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Effectiveness of Ice-vest Cooling in Prolonging Work Tolerance Time During Heavy Exercise in the Heat for Personnel Wearing Canadian Forces Chemical Defence Ensembles

B. Bain

Defence and Civil Institute of Environmental Medicine
1133 Sheppard Ave. W., P.O. Box 2000, North York, Ont.
M3M 3B9

DEPARTMENT OF NATIONAL DEFENCE-CANADA

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Abstract

The effectiveness of a portable, ice-pack cooling vest (Steelevest) in prolonging work tolerance time in chemical defence clothing in the heat (33°C dry bulb, 33% relative humidity or 25°C WBGT) was evaluated while subjects exercised at a metabolic rate of ~700 watts. Six male volunteers were used as subjects. The protocol consisted of a 20 minute treadmill walk at 1.33 $m \cdot s^{-1}$ (4.8 $km \cdot h^{-1}$) and 7.5% grade, followed by 15 minutes of a lifting task, 5 minutes rest, then another 20 minutes of lifting task for a total of one hour. The lifting task consisted of lifting a 20 kg box, carrying it 3 metres and setting it down. This was followed by a 6 metre walk (3 m back to the start point and 3 m back to the box) in 15 sec after which the lifting cycle began again. The work was classified as heavy as defined in a previous paper (McLellan et al (5)). This protocol was repeated until the subjects were unable to continue or they reached a physiological endpoint. The time to voluntary cessation or physiological endpoint was called the work tolerance time. Physiological endpoints were rectal temperature of 39°C, heart rate exceeding 95% of maximum for two consecutive minutes or visible loss of motor control or nausea. The cooling vest had no effect on work tolerance time, rate of rise of rectal temperature or sweat loss. Work tolerance time without cooling averaged 39.6 ± 9.9 minutes compared with 44.3 ± 17.8 minutes with cooling (mean ± SD). It was concluded that the Steelevest ice-vest is ineffective in prolonging work tolerance time and preventing increases in rectal temperature in the above conditions while wearing chemical protective clothing.

Background

With the deployment of Canadian Forces personnel to the Middle East, the question of the effects of heat stress on personnel performance has become a major concern. In addition to the obvious environmental stress, there is also the very serious threat of use of chemical agents as weapons. This threat requires that personnel be prepared to work in chemical defence (CD) protective clothing. It is known that protective clothing of this type exacerbates environmental heat stress by hindering the body's prime mode of heat loss, that is evaporation of sweat and thus may impede performance. Performance decrements while wearing chemical defence equipment have been well documented by several authors. For example, Fine et al (1) assessed the performance of soldiers in chemical defence ensembles who were required to perform artillery-type tasks (eg. fire direction, communications, forward observation, etc.), none of which required intense physical exertion. Environmental conditions were 91°F (33°C), 61% R.H.. The authors concluded that performance decrements could be expected to take place in as little as three hours in the field. Carter et al (2) reported five heat related casualties among 195 hospital personnel during a simulated chemical warfare scenario at a WBGT of 76-78°F (25°C). Personnel were dressed in full U.S. Army chemical defence ensembles during this exercise. Four of the five casualties occured during periods of heavy physical activity. Duggan (3) found that the cost of stepping up and down on a stool 0.31 metres high was increased by about 8% when wearing CD ensembles compared to wearing combat fatigues alone. The author indicated that metabolic heat production at this level would quickly result in overheating. In a study evaluating performance of Australian soldiers wearing combat clothes and various CD ensembles in two environmental conditions, Tilley et al (4) concluded that in hot, humid conditions (in this case 30°C, 60-65% R.H.) soldiers would be able to do little in daylight hours while wearing full CD ensembles without incurring severe heat casualties. In a previous study at this institute (McLellan et al (5)), we found that work tolerance times decreased dramatically when CD equipment was worn during work in the heat when compared to tolerance times in regular combat clothing. This was especially true at higher workloads. One method of solving or at least ameliorating the heat stress on personnel is to provide personal cooling to those who are required to work in this extreme environment.

Recently, the Environmental Physiology Section at DCIEM was asked by Director Nuclear Biological Chemical Coordination (DNBCC) to conduct an evaluation of the Steelevest ice-pack cooling vest in order to determine its effectiveness in slowing the rise of core temperature during heat stress and, in so doing, prolong work tolerance times under these conditions while wearing full CD protection. The Steelevest (Steele Inc., Kingston, WA, USA) covers the torso area to just below the hips. Cooling is provided by six gel-pack strips, three in the front and three in the back. The strips are inserted into special horizontal pockets on the vest. The vest holds these strips snugly against the torso thus ostensibly providing conductive cooling.

