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# Ice Cooling Vest on Tolerance for Exercise under Uncompensable Heat Stress

Title Cover



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## Abstract

This study was conducted to evaluate the effectiveness of a commercial, personal ice cooling vest on tolerance for exercise in hot (35°C), wet (65% relative humidity) conditions with a nuclear biological chemical suit (NBC). On three separate occasions, 10 male volunteers walked on a treadmill at 3 miles per hour and 2% incline while (a) seminude (denoted CON), (b) dressed with a nuclear, biological, chemical (NBC) suit with an ice vest (V) worn under the suit (denoted NBCwV); or (c) dressed with an NBC suit but without an ice vest (V) (denoted NBCwoV). Participants exercised for 120 min or until volitional fatigue, or esophageal temperature reached 39.5°C. Esophageal temperature ($T_{es}$), heart rate (HR), thermal sensation, and ratings of perceived

exertion were measured. Exercise time was significantly greater in CON compared with both NBCwoV and NBCwV ($p < 0.05$), whereas $T_{es}$, thermal sensation, heart rate, and rate of perceived exertion were lower ($p < 0.05$). Wearing the ice vest increased exercise time (NBCwoV, 103.6 ± 7.0 min; NBCwV, 115.9 ± 4.1 min) and reduced the level of thermal strain, as evidenced by a lower $T_{es}$ at end-exercise (NBCwoV, 39.03 ± 0.13°C; NBCwV, 38.74 ± 0.13°C) and reduced thermal sensation (NBCwoV, 6.4 ± 0.4; NBCwV, 4.8 ± 0.6). This was paralleled by a decrease in rate of perceived exertion (NBCwoV, 14.7 ± 1.6; NBCwV, 12.4 ± 1.6) ($p < 0.05$) and heat rate (NBCwoV, 169 ± 6; NBCwV, 159 ± 7) ($p < 0.05$). We show that a commercially available cooling vest can significantly reduce the level of thermal strain during work performed in hot environments.
**Keywords:** core temperature; exposure limits; thermal strain; thermoregulation

# INTRODUCTION

Elevations in rate of metabolic heat production during exercise, combined with high ambient temperatures and humidity, can lead to progressive increases in body heat content and if left unchecked this may lead to heat illness and eventually death. Human beings are usually capable of dissipating this heat through increased skin blood flow and sweating.[(1)] However, when personal protective garments are used such as those worn to protect individuals against heat and/or direct contact with and contamination by radioactive, biological, or chemical substances (i.e., HAZMAT [hazardous material] or NBC suits), this heat stress is exacerbated. The protective clothing's impermeable nature severely impedes evaporative heat loss through sweating.[(1)] In addition, it has been shown that the microenvironment between the user and the protective suit may be as much as 5°C hotter than the ambient temperature.[(2)] This can lead to dry heat gain in addition to metabolic heat production and evaporative impediment. As problematic as these protective garments may seem, they are often necessary in industrial work settings, since they protect workers from direct contact with hazardous materials.[(3)]

Fan,[(4)] cooled-air,[(5-8)] and liquid-cooled[(3,6,7,9-11)] vests and suits have been found to be an effective strategy for heat strain relief during physical work. However, environment-ventilated fan cooling may not be appropriate in settings where the suit is in place to completely stop user exposure to the environment. The use of cooled-air and liquid-cooled vests typically requires an energy supply and/or a cooler mount (typically filled with ice, or other cooling agents) that can severely limit the individual's mobility.[(1)] This leaves ice vests as one of the most cost-effective strategies for implementation during work bouts.[(1)] Research on ice vests has shown them to be effective at relieving thermal strain both in normal clothing/uniforms[(12,13)] as well as heavy protective clothing such as HAZMAT and NBC suits.[(1, 14-16)]

While ice vests provide greater operational mobility, the physical properties of the materials used in ice vests also limit their capacity as a heat sink.[(1,16,17)] After the heat sink capacity of an ice pack is reached, it must be changed to continue cooling.

This involves removal of the protective clothing. Many studies that involve the testing of ice vests have done so on prototype systems designed for research purposes.[1,16] Of the studies that have investigated the effectiveness of commercially available ice vest systems only,[12,17,18] most have considered the effectiveness during intermittent rest periods. There is little research on the use of commercially available ice vest systems during prolonged continuous work in the heat.

As industries such as mining become more reliant on personal cooling systems, they turn to those models which are commercially available. A current and foreseeable trend is for many Canadian mines to become much deeper. Unchecked, this can cause a disproportional increase in the ambient temperatures and consequently the level of heat stress imposed on workers. There are numerous sources of heat in underground mines. Factors such as rock and ground water temperature are considered to be the major determinants of temperature at a given depth in an underground mine.[19] Increased mine air temperature also occurs due to autocompression, powered equipment, electrical units, rock movement, and blasting. Autocompression of the air as it descends into the mine is significant, having the potential to increase air temperature by up to $10°C \cdot km^{-1}$.[20] The standard control measures are ventilation and refrigeration. However, due to their significant capital and operating costs, heat exposure issues could limit the depth to which existing mines may operate without compromising worker health and safety.[21] Hence, the mining industry must increasingly rely on more cost-effective strategies, such as the use of commercial cooling vests, to mitigate the risk of thermal injury for their workers.

The present study was conducted to evaluate the effectiveness of a commercially available ice cooling vest on tolerance to prolonged exercise in hot, wet conditions with insulated protective clothing (NBC suit). We evaluated the hypothesis that the use of the ice vest in combination with the NBC suit would increase work time and reduce the level of thermal strain during exercise performed under uncompensable heat stress conditions.

# METHODS

## Participants

The participants of this study were 10 young, healthy male volunteers. Their mean (±SD) characteristics were: age 22.9 ± 4.0 years, height 178.8 ± 8.2 cm, and weight 78.0 ± 10.3 kg. All participants signed an informed consent form and completed a background health questionnaire (Par-Q). The study protocol was approved by the University of Ottawa Human Research Ethics Committee.

