants

Six bar benders and thirty-three bar fixers participated in this study (Table 1). Exclusion criteria were: flu in the week prior to participation, history of diagnosed major health problem including diabetes, hypertension, cardiovascular disease, neurological problem and regular medication intake. The participants were informed of the purpose and the procedure of the study. Their participation was on a voluntary basis and the participants can withdraw at any time as they desired. The study was conducted according to the Declaration of Helsinki and the protocol was fully approved by the Human Subjects Ethics Application Review System of authors' employing institution before the commencement of the assessments. All participant information is subject to the current conditions of the Data Protection Act 1998.

2.2 Measurements

A series of physiological parameters such as energy expenditure, minute ventilation, heart rate, and oxygen consumption were measured. Oxygen consumption was expressed as absolute value (ml/min) and relative to participant's body weight (ml/min/kg). Maximum heart rate of each participant was calculated using the age-predicted equation (Tanaka et al., 2001):

$$\textit{Maximum heart rate} = 208 - 0.7 \times \textit{age} \qquad \textit{(Equation 1)}$$

The RPE, defined as the intensity of subjective effort, stress, or discomfort felt during physical activity (Foster et al., 2001), was used to quantify the perceptual response. Perceived exertion was assessed with Borg CR10 Scale, a ten-point single-item scale with anchors ranging from 1 “very very easy” to 10 “maximal exertion” (Borg, 1990). RPE has been used in evaluating physical load of construction workers (Chan et al., 2012).A heat stress index provides a scale to measure thermal environment based on human perception. The most widely used heat stress index is the Wet Bulb Globe Temperature (WBGT) that encapsulates air temperature, humidity, radiant heat and wind speed in a single index (Budd, 2008). It was developed by Yaglou and Minard (1957) and has been recognized for industrial, military and sporting applications (Taylor, 2006). The main strength of the WBGT is the inclusion of the effects of sun and wind that are the two crucial components of the outdoor climate. The WBGT has been recognized by other organizations for setting limits in industrial plants (National Institute of Occupational Safety and Health, 1986), approved by the ISO organization as an international standard for heat load assessment (ISO, 1989) and as a safety index for workers in different occupations (Chaurel et al., 1993; Gun and Budd, 1995; Singh et al., 1995). The WBGT is calculated as:

$$WBGT = 0.7T_w + 0.2T_g + 0.1T_a \qquad \textit{(Equation 2)}$$

where T_w = natural wet bulb temperature (humidity indicator); T_g = globe thermometer temperature (measured with a globe thermometer, also known as a black globe thermometer, to measure solar radiation); T_a = dry bulb temperature (normal air temperature).

The Heat Index is developed by National Weather Service (Rothfusz, 1990) based on several studies on the assessment of sultriness (Steadman, 1979a, 1979b). The Heat Index value is derived from only two conventional parameters, namely ambient dry bulb temperature and relative humidity. Practically, Heat Index can be understood as “the temperature the body feels”. The equation is as follows:

$$HI = -42.379 + 2.04901523T_f + 10.14333127RH - 0.22475541T_fRH - 6.83783E-3\ T_f^2$$
$$-5.481717E-2RH^2 + 1.22874E-3\ T_f^2\ RH + 8.5282E-4T_f\ RH^2\ -1.99E-6\ T_f^2\ RH^2$$

(Equation 3)

Where HI = Heat Index in Fahrenheit; T_f = air temperature in Fahrenheit; *RH* = percentage of relative humidity; *E* = mathematical constant (2.718).

Thermal Work Limit (TWL) uses five environmental parameters (dry bulb, wet bulb, and globe temperatures, wind speed and atmospheric pressure) and accommodates for the clothing factors to arrive at a prediction of a safe maximum continuously sustainable metabolic rate (W/m^2) for the conditions (Brake and Bates, 2002; Miller and Bates, 2007). The TWL accurately predicts work rates that would be limiting under a given set of environmental conditions. This index has been introduced to several large industrial operations under hot environments (Brake and Bates, 2002). Guidelines for TWL are proposed along with recommended interventions by Brake and Bates (2002). In this regard, work status is classified according to the values of TWL: withdrawal: < 115; buffer: 115-140; acclimatization: 141-220; and unrestricted: > 220 W/m^2.

