NAVAL HEALTH RESEARCH CENTER

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SUMMARY

Problem.

Heat strain associated with firefighting training and shipboard firefighting is a significant problem for naval personnel. Firefighting in the heavily insulated protective ensemble prevents heat dissipation, while exposure to high heat and steam in a firefighting compartment accelerates heat gain. Consequently, an effective microclimate cooling system is necessary to prevent heat illness and improve firefighting performance. Previous laboratory studies suggest that torso cooling using a 6-pack vest reduces heat strain. However, few studies exist on the effectiveness of cooling vests of different sizes in reducing heat strain when worn under the firefighting protective ensemble during rest and exercise in an environment high in heat and humidity. Size constraints of the single-piece standard Navy firefighting ensemble warrant investigation of a smaller and lighter vest.

Objective.

The primary objective of this study was to evaluate the effectiveness of two different-sized (4-pack vs. 6-pack) cooling vests in reducing heat strain in men resting and exercising in a hot/humid environment.

Approach.

Laboratory tests were conducted in an environmental chamber with ambient conditions of 94 ± 0.9°F dry bulb, 84 ± 0.5°F wet bulb, 65% relative humidity (RH), and 87 ± 0.5°F wet bulb globe temperature. Male volunteers (n=12) experienced in the use of firefighting protective equipment were monitored for rectal temperature (T_{re}), weighted mean skin temperatures (T_{msk}), heart rate (HR), energy expenditure (watts), ratings of perceived exertion (RPE), and thermal sensation (TS). All subjects participated in three tests under the following conditions: control (no cool vest), 4-pack (60 oz) gel pack cool vest, and a 6-pack (162 oz) gel pack cool vest. The cool vests were worn under the firefighting ensemble and over Navy dungarees. The heat exposure protocol consisted of two cycles of 30 min seated rest and 30 min walking on a motorized treadmill at 2.5 mph and 0% grade.

Results.

The tolerance time for the control condition (92.8 ± 19.9 min) was significantly less than both vest conditions (120 ± 0 min). Wearing a cool vest was associated with lower rates of increase in core and skin temperatures. The rates of increase in T_{re} were 1.2 ± 0.19°C·hr^{-1}, 0.76 ± 0.17°C·hr^{-1}, and 0.41 ± 0.14°C·hr^{-1} for control, 4-pack, and 6-pack vest conditions, respectively. The rate of rise in T_{msk} exceeded the rise in core temperature in all conditions and ranged from 1.4°C·hr^{-1} for a 6-pack vest to 2.1°C·hr^{-1} for control. Peak values for body temperature were also lower with the cooling vest. Peak core temperature values were 38.9 ± 0.5 °C, 38.6 ± 0.4°C, and 38.0 ± 0.3°C for control, 4-pack, and 6-pack vest conditions, respectively. The respective peak mean skin temperature (T_{msk} Peak) values for control, 4-pack, and 6-pack vests were 38.4 ± 0.5°C, 38.1 ± 0.5°C, and 36.8 ± 0.7°C. Also, the rate of body heat storage (HS) was significantly different among the conditions. The respective rates were 48.5 ± 7.0, 35.0 ± 7.4, and 22.4 ± 5.7 watts·m^{-2} for control, 4-pack, and 6-pack vest conditions, respectively. Energy expenditure varied in response to the rest/exercise cycles, but was similar among all conditions. HR corresponded to changes in energy expenditure, however during the second rest/exercise cycle HR was significantly higher for control, followed by a lower HR for the 4-pack and by the lowest HR for the 6-pack vest conditions.

Conclusions.

The two cool vests significantly increased tolerance time during rest and exercise in a hot/humid environment. Under these environmental conditions, a cool vest worn over the torso prevents excessive increases in T_{re} and T_{msk}, HR, and HS. The 4-pack and 6-pack vests provided comparable cooling during the first hour of heat exposure; however, the 6-pack vest resulted in significantly lower core and skin temperatures, HRs, and HS at the end of exposure. Wearing a cool vest can potentially reduce the risk of heat illness and improve performance of damage control personnel wearing the firefighting ensemble.

INTRODUCTION

Understanding the impact of heat strain on the performance of naval personnel has important application to shipboard fire-suppression activities. Firefighting is associated with heat strain as demonstrated by large increases in skin and core temperatures and near maximal heart rates (Duncan et al., 1979; Romet and Frim, 1987; Bennett et al., 1992). These responses can be attributed to body heat production caused by wearing 30 to 40 pounds of personnel protection equipment, the physical effort associated with carrying equipment (e.g., fire hose, ventilation fans), and the heat gain due to exposure to high ambient temperatures and humidity.