## Experimental Protocol

All participants undertook one screening visit and three experimental sessions. The three experimental trials were performed in random order. During the three experimental sessions, the evaluation of the ice cooling vest on tolerance for exercise in hot, wet conditions with the insulated protective garment was performed. No laboratory acclimatization sessions were performed prior to the experimental trials. Testing days were separated by a minimum of 72 hr. All experimental 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. Participants were also asked not to drink alcohol or exercise for 24 hr prior to experimentation. To promote euhydration, participants were asked to drink 250 mL of water the night before as well as on the morning of each experimental trial.

Following instrumentation, the participant entered the environmental chamber regulated to an ambient air temperature of 22°C and a relative humidity of ~20%. Subjects then rested in an upright seated posture clothed in shorts and running shoes only for a 30-min period. Subjects then performed a walking protocol on a treadmill at 3 miles per hour and 2% incline while (a) remaining seminude (denoted CON), (b) dressed with an NBC suit with a Climatech CM 2000 ice vest (Clima Tech Safety, White Stone, Va.) (**Figure 1**) worn under the suit (denoted NBCwV), or (c) dressed with an NBC suit but without an ice vest (denoted NBCwoV). Exercise was performed in a thermal chamber heated to 35°C and relative humidity of 65%. This ambient condition is representative of a heat stress condition experienced by miners working in Canada's deep mechanized mining operations.[22] Trials lasted for 120 min or until volitional fatigue, or esophageal temperature reached 39.5°C. All trials were performed in random order.

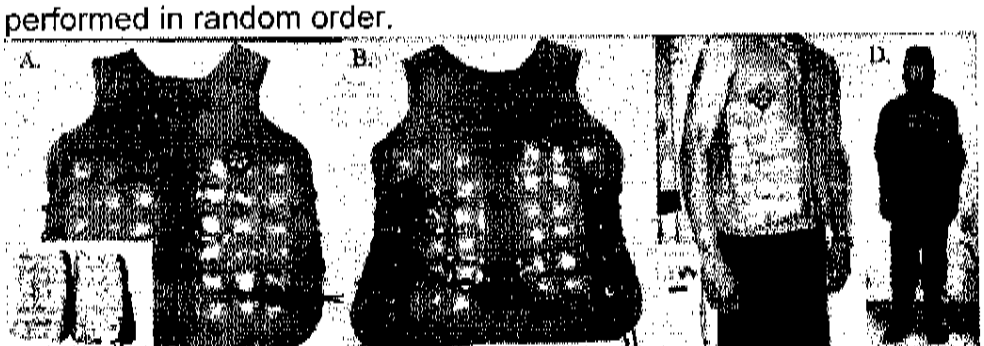


**FIGURE 1** CM2000 cooling vest and an NBC suit. A. Front view of cooling vest with ice packs (inset); B. Rear view; C. Participant wearing the vest; D. Participant wearing NBC suit

The walking intensity selected was chosen as it is typical of the average rate of heat production previously measured during conventional mining tasks.[22] The 2-hr time limit was chosen, as it reflects the upper time limit of a continuous work effort (without a rest period) performed during typical mining operations[22] under a non-heat stress condition. Further, we employed the NBC suit because it is effective in simulating uncompensable heat stress situations faced by workers while wearing various forms of protective garments/gear that severely restrict heat loss (oilers, mine rescue gear, protective heat garments, and so on).[23]

## Instrumentation

Esophageal temperature ($T_{es}$) was measured using a general purpose thermocouple temperature probe (size 9Fr, Mon-a-therm; Mallinckrodt Medical, Hazelwood, Mo.) inserted through the nostril, into the esophagus to the level of the heart. Temperatures were measured, and the data were digitized (data acquisition module, model 3497A; Agilent Technologies, Santa Clara, Calif.) at 15-sec intervals.

Heart rate (HR) was monitored continuously using a Polar coded transmitter, recorded continuously, and stored with a Polar RS400 interface and Polar ProTrainer 5 software (Polar Electro, Oy, Finland).

Perceived exertion and thermal sensation were recorded during exercise every 5 min. The Borg scale[(24)] was used to quantify perceived exertion, whereas a 7-point scale was used for thermal sensation (0 = neutral to 7 = extremely hot).

## Clothing and Cooling Vest

The cooling vest tested in this study was a commercially available ice vest, the CM2000 vest (ClimaTech Safety, White Stone, Va.). The mesh vest has ice pack inserts (**Figure 1**). Cooling occurs through direct contact with the ice packs (conduction) and through cooling of the air inside the participant's NBC suit (convection). The cooling vest was worn directly on the skin to maximize heat transfer. The weight of the vest with ice packs was 4.1 kg. The NBC suit was worn over the cooling vest and covered all of the body except for the face (a face mask was not worn) (**Figure 1**). Impermeable rubber gloves and overboots were worn over running shoes. The weight of the NBC ensemble was 3.4 kg. Together with the cooling vest, the entire NBC suit-cooling vest ensemble weighed 7.5 kg.

## Analysis of Results

Baseline data were calculated as an average of the last 5 min of the baseline resting period. Esophageal and skin temperatures and heart rate data are reported for every 5 min of exercise. The values used represent 15-sec averages at 10-min intervals. Ratings of perceived exertion and thermal sensation were reported for every 5 min of exercise. Tolerance to exercise was assessed as the total time completed during the 120-min exercise test.

A two-way repeated-measures analysis of variance was used to analyze all data sets ($T_{es}$, HR, RPE, and TS) for all three trials with the repeated factors of time and clothing condition (Levels: CON, NBCwoV and NBCwV). A repeated measures analysis of variance was also used to compare end point values for all variables ($T_{es}$, HR, RPE, and TS). Paired samples t-tests were used for pairwise post-hoc analysis. Significance was reported when $p < 0.05$. Data are reported as mean ± standard error.

All statistical analyses were performed using PASW Statistics 18.0 (SPSS Inc., IBM, Chicago, Ill.).

# RESULTS

All participants completed the 120-min exercise period during the seminude condition (CON) (**Figure 2**). In contrast, exercise time during the NBCwoV trial (103.6 ± 7.0 min) was significantly less compared with CON ($p < 0.05$). Only 4 out of 10 participants completed the 120 min of exercise wearing the NBC suit without an ice vest (NBCwoV), with the remaining 6 subjects terminating the test due to volitional fatigue. In contrast, wearing the cooling vest together with the NBC suit (NBCwV) increased exercise time by 11.9 ± 0.4 % (**Figure 2**). As such, exercise time was significantly greater during the NBCwV condition compared with the NBCwoV condition (103.6 ± 7.0 min vs. 115.9 ± 4.1 min for NBCwV and NBCwoV, respectively) ($p < 0.05$). The full 120 min of exercise was completed by 9 out of 10 subjects when the ice vest was worn under the NBC suit (NBCwV), with only one subject terminating prematurely due to volitional fatigue. Exercise time during NBCwV was not significantly different from CON.