2.3 Standard procedure

Field measurements were conducted during the summer time in Hong Kong (July-September 2010 and 2011) over six construction sites. Different stages of construction from foundation works to core structural works were studied to capture a wide spectrum of empirical data.

Prior to the field measurement, the participants were asked to rest at room temperature of approximately 22.8 °C for 15 min to stabilize their physiological status. During this period, the testing procedure was explained to each participant. While taking the rest, participants were requested to complete a pre-experiment data collection sheet which includes questions on age, height, and other personal information. Participant's body weight, percentage of body fat (InBody 230, Biospace Co., Ltd), and resting blood pressure (HEM-712C, OMRON, Japan) were measured (Figure 1&2). Body mass index (BMI) was calculated based on participant's height and body weight. Physiological parameters such as heart rate (Polar, Finland), minute ventilation, oxygen consumption, and energy expenditure were continuously measured every 5 s by a wireless and portable metabolic cart (K4b2, COSMED, Rome, Italy). Calibration of gas and volume were carried out prior to the measurement of each participant. Participants were then asked to wear a face mask, back pack and portable unit (Figure 3). The physiological data were averaged every 5 min. The minimum value of each parameter recorded during this resting period represented resting physiological status. Before the start of the test, participants were allowed to rest inside the site office for 20 minutes. This would ensure that participants have not been subject to heat exposure before initial testing.

*****insert Figure 1, 2 & 3 here*****

During the field measurement, the participants performed rebar bending and fixing tasks as per their usual daily work routine and were allowed to drink water as and when they desired. Physiological parameters were monitored by the metabolic cart continuously throughout the rebar work (Figure 4). The physiological data was averaged every 5 min and the corresponding type of work (bar bending or fixing) was recorded manually on the data sheet. The weight of the metabolic cart is 1.5 kg including the battery and a specially designed harness. Wearing the portable gas analyzer during the work does not significantly alter the participants' energy demands (Flouris et al., 2005). Without disturbing the participants' normal operation, the participants' were asked to report their perceptual responses by reporting a rating of perceived exertion (RPE) value for every 5 min (Figure 5), to indicate the amount of strain or level of exhaustion. Voluntary exhaustion was reached when the participants reported a RPE of 10 or stopped working voluntarily, whatever come first, indicated that they could not continue working anymore. The time when the participants stopped working was recorded. *****insert Figure 4, 5 & 6 here*****

At the same time, a heat stress monitor (QUESTemp°36, Oconomowoc, Wisconsin, United States) was used to measure and record the prevailing environmental data (Figure 6). The heat stress monitor measures environmental parameters simultaneously at 1 min interval: ambient or dry bulb temperature, natural wet bulb temperature, globe temperature, relative humidity from which the corresponding WBGT and HI were computed. HI in degree Celsius can be calculated by Fahrenheit and Celsius Conversion Formulas (Equation 4).

$$Celsius = (Fahrenheit - 32)*5/9 \qquad (Equation\ 4)$$

TWL in this study is calculated using the software package “TWL calculator” (Department of Employment EDaI, 2010). A clothing insulation factor of 0.60 clo (Mejet et al. 2008) corresponding to a typical dress code of wearing a T-shirt, light trousers and thick soled shoes was adopted in calculating the TWL. Entering those environmental parameters as well as atmospheric pressure and clothing insulation factor into the “TWL calculator” can determine TWL values.

2.4 Data analysis

Physiological, perceptual, and environmental parameters were synchronized every 5 min. Data are presented as mean (SD). Independent sample t-test was used to examine the difference between bar bending and bar fixing. Significance was set at $p < 0.05$.

3. Results

Participants’ characteristics were presented in Table 1. Resting blood pressure (125.4/79.8 mmHg) and resting heart rate (76.5 beat/min) were classified as normal.

Environmental conditions of the 39 field measurements were reported in Table 2. The average duration of the 39 field measurements was 151.1 min under hot environment (WBGT = 31.4 °C, and Heat Index = 37.5 °C). The TWL value was 152.2 W/m^2 which fell within the category of "buffer working zone".

*****insert Table 1 & 2 here*****

Physiological and perceptual responses of bar bending, bar fixing, and overall rebar work were presented in Table 3. Comparing to resting status, the overall rebar work in a hot environment induced higher physiological responses in heart rate (31.0%), percentage of maximal heart rate (33.9%), minute ventilation (55.7%), oxygen consumption (63.2% and 58.9%) and energy expenditure (58.4%).

