THE INFLUENCE OF DIFFERENT MINING CLOTHING ENSEMBLES ON WHOLE-BODY HEAT BALANCE

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INTRODUCTION

Underground miners traditionally work in harsh environments containing dust and noxious gases. Depending on the type of mining, workers also need to be protected against cuts and scrapes from the rock and metal, which rusts over time, and contact with various fluids, oils etc., used by mechanized mining equipment. In Canada, miners have typically worn coveralls, possibly over full undergarments, to protect them thermally from cold conditions and the physical environment. However, with increasing depth and mechanization, there is concern that the increasing risk of heat exposure may compound the deleterious effect of these conditions and further subject the workers to increased risk of heat stress. Performing work in a warm or hot environment is in general more thermally stressful than performing the same task in a neutral environment. Body heat storage of an individual is a consequence of an imbalance between the rates of heat production and total heat loss (dry and evaporative). As ambient temperature increases dry heat loss diminishes to point where the body absorbs heat from the environment. Under such circumstances, the only avenue of heat loss is via evaporation (primarily of sweat). While sweat rate and ambient humidity are of course the crucial parameters that determine the rate of evaporative heat loss for an individual, another primary influence is the insulative properties of the clothing ensemble worn.

Clothing acts as a resistance to heat and moisture transfer between the skin surface and the ambient environment (4). As such it can protect against extreme heat from external radiant sources but in parallel it also restricts the loss of excess heat produced by the body during work. The nature of this barrier for vapour transport from the body to the environment is determined by the physical properties of the materials that the clothing is composed of (3) and the interaction of these clothing properties with the environmental parameters, such as changes in air temperature or wind speed; and the personal parameters, such as body movement and size. Recently, there have been trends in the mining industry towards the use of “sports” undergarments with enhanced wicking properties instead of more traditional undergarments and also away from coveralls to other types of work-wear without knowing the consequences to the worker. The move towards the “sports’ undergarment is the result of users reporting increased comfort. However, recent anecdotal evidence suggest that wearing a multi-layered system such as the “sports” undergarments under the standard mining clothing ensemble may in fact have a deleterious effect on the miner by compromising heat loss and therefore core temperature regulation (2). In order to ascertain the potential heat stress risk of an individual working in a hot environment an understanding of the complex dynamic behavior of the human-clothing system under simulated work conditions is required.

The following study was conducted to determine the physiological responses as well as changes in body heat content, as measured by whole-body direct calorimetry, during exercise in the heat while wearing different mining clothing ensembles. In this initial study, a high constant work rate and hot environment were used to maximize the evaporative heat loss potential through the clothing system. Future studies will explore the intermittent variable work rates and more temperate humid conditions observed in the mines.

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, 20±3 years; Height, 1.76±0.06 m; Weight, 78.2±9.8 kg; Body fat, 15.7±8.8%; Body surface area, 1.96±0.14 m^2; Maximal oxygen consumption (VO_{2max}), 56.0±7.7 mL/kg/min).

All participants who volunteered were required to participant in six separate laboratory testing days (1 screening visit and 5 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 (7). 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) typical of that worn by miners in Canada; 3) *Undergarment only*, a "sports" type sweat wicking two-piece undergarment (93% polyester, 7% spandex); 4) *Mine Gear + Undergarment*, a combined condition of the standard coverall and two-piece undergarment; and, 5) *Work pant + Undergarment top*, a standard work underpant (65% polyester, 35% cotton) with a "sports" type sweat wicking long-sleeve top (93% polyester, 7% spandex). In the latter four tests, the clothing ensembles also consisted of the miner's typical personal protective or other equipment including a hard-hat with ear-muffs, safety glasses, gloves and a belt. Due to medical concerns, the standard leather safety boots, worn over socks, was replaced by close-toed shoes. Of note, for the Work pant + Undergarment top conditions, data was collected for only 5 of the 8 subjects.