Methods

Subjects

The subjects for this experiment were six males, 28-42 years of age. All subjects were examined by a medical officer prior to the experiment and were required to sign a form indicating that they had been fully briefed by the investigator and voluntarily gave their informed consent.

Protocol

Subjects were exposed to two trials in the environmental chamber, one without the cooling vest and one with the vest. The environmental conditions were 33°C, 33% relative humidity or 25°C WBGT. Subjects wore the standard Canadian Forces CD coverall, mask, butyl rubber gloves and boots over combat clothing. The cooling vest was worn under the combat shirt but over a light t-shirt. The t-shirt was worn for comfort and protection as, initially, the vest was extremely uncomfortable if worn directly against the skin. The trials were at least 24 hours apart and were conducted at the same time of day for each subject to control for circadian influences. The trials were also counter-balanced and the subjects had no advanced knowledge of the order in which the trials would be performed. The subjects performed "heavy" work as defined in a previous study (McLellan et al (5)). The work consisted of a 20 minute treadmill walk followed by 15 minutes of a lifting task, 5 minutes of rest and another 20 minutes of lifting. If the subjects completed this 60 minute schedule, a second work schedule began with the 20 minute treadmill walk. The subjects continued until they reached one of the endpoints defined below or until three hours had elapsed. The treadmill was set at a speed of 1.33 $m \cdot s^{-1}$ (4.8 $km \cdot h^{-1}$) and 7.5% grade. The lifting task consisted of carrying a 20 kg weight 3 metres, walking 6 metres (3 metres back to the start point and 3 metres back to the box) and then lifting and carrying the weight again and so on, with each cycle (from one lift to the next) taking 15 seconds. Rectal temperature (T_{re}) and heart rate (HR) were recorded every 15 minutes throughout the trial except when it was obvious that one or both variables were approaching the critical value for termination of the test in which case they were monitored continuously. Final HR and rectal temperature were recorded when subjects exited the chamber. Rectal temperature was measured using a rectal thermister (Yellow Springs Instruments) inserted 12 cm beyond the anal sphincter. Heart rate was monitored using a Sportstester heart rate monitor (Polar Electro, Finland). Metabolic rate was measured during the last 5 minutes of the treadmill walk using open circuit spirometry (Horizon, Sensormedics Co., Anaheim CA.). Nude and dressed weights were measured before and after each trial in order to estimate sweat loss using an electronic scale accurate to 0.01 kg. Evaporative efficiency was calculated as the pre- minus post-trial dressed weight divided by the pre- minus post-trial nude weight multiplied by 100. Other variables calculated were rate of rise of rectal temperature, change in core temperature from time zero (enter chamber and begin exercise) and rate of sweat loss.

The trial was terminated when any of the following behavicural or physiological endpoints were reached:

rectal temperature exceeded 39°C;
heart rate exceeded 95% of the predicted maximum for the subject for two consecutive minutes; or
the subject indicated he could not continue or was nauseous or disoriented.

The physiological endpoints are determined and approved by the DCIEM Ethics Review Committee.

Data were analysed using paired t-tests. Significance was accepted at the 0.05 level.

Results

The raw data for all the measured and calculated variables are reported in Table 1.

Work tolerance time was not significantly improved by the cooling vests. Mean tolerance times were 39.6 ± 9.9 minutes without cooling and 44.3 ± 17.8 minutes (mean ± SD) when the cooling vest was worn. None of the subjects reached the three hour maximum time limit. In fact, the longest time was only 70 minutes. There were also no differences in the change in rectal temperature (T_{re}), rate of rise of T_{re}, body weight loss, evaporative efficiency or rate of sweat loss. Change in rectal temperature averaged 1.5 ± 0.3 $°C \cdot h^{-1}$ without or without cooling. Similarly, the rate of rise of rectal temperature was 2.3 ± 0.28 $°C \cdot h^{-1}$ without cooling versus 2.2 ± 0.55 $°C \cdot h^{-1}$ with the cooling vest. Weight loss averaged 1.4 ± 0.79 kg without versus 1.05 ± 0.54 kg with cooling and rate of sweat loss amounted to 1.6 ± 0.53 $L \cdot h^{-1}$ without the vest and 1.4 ± 0.23 $L \cdot h^{-1}$ with the cooling vest. Finally, the evaporative efficiency was similar for both cooling and no cooling trials (30% for no cooling, 36% with cooling).