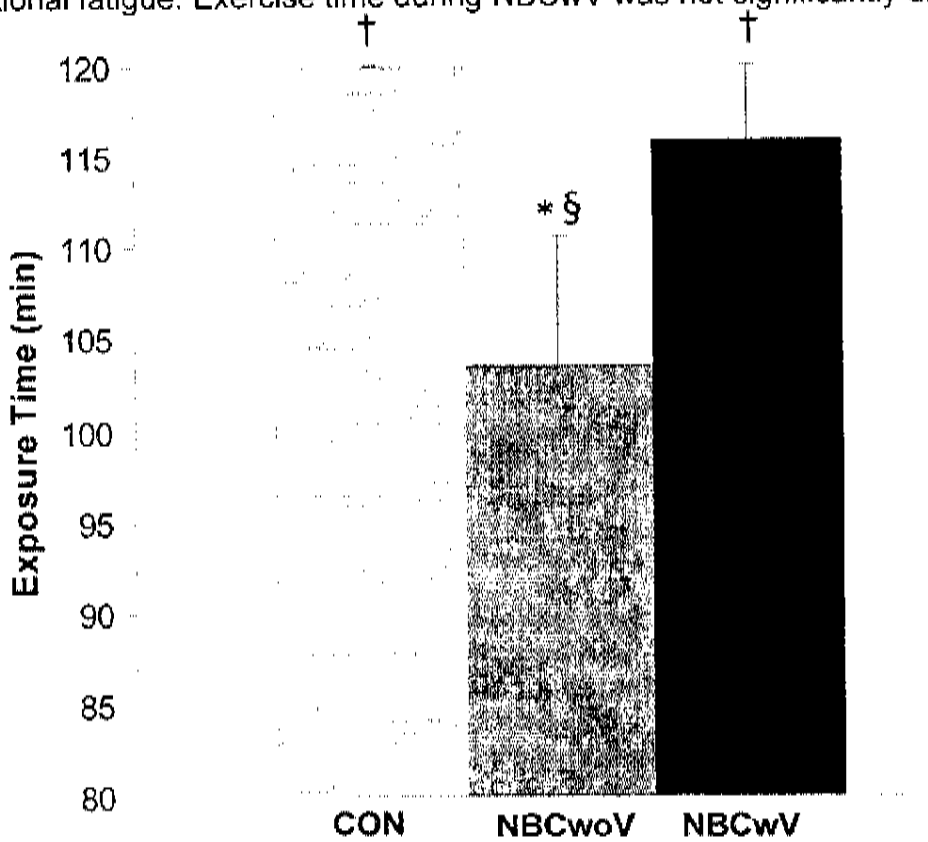


**FIGURE 2** Mean (±SE) exposure time. * Indicates values significantly different from CON; § indicates values significantly different from NBCwV; † indicates values significantly different from NBCwoV

Esophageal temperature increased progressively with time in all conditions ($p < 0.05$); however, a main effect of clothing conditions was measured ($p < 0.05$) (**Table I**, **Figure 3**). Esophageal temperature was significantly lower during the NBCwV condition compared with the NBCwoV trial from 70 to 120 min of exercise ($p < 0.05$).

In contrast, $T_{es}$ during the NBCwV condition was significantly greater compared to CON between 50 and 120 min of exercise ($p < 0.05$). During the NBCwoV condition, $T_{es}$ was significantly greater compared with CON between 40 and 120 min of exercise ($p < 0.05$).

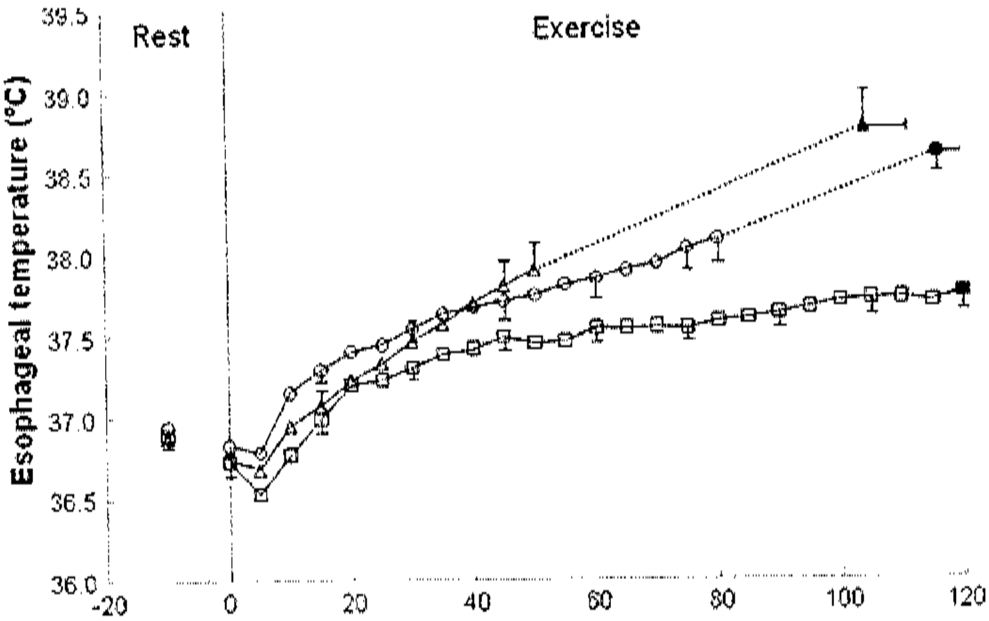


**FIGURE 3** Mean (±SE) esophageal temperature response during baseline and exercise. Solid line with open symbols represents data at exercise intervals common to all participants (n = 10) for CON (□), NBCwoV (△) and NBCwV (○). Solid symbols indicates mean esophageal temperature at maximal exposure time for CON (▪, 120 min), NBCwoV (▴, 103.6 min), and NBCwV (•, 115.9 min).