For each experimental session, the modified Snellen direct air calorimeter (6) was employed for the purpose of measuring the rate of evaporative and dry heat loss for the measurement of rate of total heat loss. The rate of metabolic heat production was measured using simultaneous indirect calorimetry. The rate of metabolic heat production was calculated as the difference between the minute-average values for VO_2 and the respiratory exchange ratio and the external work rate (5). The change in body heat content was calculated as the difference between the rate of heat production and rate of heat loss.

All calorimeter 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.

Following instrumentation, the participant entered the calorimeter regulated to an ambient air temperature of 40ºC and 15% relative humidity. The participant, seated in the semi-recumbent position, rested for a 30-min habituation period while a steady-state baseline resting condition was achieved. Subsequently, the participant performed 60 minutes of semi-recumbent cycling at a constant rate of metabolic heat production of ~400 W which is considered the onset of a “heavy” work demand according to the ACGIH screening criterion, 2001 (1). Subjects then remained seated resting for 60 minutes.

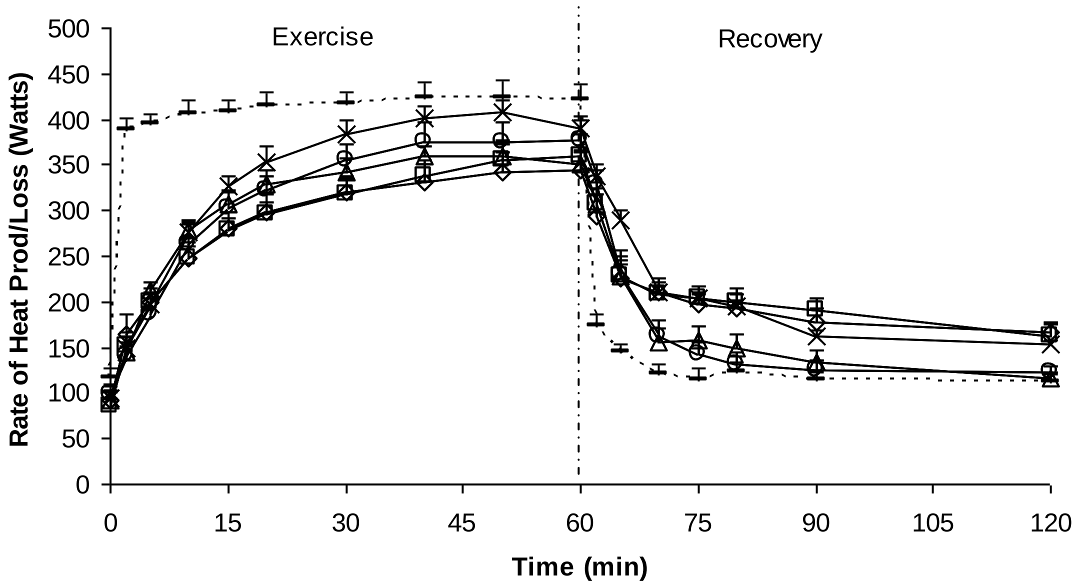
A two-way analysis of variance (ANOVA) with repeated measures was performed to analyze the whole-body heat loss responses using the repeated factors clothing and exercise time (2, 5, 8, 12, 15, 30, 45, 60 min). Paired sample t-tests were used to perform pair-wise post-hoc comparisons and changes in body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

RESULTS

As depicted in Figure 1, the average metabolic heat production during exercise was kept constant for all trials at 403 ± 13 W. During exercise, there was a main effect of clothing on total body heat loss ($p=0.010$). The rate of total body heat loss for the Control, Undergarment only, and Work pant + Undergarment top conditions were greater than the Mine gear only and Mine gear + Undergarment conditions respectively. For the recovery period, the rate of decay was greater for the Control and Undergarment only condition relative to the other three clothing conditions.

