THE EFFECT OF WEARING A COOLING VEST TO ALLEVIATE THERMAL STRAIN DURING MODERATE INTENSITY WORK

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INTRODUCTION

In the heat, a positive body heat storage and the associated increase in core body temperature elicit the reflex physiological thermoregulatory mechanisms of sweating and cutaneous vasodilation in order to enhance heat dissipation. However under circumstances where these mechanisms cannot facilitate a sufficiently high rate of heat loss, core body temperature continually rises, and if left unchecked may lead to heat illness and eventually death. The conditions under which a catastrophic increase in core body temperature may occur are determined by a complex interaction between ambient environmental conditions (i.e. air temperature, radiant temperature, relative humidity and air velocity) and personal parameters (i.e. metabolic activity and clothing).

For occupational tasks associated with physical activity, the heat stress risk is potentially greater since the elevated level of metabolism requires a greater amount of heat to be dissipated in order for heat balance to be possible. This scenario is further confounded by the insulative effects of clothing ensembles (ranging from coveralls to semi-permeable or impermeable protective clothing) that are often required for a particular job. Even occupational tasks that have a relatively low level of activity and/or clothing insulation present a significant heat stress risk if they are performed under hot environmental conditions. Examples of Canadian industries that require workers to operate under such conditions include mining sites, iron and steel foundries, brick-firing and ceramic plants, glass products facilities, electrical utilities (particularly boiler rooms), chemical plants, smelters, bakeries and steam tunnels. Other than high ambient air temperatures, such environments also often present sources of high radiant heat and high humidity. Indeed, under ambient air temperature conditions, above typical mean skin temperature (~34ºC), the negative dry heat transfer gradient causes the body to absorb heat from the environment. Therefore, the only avenue for heat dissipation is via the evaporation of sweat, and under conditions of high ambient humidity the reduced driving force for evaporative heat loss presents a high heat stress risk

Many Canadian workers routinely perform their work tasks under hot environmental conditions. Of particular note, in certain regions of the world, the mining industry can be forced to give up valuable resources deep beneath the earth surface due to the high temperature of the deep-mining environment (3, 4). As a matter of fact, the temperature of a deep mine increases with mine depth (5). Consequently, deep mining will eventually reach the threshold where the cost of circulating air, the currently most widely adopted means of mitigating high environmental temperatures along with refrigeration to pre-condition deep-mine air, overwhelms the potential gain.

Body heat balance control is ultimately dependant on the microclimate, i.e., the temperature and humidity of the micro-environment surrounding the body surface. Consequently, microclimate cooling system that improve the environment immediate in the vicinity or at the skin environment interface of the worker are therefore a potentially more cost-effective strategy than the removal of heat via bulk ventilation or the use of mine-wide refrigeration. For industries like the Canadian mining industry, this could represent significant cost savings. In this study we evaluated the effects of a commercial cooling vest unit on the thermoregulatory response during work performed in the heat in individuals wearing mining protective gear. The vest tested employed a phase change principle whereby liquid packets when pre-chilled become solid, these packets then return to a liquid phase as they absorb heat while the vest is being worn.

METHODS

Following approval of the experimental protocol from the University of Ottawa Research Ethics Committee and obtaining written informed consent, 8 healthy non-smoking males participants volunteered to participate in the study. Mean characteristics of these participants were: Age, 19±2 years; Height, 1.75±0.07 m; Weight, 76.3±12.1 kg; Body fat, 15.3±11.5%; Body surface area, 1.92±0.17 m^2; Maximal oxygen consumption (VO_{2max}), 56.8±9.1 ml/kg/min.

All participants were required to participant in 4 separate laboratory testing days (1 screening visit and 3 experimental testing sessions). On testing day 1, body adiposity and VO_{2max} were measured. Maximal oxygen consumption was measured during a progressive treadmill running protocol. The hydrostatic weighing technique was used to determine body density. Calculation of the percentage of body fat was based on the Siri equation (8) Also, during this session, the subjects were familiarized with all procedures to be performed during the investigation period. During the 5 experimental testing sessions, the calorimeter experimental exercise protocol was performed while wearing either: 1) *Control*, no clothing with exception of single-layers shorts; 2) *Mine gear only,* standard mining coverall (65% polyester, 35% cotton) as typically worn by miners in Canada; and 3) *Mine gear + Cooling Vest*; CM2000 cooling vest manufactured by ClimaTech). In latter 2 tests the clothing ensembles also consisted of the miner’s typical personal protective or other equipment including a hard-hat with ear-muffs, gloves and socks with close-toed shoes.