**TABLE I Mean (±SE) Esophageal Temperature Response**

| Time | $n^A$ | CON | $n^A$ | NBCwoV | $n^A$ | NBCwV |
|---|---|---|---|---|---|---|
| Baseline | 10 | 36.91 ± 0.08 | 10 | 36.88 ± 0.04 | 10 | 36.94 ± 0.08 |
| 30 | 10 | 37.31 ± 0.07§ | 10 | 37.47 ± 0.12 | 10 | 37.55 ± 0.07 |
| 40 | 10 | 37.42 ± 0.08†§ | 10 | 37.70 ± 0.14* | 10 | 37.68 ± 0.09 |
| 50 | 10 | 37.45 ± 0.08†§ | 10 | 37.90 ± 0.17* | 10 | 37.75 ± 0.11* |
| 60 | 10 | 37.54 ± 0.08†§ | 9 | 38.05 ± 0.15* | 10 | 37.85 ± 0.12* |
| 70 | 10 | 37.55 ± 0.07†§ | 9 | 38.24 ± 0.16*§ | 10 | 37.95 ± 0.13*† |
| 80 | 10 | 37.58 ± 0.07†§ | 9 | 38.50 ± 0.15*§ | 10 | 38.09 ± 0.14*† |
| 90 | 10 | 37.63 ± 0.08†§ | 9 | 38.71 ± 0.18*§ | 9 | 38.09 ± 0.08*† |
| 100 | 10 | 37.70 ± | | 38.69 ± | | 38.26 ± |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 0.08†§ | 6 | 0.22*§ | 9 | 0.09*† |
| 110 | 10 | 37.72 ± 0.09†§ | 6 | 38.80 ± 0.21* | 9 | 38.41 ± 0.12*† |
| 120 | 10 | 37.75 ± 0.10†§ | 4 | 38.97 ± 0.21* | 9 | 38.67 ± 0.12*† |
| Exposure Limit[B] | 10 | 37.75 ± 0.10†§ | 10 | 39.03 ± 0.13*§ | 10 | 38.74 ± 0.13*† |

*Note:* Mean exercise duration for each condition: CON 120 min, NBCwoV 103.6 min, and NBCwV, 115.9 min.

[A]n, Subject numbers by measured exercise intervals.

[B]Represents the mean esophageal temperature measured at the end point of exercise due to volitional fatigue or at completion of the 120 min of exercise.

§, Is significantly different from NBC suit plus ice vest (NBCwV).

†, Is significantly different from NBC suit only (NBCwoV).

*, Values are significantly different from shorts only (CON).

Heart rate increased consistently throughout exercise for all trials ($p < 0.05$) (**Table II**). HR values were significantly lower for CON compared with both NBCwoV and NBCwV between 50 and 120 min of exercise ($p < 0.05$). HR was significantly lower during the NBCwV condition compared with NBCwoV from 60-100 min of exercise ($p < 0.05$). Further, no differences in end-exercise HR were measured between NBCwV and NBCwoV; however, these values remained significantly elevated from CON.

**TABLE II Mean (±SE) Heart Rate Response**

| **Time** | **n[A]** | **CON** | **n[A]** | **NBCwoV** | **n[A]** | **NBCwV** |
|---|---|---|---|---|---|---|
| Baseline | 10 | 65 ± 4 | 10 | 62 ± 5 | 10 | 64 ± 5 |
| 30 | 10 | 99 ± 4 | 10 | 109 ± 9 | 10 | 111 ± 7 |
| 40 | 10 | 102 ± 4 | 10 | 120 ± 9 | 10 | 118 ± 7 |
| 50 | 10 | 101 ± 5†§ | 10 | 125 ± 9* | 10 | 122 ± 8* |
| 60 | 10 | 104 ± 5†§ | 9 | 137 ± 9*§ | 10 | 126 ± 9*† |
| 70 | 10 | 105 ± 4†§ | 9 | 143 ± 10*§ | 10 | 129 ± 8*† |
| 80 | 10 | 107 ± 5†§ | 9 | 152 ± 8*§ | 10 | 133 ± 9*† |
| 90 | 10 | 109 ± 6†§ | 9 | 157 ± 9*§ | 9 | 140 ± 8*† |
| 100 | 10 | 113 ± 6†§ | 6 | 159 ± 6*§ | 9 | 147 ± 8*† |
| 110 | 10 | 116 ± 7†§ | 6 | 164 ± 7* | 9 | 155 ± 8* |
| 120 | 10 | 120 ± 6†§ | 4 | 166 ± 7* | 9 | 159 ± 7* |
| Exposure Limit[B] | 10 | 120 ± 6†§ | 10 | 169 ± 6* | 10 | 159 ± 7* |

*Note:* Mean exercise duration for each condition: CON 120 min, NBCwoV 103.6 min, and NBCwV 115.9 min.

[A]n = subject numbers by measured exercise intervals.

[B]Represents the mean heart rate measured at the end point of exercise due to volitional fatigue or at completion of the 120 min of exercise.

†, Significantly different from NBC suit only (NBCwoV).

§, Significantly different from NBC suit plus ice vest (NBCwV).

*Values significantly different from shorts only (CON).

The ratings for thermal sensation were significantly lower in CON compared with NBCwV (between 50 and 120 min) and NBCwoV (between 40-120 min) during the mid- to late stages of the 2-hr exercise bout ($p < 0.05$). A greater thermal sensation was measured between NBCwoV and NBCwV during the mid- to late stages of exercise (i.e., between 70 min and end-exercise, $p < 0.05$). End point ratings of thermal sensation were also significantly different between conditions, with highest values measured during NBCwoV (i.e., 6.4 ± 0.4, 4.8 ± 0.6, and 2.3 ± 0.2 for NBCwoV, NBCwV and CON, respectively, $p < 0.05$) (**Figure 4**).