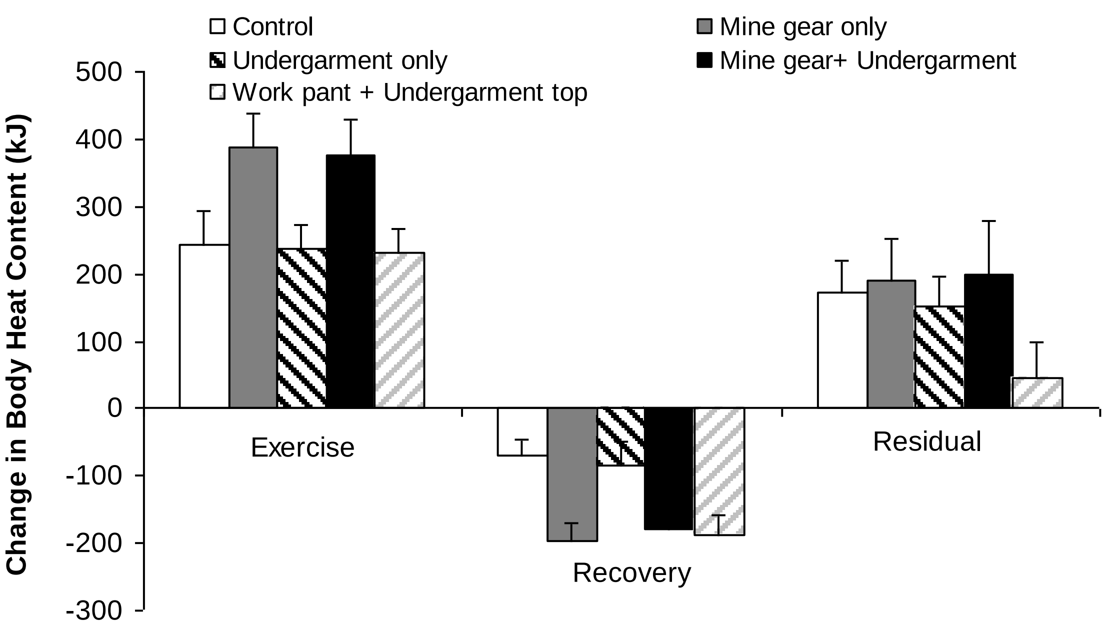
The mean changes in body heat content during the 60 minute exercise period and 60 minute recovery period are presented in Figure 2. The change in body heat content during the 60-min work period were similar between the both the Undergarment only, Work pant + Undergarment top only relative to the semi-nude Control condition. The change in body heat content for the Mine gear only ($p=0.045$) and Mine gear + Undergarment ($p=0.018$) were significantly greater than Control.

Figure 1. Average metabolic heat production (--▬--) for all conditions combined and mean rate of total heat loss for the Control (o), Mine gear only (□), Undergarment only (Δ), Mine gear + Undergarment (◊), and Work pant + Undergarment top (x)



During the recovery period, the change in body heat content were greater for the Mine gear only (p=0.008), Mine gear + Undergarment (p=0.026) and Work pant + Undergarment top (p=0.001). Similarly, no differences in residual heat storage was measured at the end of the experimental session (i.e., as measured by the change in body heat content during exercise minus the change in body heat content during recovery).

Figure 2. Mean changes in body heat content during and following exercise



CONCLUSIONS

The results show that "sports" undergarments with enhanced wicking properties do not compromise whole-body heat loss during and following exercise in the heat when compared to semi-nude Control. Similarly, when the undergarment top only is worn in combination with standard mining work pants only, the responses were similar to those measured in the semi-nude Control and Undergarment only conditions. However, when the "sports" undergarment is worn under clothing such as mining coveralls, the "sports" undergarment appears to have a detrimental effect on whole-body heat loss resulting in a significantly greater storage of heat during exercise. These results suggest that while "wicking" type undergarments by themselves are not detrimental compared to the semi-nude Control condition of basic shorts, workers should not wear "sports" undergarment under standard work clothing ensembles as this may increase the risk of heat-related injuries.

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