The presentation of the experimental trials was balanced between participants so that the effect of order was avoided. Testing days were separated by a minimum of 72 h. All trials were performed at the same time of day. Participants were asked to arrive at the laboratory after eating a small breakfast (i.e. dry toast and juice), but consuming no tea or coffee that morning, and also avoiding any major thermal stimuli on their way to the laboratory. Participants were also asked to not drink alcohol or exercise for 24 h prior to experimentation. On arrival to the laboratory subjects were instrumented and subsequent entered a temperature controlled chamber maintained at an air temperature of 40°C and 15% relative humidity. Subjects remained resting for 30 min (habituation period) in the upright seated posture. They then were required to cycle for 60 minutes at a constant rate of heat production of ~400W which is considered the onset of a "heavy" work demand according to the ACGIH screening criterion, 2001 (1). This was then followed by 60 minutes of recovery to determine the effects on post-exercise recovery.

Esophageal temperature was measured using a thermocouple temperature probe (Mon-a-therm General Purpose, Mallinckrodt Medical, MO, USA) inserted through a nostril, into the esophagus, estimated to be positioned at the level of the heart (7). Rectal temperature was measured using a paediatric thermocouple probe (Mon-a-therm General Purpose Temperature Probe, Mallinckrodt Medical, St-Louis, MO, USA) inserted to a minimum of 12 cm past the sphincter. Skin temperature was measured at 9 points over the body surface using 0.3 mm diameter T-type (copper/constantan) thermocouples integrated into heat-flow sensors (Concept Engineering, Old Saybrook, CT, USA). Participants were asked to subjectively rate their thermal sensation using an ASHRAE 7-point scale ranging from neutral (0) to extremely hot (7) throughout the trials.

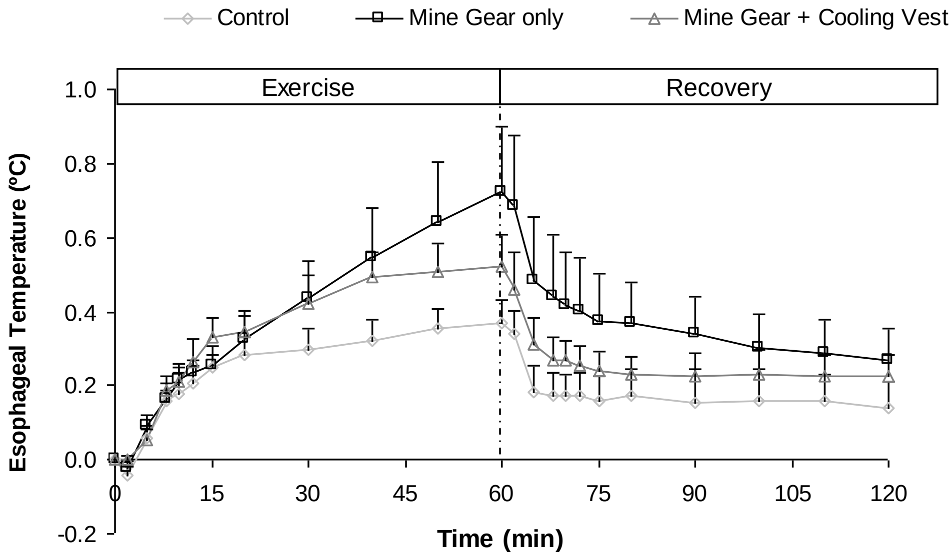
A two-way analysis of variance (ANOVA) with repeated measures was performed to analyze the whole-body heat loss responses using the repeated factors clothing and time (exercise and recovery: 2, 5, 8, 10, 12, 15, 30, 45, 60 min). Paired sample t-tests were used to perform pair-wise post-hoc comparisons. Significance was assumed for $p < 0.05$.

RESULTS

During exercise there was a significant increase in esophageal temperature from baseline ($p<0.001$) across all conditions. There was also a trend ($0.05<p<0.10$) for the esophageal temperature to be different between conditions ($p=0.086$). The esophageal temperature for the Control condition was significantly lower as compared to both the Mine Gear only and the Mine Gear + Cooling Vest conditions for between 30 min and end of exercise. We observed a lower esophageal temperature for the Mine Gear + Cooling Vest condition from 40 min to the end of exercise as compared to the Mine Gear only. During recovery there was a significant decrease in esophageal temperature from the end of exercise ($p<0.001$) across all conditions. Recovery esophageal temperatures were significantly different between the three conditions ($p=0.042$) with the Control condition being significantly lower than the Mine Gear only for the entire recovery period. Further, the Control condition was significantly lower than the Cooling Vest at 5 to 15 min of recovery (Figure 1).