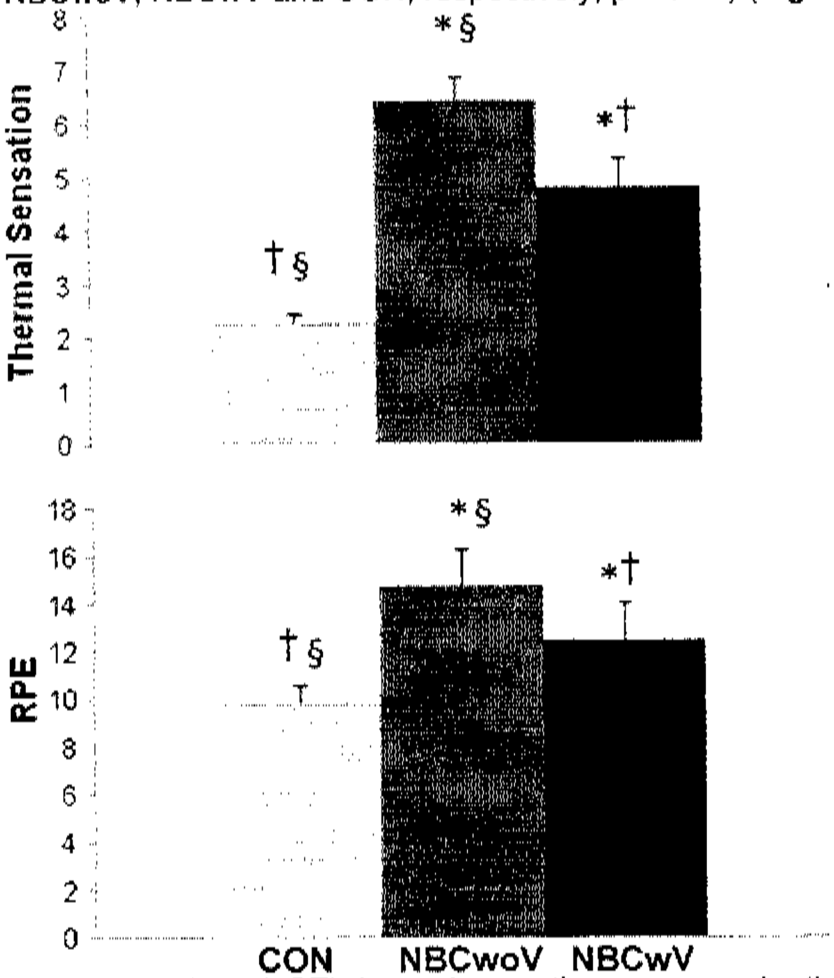


**FIGURE 4** Mean (±SE) thermal sensation scores and ratings of perceived exertion at maximal exposure time for CON (120 min), NBCwoV (103.6 min) and NBCwV (115.9 min). * Indicates values significantly different from CON; § indicates values significantly different from NBCwV; † indicates values significantly different from NBCwoV.

The ratings of perceived exertion were significantly lower in CON compared with NBCwV (i.e., between 10 min and end-exercise) and NBCwoV (between 10 and end-exercise). A greater perceived level of exertion was measured between NBCwoV and NBCwV during the mid- to late stages of exercise (i.e., between 70 min and end-exercise, $p < 0.05$). End point ratings were significantly different between conditions, with values of 14.7 ± 1.6, 12.4 ± 1.6, and 9.8 ± 0.8 for NBCwoV, NBCwV, and CON, respectively ($p < 0.05$) (**Figure 4**).

# DISCUSSION

A key finding of this study was the effectiveness of the commercial CM2000 ice cooling vest in improving tolerance for a prolonged continuous exercise bout under uncompensable heat stress conditions. This was evidenced by lower core temperature and heart rate responses as well as ratings of thermal sensation and perceived exertion. High ambient air temperatures lead to dry heat gain (conductive heat transfer) due to the thermal gradient created between the air and body surface (i.e., $T_{air} > T_{sk}$), while the protective suit impedes evaporative heat loss through sweat.[25] This condition creates an uncompensable heat stress, as the metabolic heat production of exercise cannot be dissipated due to compromised avenues of heat loss.[25] The result is observed in the present study as a steady rise in core temperature and a reduction in the tolerance for exercise. While the cooling vest attenuated the increase in core temperature, it did not completely compensate for the high thermal load, as core temperature continued to rise during its use, albeit at a reduced rate of increase.

## Microclimate Cooling in the Management of Heat Stress

In cases where a particular industrial process does not allow the worker to regulate physical activity (i.e., the work is externally paced) and it is not possible for the environment to be sufficiently modified in order to reduce heat stress risk to an acceptable level, auxiliary cooling garments must be provided to the worker. Studies demonstrate that personal cooling garments can significantly attenuate the rate of rise in core body temperature during work in the heat and, therefore, reduce the risk of heat-related injury. One of the most effective personal cooling systems developed to date has been the water-cooled garments.[26,27] However, this system is typically coupled with a non-portable refrigeration system restricting work activities within range of the unit.[28] Furthermore, the use of water-cooled garments by industry remains costly, inconvenient, and, in many work environments, unfeasible. While both ice vests and cooling garments made of phase change materials are low-efficiency compared with water-cooled garments, they are simple structured, portable, and require no power supply.[28] Some phase change cooling vests may form an ice slush substance and provide conductive/cooling comparable to but not as cold nor as long as ice. However, in contrast to an ice vest, garments made of phase change materials cannot be used where evaporation is restricted, such as during the use of protective clothing or high humidity conditions.[28]

Despite the limited cooling capacity of ice vests, the practical application of ice cooling garments becomes evident through the observation of its effects on the individuals tolerance for prolonged continuous exercise. In the present study, only 4 of 10 participants completed the 2-hr exercise protocol with the NBC protective garment only, whereas 9 of 10 participants completed the full 2-hr work bout when the ice vest was worn under the garment.

The benefit of the ice cooling vest does, however, demonstrate a time-dependent influence. A significant reduction in heart rate and core temperature responses, as well as ratings of perceived exertion and thermal sensation with the use of the ice vest under the NBC suit, were measured only in the mid-stages (i.e., ≥ 60 min) of exercise when compared with the response measured with the NBC suit without the ice vest. This may suggest that for short duration work bouts of low to moderate intensity, the use of ice vests may have limited benefit in reducing the level of thermal strain.

