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A field study of the effectiveness and practicality of a novel hybrid personal cooling vest worn during rest in Hong Kong construction industry

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ABSTRACT

A novel hybrid cooling vest (HCV) incorporated with phase change materials (PCMs) and ventilation fans has been developed for construction workers in Hong Kong to attenuate heat stress and prevent heat-related illnesses, and its effectiveness and practicality have been validated in this study. A total of 140 wear trials involving of 140 workers were conducted in Hong Kong construction sites during the summer time. Each wear trial involves a two-day wear test, of which one day workers wore the HCV (denoted as VEST) during resting, and another day they wore traditional workwear (denoted as CON). Subjects were asked to rate their perceived exertion (RPE), thermal sensations (TS) and 7 other subjective attributes. There were significant differences in the effectiveness on reducing workers' heat strain between VEST and CON in terms of alleviations of heart rate (ΔHR), ΔTS, ΔRPE as well as ΔPeSI ($p < 0.001$). The practicality of HCV is evidenced by a significant improvement by 0.93–1.34 on the rating scores of perceived cooling effect, sensations of comfort and skin dryness during rest and fatigue recovery in VEST at the level of 0.05, and high ratings of 4.85–5 (rating scale from 1 to 7, and the higher the better) by subjects on the preference, fitness as well as effectiveness to combat heat stress. In addition, a remarkable proportion of 91 per cent of subjects prefer to use this newly designed HCV as a cooling measure during rest. The power to alleviate perceptual heat stain (PeSA) in VEST is about twice of that by rest, which means HCV can notably improve the workers' perceptual heat strain in a limited resting duration. However, the strain alleviation power of HCV nearly remains unchanged with the prolonged rest duration. Thus, the optimal work-rest schedule needs to be investigated in a further study.

1. Introduction

Construction workers in Hong Kong are particularly susceptible to heat-related illnesses, for the weather is very hot and humid during summer. The accidents on workers suffering from heat strokes or other heat-related illness were frequently reported (Labour Department, 2009; Leung et al., 2008; Shafie et al., 2007). They are also at high risk of heat related accidents, because the chance of risky behaviors increased concomitantly with environmental temperatures above 24 °C (Ramsey et al., 1983). A large number of construction activities have to be performed outdoors under direct sunlight, e.g. bar bending and fixing. In such conditions, improving the microclimate around the body might be a practical measure to reduce their heat strain, because the change of climate condition of worksites is generally impractical.

A great many researches on cooling vests had been carried out and mostly focused on its application on sporting (Arngrïmsson et al., 2007; Kenny et al., 2011; Stannard et al., 2011; Song and Wong, 2016), military (Balldin et al., 2007; Gao et al., 2011; Jovanović et al., 2014; Luomala et al., 2012; Maclellan, 2007; Zhao et al., 2013) and the chemical industry (Karkalic et al., 2015). The majority of these researches indicated the cooling vest indeed has a positive effect on alleviating heat strain and improving work performance, but a few held the opposite opinion. Wear trials of 10-km running in a climate chamber suggested the use of cooling vests during warm-up did not produce any physiological or psychological benefit, or improve 10-km performance either (Stannard et al., 2011). Another research also indicated no significant effects of cooling vest on simple mental task performance was found (O'Neal and Bishop, 2010). Thus, the effectiveness of cooling vest to improve heat strain and work performance has yet not been confirmed consistently. It should be with caution when applying the cooling vest on construction industry. And hence, the evaluation of its effectiveness and practicality in construction industry should come first.

In addition, most evaluation works on cooling effects of vests were

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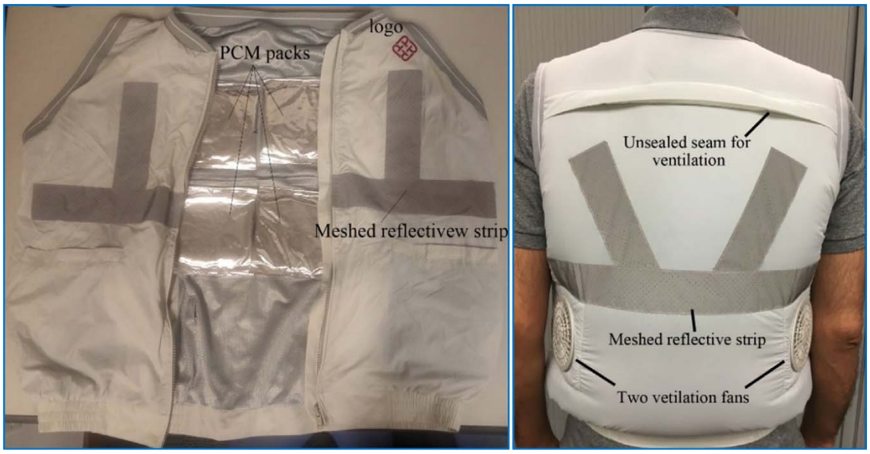

Fig. 1. Front and back views of the newly designed HCV.

carried out in the laboratories, and subjects in those studies were not professional construction workers. Few studies have assessed cooling vests using construction workers in construction sites. Chan et al. (2016a) evaluated the effectiveness and practicality of two commercial cooling vests in four industries. Though their cooling effects were confirmed, workers were still unsatisfied with these commercially available cooling vests, because of their short cooling time, heavy weight, and lack of industry-specific design (Chan et al., 2013, 2016b, 2016c). Chan et al. (2016a) also pointed out that workers involved in different industries have different expectations regarding the cooling vest.