Moreover, bar fixing induced significantly higher physiological responses in heart rate (113.6 vs. 102.3 beat/min, $p < 0.05$), percentage of maximal heart rate (65.0 vs. 58.2%, $p < 0.05$), oxygen consumption (9.53 vs. 7.14 ml/min/kg, $p < 0.05$; and 535.4 vs. 460.6 ml/min, $p < 0.05$), and energy expenditure (2.67 vs. 2.26 Kcal/min, $p < 0.05$) (186 vs. 158 W, $p < 0.05$) as compared to bar bending. There is no significant difference in minute ventilation between bar bending and fixing. Perceptual response was also higher in bar fixing as compared to bar bending, but such difference was not statistically significant.

In terms of percentage difference, bar fixing induced higher perceptual and physiological responses such as RPE (9.8%), heart rate (10.0%), percentage of maximal heart rate (10.5%), minute ventilation (4.3%), oxygen consumption (25.1% and 14.0%) and energy expenditure (15.4%), as compared to bar bending (Table 3).

*****insert Table 3 here*****

4. Discussion

The present study aimed to quantify the physical workload of bar bending and fixing. Field studies were conducted during the normal work time for construction workers in Hong Kong (between 8:00 am and 12:00 noon in the morning; and between 1:00 pm and 5:00 pm in the afternoon). Six bar benders and thirty-three bar fixers performed tasks of fixing and bending steel reinforcement bars on six building construction sites. In this regard, energy expenditure of overall rebar work, bar bending, and bar fixing were 2.57 Kcal/min (179 W), 2.26 Kcal/min (158 W) and 2.67 Kcal/min (186 W), respectively. The second aim of the present study was to compare the physiological and perceptual responses between bar benders and bar fixers when they work in a hot environment. We found that bar fixing induced significantly higher physiological responses in heart rate, percentage of maximal heart rate, oxygen consumption and energy expenditure. Perceptual response was also higher in bar fixing as compared to bar bending, but such difference was not statistically significant.

The environmental heat stress of the present study was higher than previous studies. Bates and Schneider (2008) recorded WBGT between 26.1 to 28.6 °C and TWL between 189.3 to 237.7 W/m^2 in construction site located at United Arab Emirates area, whereas Inaba and Mirbod (2007) reported WBGT between 26.5 to 29.8 °C in Japan. It has been shown that working under hot environment reduces the power output in human as compared with warm environment (Hargreaves, 2008).

The rebar worker’s heart rate value (110.8 beat/min) in the present study was higher than that reported by Bates and Schneider (2008) (90 beat/min), but comparable to the intensity of high-rise construction workers such as scaffolder (120.2 beat/min), steel fixer (114.7 beat/min), formworker (112.3 beat/min), electrician-plumber (111.2 beat/min) and concreter (101.9 beat/min) (Chang et al., 2009). Furthermore, the oxygen consumption during rebar work (517.1 ml/min) was lower than the manual lifting and lowering tasks performed once (700 ml/min) and twice per minute (1050 ml/min) in room temperature, i.e. 22 °C and 48%

relative humidity (Li et al., 2009). The results of the present study enable the calculation of daily energy expenditure of rebar work. For example, the minimum daily energy expenditure of a bar fixer who spent 8 hours fixing the bar under hot environment would be:

(2.67 x 8 x 60) + (1.07 x 16 x 60) = 2309 Kcal.

In addition, energy expenditure of extra manual lifting and lowering tasks could be calculated by the equations previously developed (Li et al., 2009).

With this energy expenditure information in mind, sufficient energy intake should be ensured for the rebar workers. Furthermore, it has been shown that increased dietary carbohydrate intake is associated with enhanced exercise capacity in hot environment and may have positive ergogenic effects on the central nervous system (Hargreaves, 2008).

Guidelines for preventive action such as rest-work ratios have been developed by empirical approach and rational approach. The empirical approach is based on direct recording of environmental conditions and subsequent heat strain measures taken from participants to establish the relationship between WBGT and metabolic rate, maximum allowable exposure duration (ISO 7243, 1989). According to these guidelines, rebar workers in the present study worked at the intensity of 2.57 Kcal/min (e.g. 179 Ws) in a hot environment (WBGT = 31.4 °C) should have ~15 min rest every hour. It was argued that data from empirical studies are taken from experiments in a climatic chamber, which cannot adequately address construction site conditions to guide a heat risk management system (Rowlinson et al., 2014).