However, it is apparent from our findings that despite the low cooling capacity, ice vests can significantly increase exercise capacity under uncompensable heat stress conditions. We showed an increase in tolerance for exercise when the ice vest is worn under the NBC suit (i.e., a 12% increase in exposure time during NBCwV compared with NBCwoV) which was paralleled by a reduced level of thermal strain as evidenced by a lower end-point core temperature. While heart rate was not significantly lower at the end of exercise with the use of the ice vest, heart rate across time was significantly reduced with the use of the ice vest under the NBC suit compared with the NBC suit alone. The similar level of cardiovascular strain measured at the end point of exercise likely reflects a greater sweat-induced reduction in central blood volume due to the longer duration of exercise performed with the ice vest under the NBC suit compared with the NBC only condition (NBCwoV). Moreover, despite the longer exposure time observed during exercise performed with the ice vest under the NBC suit, both the level of perceived exertion and thermal sensation were reduced with the use of the ice vest compared with the suit-only condition.

The lower perceived level of physical and thermal strain provided by the ice vest, as reported with ratings of perceived exertion and the thermal sensation scale, is an important aspect when considering the nature of much of the work performed in hot environments while wearing protective clothing. Mining, fire fighting, and military tasks are inherently performed in arduous and/or hostile environments, and changes in perceived exertion and thermal sensation are an important consideration when implementing heat stress management strategies. Since heat stress can influence human cognitive function, increasing a worker's comfort may improve awareness and decision-making, and therefore safety.[29,30] Relief of the discomfort caused by the protective clothing can further decrease the risk of an accident.[25] Noteworthy, Aoyagi et al.[31] found that during moderate exercise in heavy protective clothing, training and heat acclimation did not reduce perceived levels of heat stress and exertion. This brings forward the importance of employing simple-structured, portable cooling systems, as they may be one of few cost-effective methods for increasing perceived comfort and reducing the risk of physical and/or thermal injury in these strenuous environments.

It has been shown that during intermittent work, body heat storage and other indices of thermal strain continue to increase progressively across consecutive exercise bouts.(32) In an effort to reduce the progressive strain incurred in these situations, many studies have looked at different strategies for cooling during intermittent rest periods, including fan cooling,(33) hand immersion,(12,18, ,34) and ice vest use.(12) Recent studies show that recovery from dynamic exercise is associated with a rapid attenuation of local skin blood flow and sweating. The result is reduced heat dissipation that is paralleled by a concomitant prolonged elevation in core temperature.(35) It is possible therefore that in addition to attenuating the level of thermal strain during exercise, ice vest cooling could be used as an effective strategy for enhancing the rate of core temperature recovery during the post-exercise period. Bennet et al.(14) demonstrated that an ice vest reduced thermal strain during light intensity intermittent exercise (i.e., two 30-min exercise/rest cycles) performed in warm ambient conditions (34.4°C) while wearing a firefighting ensemble. Moreover, Barr et al.(18) demonstrated immersion of the hand and forearm in cool water (19°C) in combination with the use of an ice vest during recovery between exercise bouts (i.e., two 20-min bouts of exercise separated by a 15-min rest period) was effective in reducing the level of thermal and cardiovascular strain. The potential for dramatic reductions in thermal strain therefore may lie in the integration of a combination of cooling strategies during intermittent work.

### Limitations

A key limitation of this study relates to the young population group employed in this study. Young healthy adults may not be representative of the general industrial work force population. In fact, a recent report stated that only 7% of semiskilled mining occupations in Canada are held by individuals under the age of 30.(36) The issue of aging workers has become an important concern for mining because of a series of layoffs, by seniority, over the past decade. This has taken the younger workers out of the industry and has resulted in a predominantly older work force. Further, the health and fitness of workers is often compromised due to sedentary lifestyles and the changing nature of mining due to mechanization. As a result the prevalence of chronic disease such as Type 2 diabetes has risen dramatically. In light of the fact that age, chronic disease, poor physical fitness, and health conditions increase vulnerability to heat-related illnesses and injuries,(37) it will be increasingly important to examine the benefits of different heat stress prevention and control measures so appropriate safety guidelines can be implemented to provide protection for all workers.

## CONCLUSION

Our findings demonstrate that the CM2000 ice cooling vest or an ice vest with equivalent operating characteristics is an effective strategy in reducing the level of thermal and cardiovascular strain in individuals performing prolonged continuous work (up to 2 hr) in uncompensable heat stress conditions. Future research should focus on the combination of cooling vest methodologies with other cooling techniques (hand immersion, fan cooling) to maximize the reduction of thermal strain during intermittent work bouts in both young and older workers.

## ACKNOWLEDGMENTS

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## List of Figures

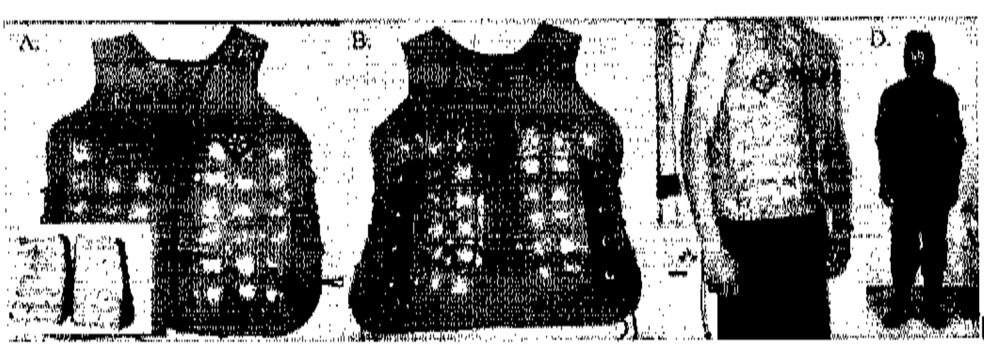


**FIGURE 1**
CM2000 cooling vest and an NBC suit. A. Front view of cooling vest with ice packs (inset); B. Rear view; C. Participant wearing the vest; D. Participant wearing NBC suit