Evidence supports the use of microclimate cooling systems as a countermeasure to heat strain (Speckman et al., 1988). The benefits of microclimate cooling are documented in Air Force ground crews (Terrian and Nunneley, 1983), helicopter crews (Banta and Braun, 1992), shipboard personnel working in high-heat areas (Janik et al., 1987), and armored vehicle crew and soldiers wearing chemical protection overgarments in the heat (Speckman et al., 1988; Muza et al., 1988). However, microclimate cooling systems using air- or water-cooled undergarments may not be practical for shipboard firefighters. Pimental et al. (1991) reported that a passive cool vest employing frozen gel blocks worn under the firefighting protective ensemble was an effective countermeasure to heat strain during rest and exercise. However, they evaluated only a large 6-pack cool vest since their primary purpose was to compare heat strain while wearing the firefighting ensemble in different configurations. Consequently, due to the size constraints of the single-piece firefighting ensemble, it is necessary to determine if a smaller and lighter 4-pack cool vest can provide cooling comparable to the 6-pack vest. Therefore, the purpose of this study was to compare differences in the heat strain reduction of two different-sized gel pack cool vests with a no vest condition (control) in naval firefighters performing rest and exercise cycles in a hot/humid environment.

METHODS

Subjects.

Twelve males served as subjects and all were experienced in the use of firefighting protection equipment. Nine of the twelve subjects worked in a hot environment five days a week. The amount of time daily spent in this environment ranged from one to six hours. Three subjects did not work in a hot environment. The physical characteristics of the subjects are presented in Table 1.

Table 1. Physical characteristics of the subjects.

Subject	Age (yrs)	Height (cm)	Weight (kg)	BSA (m^2)	Body Fat (%)
1	32	174.0	64.0	1.77	12.4
2	21	175.3	68.8	1.85	17.0
3	20	172.7	57.4	1.68	10.0
4	22	172.7	65.4	1.78	14.7
5	27	165.1	65.5	1.73	15.7
6	23	180.3	71.4	1.90	14.2
7	29	172.7	70.1	1.83	20.0
8	26	165.1	84.2	1.91	23.0
9	24	179.1	79.2	1.99	24.0
10	27	194.3	66.6	2.40	22.7
11	25	177.8	82.2	2.00	21.5
12	27	171.4	66.6	1.79	17.2
Mean±SD	25.3±3.5	175.0±7.7	74.0±13.7	1.88±.2	17.7±4.5

BSA = body surface area (m^2)

Medical Screening.

Each subject gave his informed consent prior to participation in testing. All subjects underwent medical screening which included a medical history questionnaire, body composition assessment, and resting electrocardiogram (ECG). Body surface area (m^2) was calculated according to the height and weight regression equation of DuBois (Carpenter, 1964). A U.S. Navy regression equation was used to calculate percent body fat using height and circumference measures of the neck and abdominal region (Hodgdon and Beckett, 1984).

ECG electrodes were placed on each subject's chest in the area of the heart (Mason-Liker configuration). Two electrodes were placed on the upper chest near the shoulders, and two others on the waist toward the sides of the body. Six electrodes were also placed on the chest around the lower border of the left chest. Resting ECGs and blood pressures (BP) were taken in supine, seated, and standing conditions. All subjects completed an incremental treadmill exercise test to voluntary exhaustion (Bruce protocol). Maximum HR was determined as the highest HR obtained during the test. Throughout recovery, the subject's HR and BP were monitored until they returned to resting values.

Experimental Procedures.

The previous night and the morning of the heat-exposure test, subjects were instructed to drink generous amounts (32 oz) of fluid (noncaffeinated beverages) to ensure normal body hydration. Urine was collected prior to testing for measurement of specific gravity to determine body fluid level.

The heat exposure protocol consisted of two cycles of 30 min seated rest, and 30 min walking on a motorized treadmill at 2.5 mph and 0% grade. The ambient environment during heat exposure was 94 ± 0.9°F dry bulb, 84 ± 0.5°F wet bulb, 87 ± 0.5°F wet bulb globe temperature, and 65% RH.