Discussion

The work tolerance times and values for variables such as the change in rectal temperature, rate of core temperature rise and sweat rate in the no cooling condition found in this study are similar to those we have reported in another experiment (McLellan et al (5)). In that experiment, subjects were dressed in three levels of protective clothing; Topp Low (combat fatigues only), Topp Medium (chemical protective garment over top of the combat clothing without the gas mask, gloves or boots) and Topp High (complete coverage by chemical gear ie mask, gloves and boots). In the present study the dress corresponded to Topp High, the work rate was the same as that which was defined as "heavy" in the previous study and environmental conditions were similar to the "hot" condition although relative humidity in this experiment was 33% vs 50% in the previous study. The results are remarkably similar. For example, in the previous study work tolerance time averaged 34 minutes in the above conditions vs 39 minutes in the present study. Similarly, the rate of rise of rectal temperature was 2.6 $°C \cdot h^{-1}$ vs 2.3 $°C \cdot h^{-1}$ in the present study. Rate of fluid loss was also similar between the two experiments (both approximately 1.5 $L \cdot h^{-1}$).

It is apparent from the results that the Steelevest cooling vest is not effective in extending work times under the above environmental conditions and work rates when subjects are dressed in chemical protective clothing. These vests have previously been found to be effective in extending performance times in the heat (Pimental and Avellini (6)), however, the subjects in that study were not wearing chemical protective clothing and the work rate was not as high as in the present experiment (~60 vs 175 watts). In addition, the subjects in the above study were heat acclimated for two weeks prior to the test exposures which would undoubtedly have been of great benefit in that scenario where evaporative heat loss was possible. Their subjects were also encouraged to drink as much water as possible. The availability of water, the heat acclimation and the ability to evaporate sweat would likely account for the fact that, despite the extreme conditions (46°C dry bulb, 45% relative humidity), three out of eight subjects were able to complete the three hour heat exposure without any cooling at all. Chemical defence clothing, however, in addition to providing significant insulation, is only semi-permeable to water vapour. Because of this characteristic of the clothing fabric, the subjects in the present study were unable to remove body heat via evaporation. This is indicated by the low evaporative efficiency values (30 -36%). This will have great impact on the ablility to tolerate heat stress as evaporative cooling is the main avenue for heat loss from the body during exercise (Astrand and Rodahl (7)).

Because the vest simply covers the torso and can only remove heat through conduction, it is probably not able to remove enough heat from the body at the work rates used in this experiment, especially when combined with the increased heat entrapment provided by the chemical protective suit.

In summary, the effectiveness of a portable ice-pack cooling vest (Steelevest) in prolonging work tolerance time was evaluated at a temperature of 33°C dry bulb, 33% relative humidity (25°C WBGT) using six male subjects wearing chemical protective clothing. Metabolic rate averaged aproximately 700 watts. Under the above conditions, the cooling vest was ineffective in prolonging work tolerance time and did not affect the response of rectal temperature or sweat loss.

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Table 1- Raw Data

Subject	Change in Rectal Temp-(°C)-NC	Change in Rectal Temp-(°C)- Cool	Rate of Rise of Tre-(°C/h)-NC	Rate of Rise of Tre-(°C/h)- Cool	Wt Loss- (Kg) NC	Wt Loss-(Kg) Cool
DB	2	1.6	2.26	1.52	1.75	1.81
SR	1.1	1.3	2.44	2.51	0.66	0.55
JM	1.3	1.1	1.81	2.2	0.85	0.71
FT	1.6	1.8	2.52	2.63	2.72	0.8
BB	1.8	1.8	2.29	1.54	1.44	1.69
TM	1.3	1.4	2.6	2.8	0.76	0.76

Subject	%Evaporative Efficiency- NC	%Evaporative Efficiency- Cool	Sweat Loss- (L/h) NC	Sweat Loss-(L/h) Cool	Tolerance time- (min)- NC	Tolerance Time- (min)- Cool
DB	31.1	30	1.836	1.446	53	63
SR	33.7	23.7	1.98	1.722	27	31
JM	19.7	36.3	1.464	1.062	43	30
FT	43.5	15.5	1.188	1.422	38	41
BB	9.2	46.2	4.296	1.2	47	70
TM	43.4	67	1.52	1.52	30	31

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