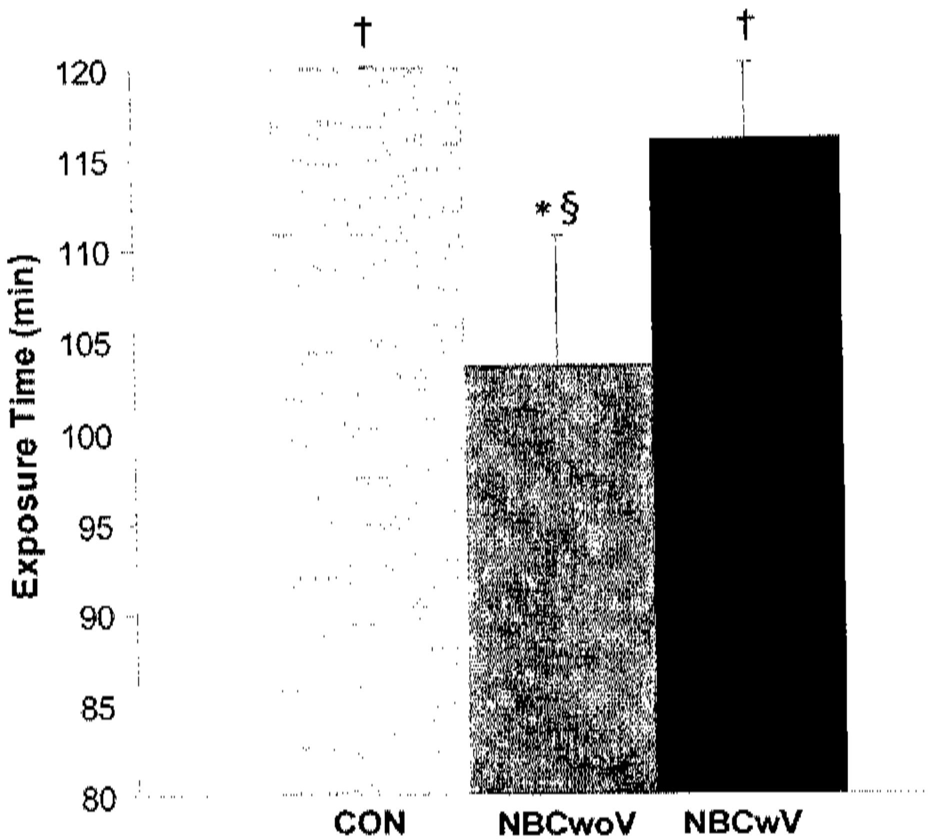


**FIGURE 2** Mean (±SE) exposure time. * Indicates values significantly different from CON; § indicates values significantly different from NBCwV; † indicates values significantly different from NBCwoV

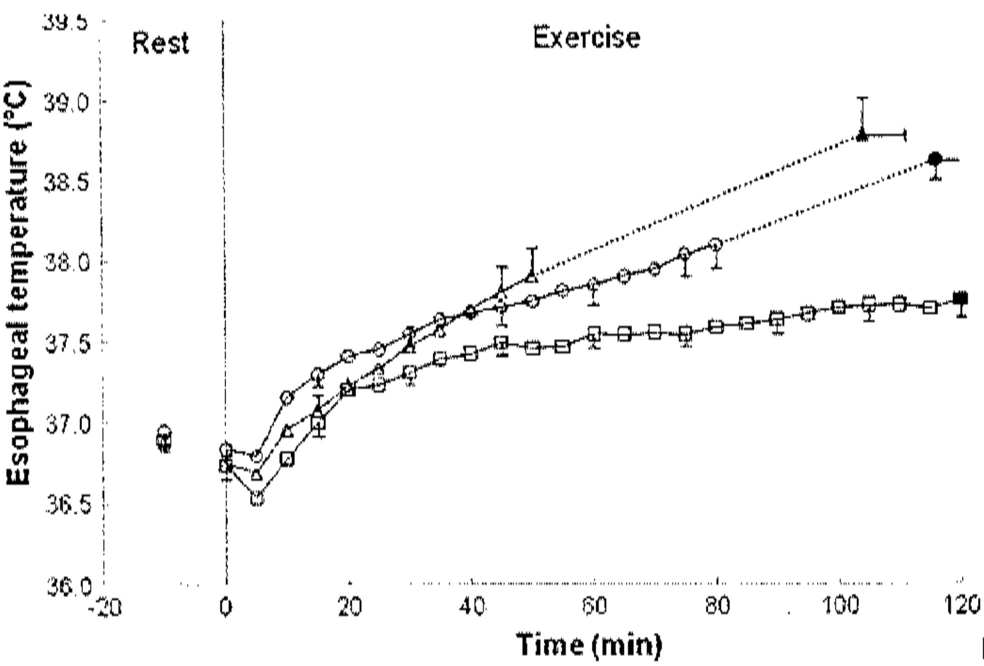


**FIGURE 3** Mean (±SE) esophageal temperature response during baseline and exercise. Solid line with open symbols represents data at exercise intervals common to all participants (n = 10) for CON (□), NBCwoV (▵) and NBCwV (○). Solid symbols indicates mean esophageal temperature at maximal exposure time for CON (▪, 120 min), NBCwoV (▴, 103.6 min), and NBCwV (•, 115.9 min).