The rational approach explores the relationship between maximum exposure duration and heat stress through taking explicit account of the internal mechanism of the human thermoregulation process (ISO 7933, 1989). The TWL was developed from the 1989 version of ISO 7933, the required sweat rate (RSR) model (ISO 7933, 1989). The average TWL value recorded in the present study was 152.2 W/m^2. According to the guidelines developed by Brake and Bates (2002), any practicable intervention to reduce heat stress should be implemented in this buffer zone, such as work-rest cycling and fluid intake. It is acknowledged that the current analysis was limited to the physiological parameters monitored by metabolic cart (K4b2, COSMED, Rome, Italy). Further research on the response of core temperature and sweating to heat stress is required.

The purpose of work-rest scheduling is to balance productivity demands with safety concerns and the physical workload of the personnel (Carnahan et al., 2000). A proper design of a work-rest schedule is an effective means in improving a worker's comfort, health, and productivity (Kopardekar and Mital, 1994). A properly designed work-break cycle is important to avoid physical fatigue and the loss of productivity (Hsie et al., 2009). Recent research work has computed the maximum duration (Heat Tolerance Time) that a rebar worker could work continuously without jeopardizing his/her health (Chan et al., 2012). Recovery plays a considerable role to the well-being of rebar workers as well as in their productivity (Maxwell et al., 2008). 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 (Maxwell et al., 2008), which can subsequently lead to heat syndromes especially in a hot environment.

The major mechanism for heat loss when working in a hot environment is evaporation of sweat (Hargreaves, 2008). This requires heat transfer to the skin via cutaneous vasolidation and the loss of fluid which, if not replaced, can result in dehydration. Previous study reported that sweat rates > 1 L/hour can be expected of workers in hot environment (Brake and Bates, 2003; Miller and Bates, 2007). The acute implication of dehydration is the result of a depleted blood volume and the consequent cardiovascular strain. The reduced blood volume causes a compensatory increase in heart rate of around 10 beat/min for every 1% of body weight lost (Wilson and Corlett, 1985). During self-pace work this may results in a slower working pace and subsequently lowers productivity. Therefore, it is important to deliver an active education program and promoting awareness of sufficient hydration and rehydration strategy to rebar workers. It has been shown that construction workers who begin work in well hydrated conditions are likely to maintain good levels of hydration during the shift (Bates and Schneider, 2008). Additionally, it is also useful to screen the hydration status of rebar workers at the worksite such as before work, during breaks, and after work. Previous study suggested that a urine specific gravity value of construction worker below 1.015 is optimal to prevent hypohydration or dehydration (Bates et al., 2010). Practical rehydration rate of 1L/hour has been made for construction workers in a hot environment (Bates et al., 2010). Moreover, the inclusion of carbohydrate in rehydration beverages may provide additional benefits (Hargreaves, 2008).

Workers who are more acclimatize to the heat stress and high workload have less risk for heat related illness (Bonauto et al., 2007). Heat acclimatization is a series of physiological changes or accommodations of the body in response to repeated heat stress exposures. Acclimatized workers have better physiological function such as expanded plasma volume, increased stroke volume and cardiac output and enhanced sweat rate, better distribution of heat within the body, and lose excess heat to environment more efficiently (Hargreaves, 2008). During the first week of an unaccustomed heat exposure, work performance is most affected and the threat of heat illness is greatest (Taylor, 2006). Additionally, it has been reported that 14% of heat-related illness occurred within the first week for inexperience construction workers (Bonauto et al., 2007). Therefore, it is suggested that special attention and arrangement should be given to less acclimatized rebar workers.

It has been reported and observed that construction workers will self-pace, adjusting either the work rate or the duration of work intervals to maintain thermal balance and avoid heat related illness (Bates and Schneider, 2008; Miller and Bates, 2007; Taylor, 2006). In this regard, it has been shown that there was no difference in manual workers' heart rate responses under variate environmental heat stress and it is evident that self-pacing is a protective response to working in heat which does not require a highly informed workforce

(Miller et al., 2011). Thus, recognition of this would facilitate the holistic approach to management of heat stress in hot climates.