Recently, the authors developed a newly designed hybrid cooling vest (HCV) for construction workers, with a lighter weight and a stronger cooling power. Laboratory tests had been conducted, and it was validated that wearing of the HCV during rest could reduce physiological strain (HR, skin and core temperatures) and enhance work performance (Chan et al., 2017). This study aims to conduct a field study in construction sites of Hong Kong to measure the perceptual and physiological responses of professional construction workers while wearing the HCV during resting and to collect their subjective ratings on HCV, i.e. perceived cooling effect, skin dryness and comfort sensations during rest, fatigue recovery after rest, preference to HCV, fitness of HCV, and the effectiveness to combat heat stress, and subsequently to evaluate its effectiveness and practicality in construction industry.

2. Methods

2.1. Field study

To validate the effectiveness and practicality of the HCV, 14 field studies were conducted during the summer time (August to September 2016) with 140 workers involved in construction sites of Hong Kong. Each field study consists of a two-day wear trial, one day with the HCV (denoted as VEST) and one day without the HCV as the control group (denoted as CON). The HCV was worn over a construction uniform. A heat stress monitor (QUESTemp°36, Oconomowoc, Wisconsin) was used to capture the environmental conditions of construction sites. Wet-bulb global temperature (WBGT) of the workplace was monitored simultaneously at 1-min intervals, which is one of the most widely used and accepted index for evaluating the environmental heat stress and managing occupational heat stress.

2.1.1. Subjects

One hundred and forty male construction workers participated in field studies. The mean and standard deviation (SD) of the anthropometric information of subjects are 32.1 ± 9.1 year of age, 171.8 ± 5.5 cm of height and 69.7 ± 14.2 kg of weight. Subjects were asked to sign the consent form if they agreed to be a part of the study. They were also notified that they could quit this study at any time without penalty. The research was conducted with the approval of Polytechnic University's Human Subjects Ethics Sub-committee. To ensure sufficient statistical power in making inferences about the population, the number of volunteers 140 is much larger than the suggested target sample size ($n = 45$) for construction industry (Chan et al., 2016a) according to the Penn State's equation as Eq. (1) (Watson, 2009).

$$n = \frac{P(1-P)}{\frac{A^2}{Z^2} + \frac{P(1-P)}{N}} \tag{1}$$

where, n is the sample size required; N is the number of people in the population; P is the estimated variance in population; A is the precision desired, and Z is based on confidence level, and their values are given to be 816, 0.5, 0.1 and 1.96 for 95% confidence, respectively (Chan et al., 2016a).

2.1.2. The hybrid cooling vest

The HCV is a newly developed hybrid cooling vest for construction workers (Fig. 1). Details of this HCV has been published in Chan et al.'s study (2017). It was incorporated with 8 packs of phase change materials (PCMs, the surface area and weight per pack are 120 cm^2 and 80 g, respectively) (Climator, Sweden) and a pair of air ventilation fans. The melting point and the latent heat of fusion of PCMs are 28 °C and 131 J/g, respectively. Two PCM packs were placed at the chest region, 2 at the abdomen and 4 at the back. Two fans were embedded to the lower back region, powered by a lithium polymer battery (7.4 V, 4400 mA h). The total mass of the HCV is 1.26 kg. During wear trials, the HCV was worn over a work attire, including a short-sleeved shirt and a pair of long pants (Chan et al., 2016b). The HCV were stored in an air-conditioning room with a temperature of around 23 °C to make sure that PCM was not melted before use.

2.1.3. Experimental procedure

Field study procedure was designed according to the daily work-rest schedule (Fig. 2). Prior to working, a 30-min pre-work session (Session 1, from 8:00 a.m. to 8:30 a.m.) was designed to stabilize their physiological status, collect their personal information and to brief the experimental protocol. Workers started working at 8:30 a.m. and ended at 4:00 p.m. There were 2 rest sessions during work: Rest 1 (Session 3, a 15-min rest in the morning), and Rest 2 (Session 7, a 30-min rest in the afternoon). As the same with the chamber test protocol (Chan et al., 2016b, 2017), the HCV was worn only during the two rest sessions and the ventilation fans were turn on once the HCV was worn on.

To evaluate the effectiveness of HCV, the heart rate (HR) of subjects during wear trail was monitored by the heart rate belt (Polar T34 Transmitter, Finland), and subjects were required to report their ratings