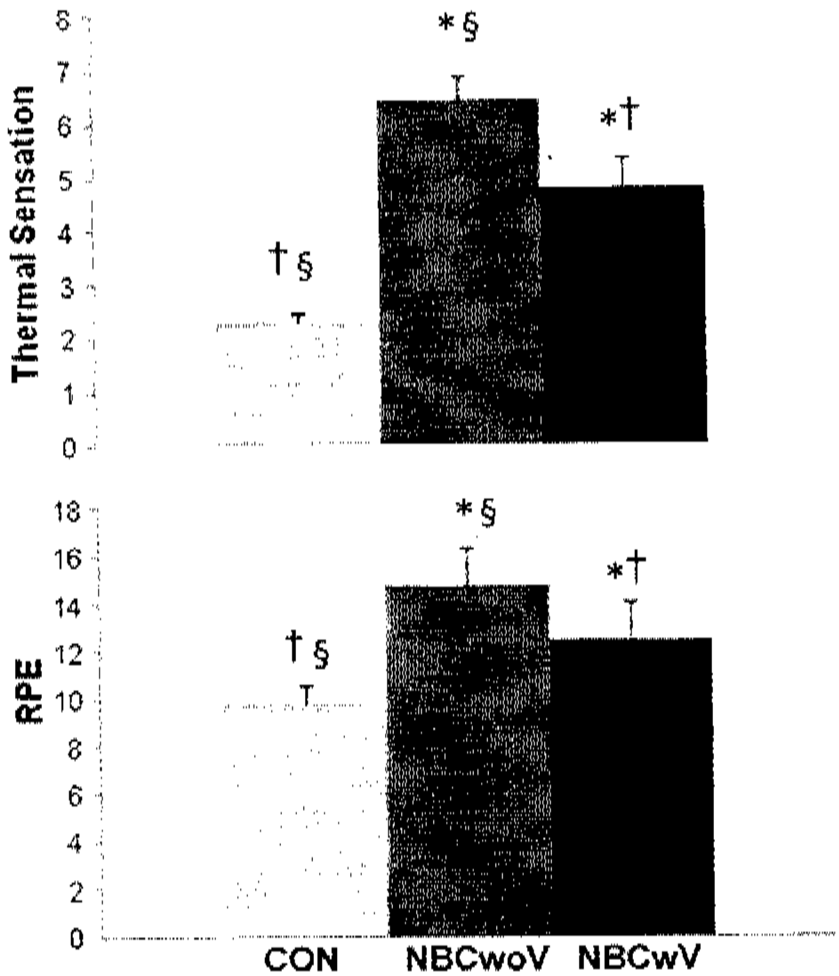


**FIGURE 4** Mean (±SE) thermal sensation scores and ratings of perceived exertion at maximal exposure time for CON (120 min), NBCwoV (103.6 min) and NBCwV (115.9 min). * Indicates values significantly different from CON; § indicates values significantly different from NBCwV; † indicates values significantly different from NBCwoV.

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**TABLE I Mean (±SE) Esophageal Temperature Response**

| Time | $n^A$ | CON | $n^A$ | NBCwoV | $n^A$ | NBCwV |
|---|---|---|---|---|---|---|
| Baseline | 10 | 36.91 ± 0.08 | 10 | 36.88 ± 0.04 | 10 | 36.94 ± 0.08 |
| 30 | 10 | 37.31 ± 0.07§ | 10 | 37.47 ± 0.12 | 10 | 37.55 ± 0.07 |
| 40 | 10 | 37.42 ± 0.08†§ | 10 | 37.70 ± 0.14* | 10 | 37.68 ± 0.09 |
| 50 | 10 | 37.45 ± 0.08†§ | 10 | 37.90 ± 0.17* | 10 | 37.75 ± 0.11* |
| 60 | 10 | 37.54 ± 0.08†§ | 9 | 38.05 ± 0.15* | 10 | 37.85 ± 0.12* |

| | | | | | | |
|---|---|---|---|---|---|---|
| 70 | 10 | 37.55 ± 0.07†§ | 9 | 38.24 ± 0.16*§ | 10 | 37.95 ± 0.13*† |
| 80 | 10 | 37.58 ± 0.07†§ | 9 | 38.50 ± 0.15*§ | 10 | 38.09 ± 0.14*† |
| 90 | 10 | 37.63 ± 0.08†§ | 9 | 38.71 ± 0.18*§ | 9 | 38.09 ± 0.08*† |
| 100 | 10 | 37.70 ± 0.08†§ | 6 | 38.69 ± 0.22*§ | 9 | 38.26 ± 0.09*† |
| 110 | 10 | 37.72 ± 0.09†§ | 6 | 38.80 ± 0.21* | 9 | 38.41 ± 0.12*† |
| 120 | 10 | 37.75 ± 0.10†§ | 4 | 38.97 ± 0.21* | 9 | 38.67 ± 0.12*† |
| Exposure Limit[B] | 10 | 37.75 ± 0.10†§ | 10 | 39.03 ± 0.13*§ | 10 | 38.74 ± 0.13*† |

*Note:* Mean exercise duration for each condition: CON 120 min, NBCwoV 103.6 min, and NBCwV, 115.9 min.

[A]n, Subject numbers by measured exercise intervals.

[B]Represents the mean esophageal temperature measured at the end point of exercise due to volitional fatigue or at completion of the 120 min of exercise.

§, Is significantly different from NBC suit plus ice vest (NBCwV).

†, Is significantly different from NBC suit only (NBCwoV).

*, Values are significantly different from shorts only (CON).

**TABLE II Mean (±SE) Heart Rate Response**

| Time | n[A] | CON | n[A] | NBCwoV | n[A] | NBCwV |
|---|---|---|---|---|---|---|
| Baseline | 10 | 65 ± 4 | 10 | 62 ± 5 | 10 | 64 ± 5 |
| 30 | 10 | 99 ± 4 | 10 | 109 ± 9 | 10 | 111 ± 7 |
| 40 | 10 | 102 ± 4 | 10 | 120 ± 9 | 10 | 118 ± 7 |
| 50 | 10 | 101 ± 5†§ | 10 | 125 ± 9* | 10 | 122 ± 8* |
| 60 | 10 | 104 ± 5†§ | 9 | 137 ± 9*§ | 10 | 126 ± 9*† |
| 70 | 10 | 105 ± 4†§ | 9 | 143 ± 10*§ | 10 | 129 ± 8*† |
| 80 | 10 | 107 ± 5†§ | 9 | 152 ± 8*§ | 10 | 133 ± 9*† |
| 90 | 10 | 109 ± 6†§ | 9 | 157 ± 9*§ | 9 | 140 ± 8*† |
| 100 | 10 | 113 ± 6†§ | 6 | 159 ± 6*§ | 9 | 147 ± 8*† |
| 110 | 10 | 116 ± 7†§ | 6 | 164 ± 7* | 9 | 155 ± 8* |
| 120 | 10 | 120 ± 6†§ | 4 | 166 ± 7* | 9 | 159 ± 7* |
| Exposure Limit[B] | 10 | 120 ± 6†§ | 10 | 169 ± 6* | 10 | 159 ± 7* |

*Note:* Mean exercise duration for each condition: CON 120 min, NBCwoV 103.6 min, and NBCwV 115.9 min.

[A]n = subject numbers by measured exercise intervals.

[B]Represents the mean heart rate measured at the end point of exercise due to volitional fatigue or at completion of the 120 min of exercise.

†, Significantly different from NBC suit only (NBCwoV).

§, Significantly different from NBC suit plus ice vest (NBCwV).

*Values significantly different from shorts only (CON).