All subjects participated in three different tests with the following conditions: no vest (control), 4-pack cool vest, and a 6-pack cool vest with the vest worn under the firefighting ensemble. The tests were administered in random order. During each test, subjects wore a T-shirt, long-sleeved cotton shirt, jeans (Navy dungarees), socks, and boondocker boots as the basic undergarment. In the cool-vest trials, the vest was worn over this clothing ensemble and under the protective overgarment. The cool vests (Steele, Inc., Kingston, WA 98346) contained either four or six frozen gel thermostrips, weighing 15 oz and 27 oz, respectively, which were kept frozen at -28°C until use. The 6-pack vest had three frozen gel strips placed horizontally across the front of the vest in separate pockets, and three corresponding strips across the back. The 4-pack had two strips placed vertically on the front, and two strips placed horizontally on the back. Each pocket of the two vests was externally insulated with Thinsulate to keep the thermostrips cool. During each test, the subjects wore the standard Navy-issue damage control gear: flash hood, helmet, gloves, single-piece Nomex firefighting ensemble, and an oxygen breathing apparatus.

Prior to each heat exposure, subjects inserted a rectal thermistor to a depth of 20 cm in the rectum. Skin thermistors were placed over the right shoulder, upper right chest, midlateral thigh, and midlateral calf. Three ECG electrodes were placed on the chest to monitor HR. T_{re}, T_{msk}, and HR were recorded at 1-min intervals by a portable Squirrel data logger (Science/Electronics, Miamisburg, OH 45342) worn outside the ensemble. HR was also recorded by a Polar Heartwatch system (Polar, USA, Inc., Stamford, CT 06902). Pre- and post-nude body weights as well as fluid intake and output were recorded to determine change in body weight.

In addition, subjects were asked to rate their perception of physical exertion and TS at 15-min intervals. RPE were determined from the Borg 15-point scale (6 to 20) (Borg, 1985). The scale ranged from very very light (6) to very, very hard (20) physical exertion. For the ratings of TS, an eight-point scale (1 to 8) was used which ranged from unbearably cold (1) to unbearably hot (8) (Young, 1987). Ratings of TS included an overall body rating, as well as five local body areas (head, neck, chest, arms, and legs).

Energy expenditure was measured once during each rest and exercise period at minutes 15, 45, 75, and 105. The helmet and oxygen breathing apparatus were removed and the subject's expired air was collected for two minutes in a meteorological balloon in series with a mouthpiece and two-way valve. During these periods, subjects were allowed to drink as much water as desired to minimize the effects of dehydration. Expired oxygen and carbon dioxide concentrations were measured by gas analyzers (Med-Graphics Metabolic System), and gas volume was determined by a 120-liter Tissot tank.

After their final session, all subjects completed a questionnaire concerning their perception of the benefits and limitations of using the cool vests during firefighting.

The following criteria were used for removal of the subject from heat exposure: T_{re} of 103.1°F; systolic BP of 220 mm Hg or diastolic pressure of 120 mm Hg; HR of 85% of predicted maximum or greater for 20 min; absence of sweating or presence of chills, nausea, weakness, or dizziness; or subject desiring to terminate heat exposure.

T_{msk} was calculated as the average of four skin temperatures using a weighted regression equation (Ramanathan, 1964). Mean body temperature (T_{mb}) was calculated according to a weighted regression equation (Stolwijk and Hardy, 1966) using T_{re} and T_{msk}. Body heat content (BHC) was calculated using T_{mb}, body weight in kilograms, and the specific heat of the body (0.83 $kcal \cdot kg \cdot {}^{o}C^{-1}$). Heat storage (HS) ($kcal \cdot kg^{-1}$) equaled the difference in BHC from resting to peak values. The rate of HS was calculated as the change in BHC ($kcal \cdot m^{-2} \cdot hr^{-1}$ and $watts \cdot m^{-2}$) over time.

The average total body sweat loss was calculated as the difference between pre- and post-body weight, corrected for fluid input and output. Fluid balance ($l \cdot hr^{-1}$) was calculated using the fluid intake, fluid output, and sweat rate.

Statistical Analysis.

Data was statistically analyzed by a repeated measures analysis of variance with two factors, time and condition. Comparison of means was achieved using 95% confidence intervals. Complete data were analyzed through the second rest period. Repeated measures analysis of variance was also done through the second exercise period, however only six control group subjects were included in the analysis due to reduced tolerance time. Significance is reported at $p<0.05$.

RESULTS

Heat Exposure Tolerance Time.

The tolerance time for the control group was significantly less than both vest conditions. The mean (± SD) tolerance time was 92.8 ± 19.9 min for the control condition. Six subjects completed between 68 and 84 min, three subjects completed between 99 and 101 min, and three subjects completed 120 min. All subjects with vests completed 120 min of heat exposure.

Energy Expenditure and HRs.

Energy expenditure (watts) varied with rest and exercise, but was similar ($p>.05$) among conditions (Table 2).