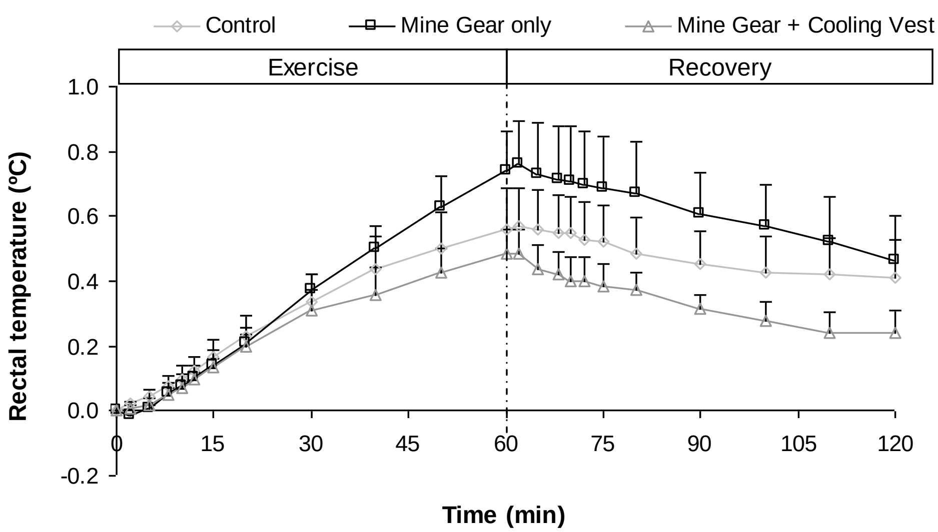
Rectal temperature was not significantly different between conditions during exercise ($p=0.437$). However, it is noteworthy that during exercise rectal temperature of the Mine Gear + Cooling Vest condition tended to be lower than the other conditions. In the recovery period, rectal temperature for the Control condition was significantly higher than the Cooling Vest condition for the last 30 min of the recovery period. Also, the Mine Gear + Cooling Vest condition was significantly lower than the Mine Gear only condition during the entire recovery period (Figure 2).

Figure 1. Change in esophageal temperature during exercise and post-exercise recovery.



There were no significant differences in mean skin temperature response during and following exercise. The change in heart rate from baseline was significantly different between conditions during exercise (p=0.018) and recovery (p=0.003). During exercise, heart rate for the Control and Mine Gear + Cooling Vest conditions were significantly lower than the Mine Gear only condition from 40 min to the end of exercise. No differences were observed between the Control and Mine Gear + Cooling Vest. During recovery, heart rate for the Control and Mine Gear + Cooling Vest conditions were significantly lower than the Mine Gear only condition for the entire recovery period. No differences were observed between the Control and Mine Gear + Cooling Vest during recovery.

Figure 2. Change in rectal temperature during exercise and post-exercise recovery



The subjective thermal sensation response was significantly lower during the first 30 minutes of exercise for the Cooling Vest condition (1.6±1.1) than the Control condition

(2.8±0.8) (p=0.035). Thermal sensation during exercise with the Mine Gear + Cooling Vest was significantly lower (1.8±1.3) as compared to the Mine Gear only condition (3.8±1.3) (p=0.002). There was a trend for the Control condition to be lower than the Mine Gear only condition during exercise (p=0.054) but not recovery (p=0.311).

CONCLUSION

We show that the use of a commercially available phase change cooling vest (CM2000 cooling vest manufactured by ClimaTech) worn under standard mining clothing during work performed in the heat has a beneficial effect on the level of thermal and cardiovascular strain experienced by the worker. While there is empirical evidence suggesting that microclimate cooling can significantly increase the rate of heat loss and therefore improve body heat balance control (2, 6), this is the first study to demonstrate the benefits of a commercial cooling vest in attenuating the rate of core temperature increase using a moderate work intensity comparable of the work intensity that could be demanded by certain mining tasks. Microclimate cooling system may therefore be an appropriate countermeasure or control measures which can be implemented to reduce the effects of heat exposure during work performed in arduous mining conditions. Further studies are required to examine the benefits of phase change cooling vest during more intense work and under different combinations of ambient air temperature and humidity. In summary, the use of cooling vests could be employed in array of work conditions and workplaces (iron and steel foundries, brick-firing and ceramic plants, chemical plants, bakeries and others) to reduce the risk of heat-related injuries.

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