Acknowledgements

This project is funded by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (RGC Project No. PolyU510409).The support from the Hong Kong Polytechnic University's Institute of Textiles and Clothing (ITC) is deeply appreciated. The research team is also indebted to the technical support from technicians of the Hong Kong Polytechnic University and the Hong Kong Institute of Education. In particular, the participation of volunteers in this experimental study is gratefully acknowledged. This paper forms part of the research project titled "Experimental research on health and safety measures for working in hot weather", from which other deliverables will be produced with different objectives/scopes but sharing common background and methodology. The authors also wish to acknowledge the contributions of other team members including Dr Michael Yam, Dr Daniel Chan, Prof Esmond Mok, Dr Geoffrey Shea, Dr Min Wu, Dr Herbert Biggs, Dr Donald Dingsdag, and Miss Alice Guan.

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Table 1

Characteristics of the participating rebar workers (*n* = 39).

	Mean ± SD	Range
Age (year)	44.2 ± 10.9	20 - 63
Height (cm)	169.2 ± 6.5	160 - 180
Body weight (kg)	60.3 ± 6.2	53.8 - 74.2
Body mass index (kg/m^2)	22.1 ± 2.7	17.0 - 27.4
Percentage of body fat (%)	15.2 ± 6.2	3.0 - 27.9
Resting:		
-lower blood pressure (mmHg)	79.8 ± 9.9	58 - 95
-upper blood pressure (mmHg)	125.4 ± 10.4	100 - 142
-heart rate (beat/min)	76.5 ± 11.9	55.0 - 92.0
-percentage of maximal heart rate (%)	41.9 ± 5.4	33.8 - 54.1
-minute ventilation (L/min)	10.1 ± 1.7	6.3 - 14.4
-oxygen consumption (ml/min/kg)	3.29 ± 0.87	1.33 - 4.76
-oxygen consumption (ml/min)	212.7 ± 56.6	90.6 - 315.2
-energy expenditure (Kcal/min)	1.07 ± 0.27	0.44 - 1.57

Table 2

Environmental conditions of 39 field measurement sessions.

	Mean ± SD	Range
Duration of session (min)	151.1 ± 22.4	89.0 – 211.0
Wet bulb temperature (°C)	27.8 ± 1.0	26.2 – 31.6
Dry bulb temperature (°C)	32.3 ± 2.0	28.7 – 36.5
Relative humidity (%)	58.1 ± 14.1	31.1 – 89.5
WBGT[a] (°C)	31.4 ± 2.2	27.8 – 35.7
Heat Index (°C)	37.5 ± 2.2	33.4 – 41.5
Thermal Work Limit (W/m^2)	152.2 ± 36.1	80.1 – 228.9

[a] Wet bulb globe temperature index.

Table 3

Physiological and perceptual responses between bar bending and fixing.

	Bar bending ($n = 6$)	Bar fixing ($n = 33$)	Percentage difference (fixing – bending)	Overall rebar work ($n = 39$)
RPE	3.7 ± 1.9	4.1 ± 1.6	9.8%	3.8 ± 1.9
Heart rate (beat/min)	102.3 ± 9.2*	113.6 ± 19.8	10.0%	110.8 ± 18.4
Percentage of maximal heart rate (%)	58.2 ± 5.2*	65.0 ± 11.6	10.5%	63.4 ± 10.8
Minute ventilation (L/min)	22.1 ± 6.8	23.1 ± 7.9	4.3%	22.8 ± 7.6
Oxygen consumption (ml/min/kg)	7.14 ± 2.98*	9.53 ± 6.17	25.1%	8.94 ± 5.65
Oxygen consumption (ml/min)	460.6 ± 181.7*	535.4 ± 240.6	14.0%	517.1 ± 229.5
Energy expenditure (Kcal/min)	2.26 ± 0.90*	2.67 ± 1.21	15.4%	2.57 ± 1.15

*significant different from bar fixing at $p < 0.05$.

Figure captions

Fig. 1. Measuring body weight and percentage of body fat.

Fig. 2. Measuring resting blood pressure.

Fig. 3. The portable metabolic cart used in this study.

Fig. 4. Real-time collection of physiological parameters for bar fixer.

Fig. 5. Report of rating of perceived exertion for bar bender.

Fig. 6. Heat stress monitor (QUESTemp°36).