Table 2. Energy expenditure (watts) during rest and exercise periods.

	Rest I	Exercise I	Rest II	Exercise II
Control (no vest)	105 ± 28 n = 12	420 ± 70* n = 12	138 ± 24 n = 9	410 ± 40* n = 3
4-pack vest	97 ± 12 n = 12	414 ± 86* n = 12	110 ± 18 n = 12	432 ± 72* n = 12
6-pack vest	90 ± 47 n = 12	426 ± 88* n = 12	104 ± 24 n = 12	432 ± 100* n = 12

* = Significantly higher than rest($p<.05$)

There was a significant ($p<.05$) effect of time and condition on HR. The cyclical HR response paralleled energy expenditure over the rest and exercise cycles. There was no significant difference in HR among the three conditions during the first rest/exercise cycle. However, during the second rest period HR was significantly ($p<.05$) different among the conditions. At 90 min, HRs were 129 ± 12, 103 ± 15, and 84 ± 8 beats per minute (bpm) for control, 4-pack vest, and 6-pack vest conditions, respectively. At the end of the second exercise period, the 6-pack vest had a significantly ($p<.05$) lower HR than either control or 4-pack vest conditions (170 ± 15, 169 ± 15, and 148 ± 15 bpm for control, 4-pack and 6-pack vests, respectively). The average HR response for all conditions over time is shown in Figure 1.

Body Temperatures and HS.

For T_{re}, T_{sk}, and T_{mb}, there was a net increase over time which differed among the three conditions. The body temperatures increased progressively during the exercise periods for all conditions. During the rest period, body temperatures continued to increase, plateau, or decrease, depending upon the condition. At the end of the first exercise period, control had a significantly higher T_{re} than the 6-pack vest, and during the second rest, T_{re} was significantly different among all conditions (38.5 ± 0.3, 37.8 ± 0.4, and 37.4 ± 0.2 °C for control, 4-pack, and 6-pack, respectively). The same trend continued through the final exercise period with T_{re} remaining significantly different among the groups. The rates of increase in T_{re} were 1.2 ± 0.19, 0.76 ± 0.17, and 0.41 ± 0.14 °C·hr^{-1} for control, 4-pack, and 6-pack vest conditions, respectively. The average T_{re} response over time for each condition is plotted in Figure 2.

At the end of the first exercise period, T_{msk} was significantly different among all conditions. Control had the highest T_{msk}, followed by the 4-pack and 6-pack vest conditions, respectively. This trend continued throughout heat exposure with significant differences among groups during the second rest/exercise cycle. The rate of rise in T_{msk} exceeded the rise in T_{re} for all conditions and were 2.1 ± 0.36, 1.8 ± 0.43, and 1.41 ± 0.44 °C·hr^{-1}, for control, 4-pack, and 6-pack, respectively. The T_{msk} response over time is plotted in Figure 3. **Convergence of T_{re} and T_{msk} occurred in seven of the twelve subjects during the control condition, and in two of twelve subjects during the 4-pack vest condition. During the 6-pack vest condition, no subjects experienced convergence of core and skin temperatures.**

T_{mb} was significantly ($p<0.05$) different among the conditions during the first exercise and second rest/exercise cycle (Figure 4). The rates of increase in T_{mb} were 1.3 ± 0.20, 0.93 ± 0.18, and 0.60 ± 0.15 °C·hr^{-1} for control, 4-pack, and 6-pack vest conditions, respectively.

The peak T_{re}, T_{msk}, and T_{mb} as well as HR are shown in Table 3. The peak values in both vest configurations occurred at the end of heat exposure (120 min). For the control condition, with the exception of HR, peak values also occurred at the termination of heat exposure, with termination times ranging from 68 to 120 min. Peak HR for the control condition occurred during the first exercise period (30 to 60 min) for six subjects, and the second exercise period (90 to 120 min) for the remaining six subjects.

Table 3. Peak rectal temperature (T_{re}), weighted mean skin temperature (T_{msk}), mean body temperature (T_{mb}), and heart rate (HR) responses during heat exposure.

	T_{re} Peak (°C)	T_{msk} Peak (°C)	T_{mb} Peak (°C)	HR Peak (bpm)
Control	38.9 ± 0.5*	38.4 ± 0.5*	38.7 ± 0.5*	166 ± 14*
4-pack vest	38.6 ± 0.4*	38.1 ± 0.5*	38.4 ± 0.4*	169 ± 16*
6-pack vest	38.0 ± 0.3	36.8 ± 0.7	37.7 ± 0.3	148 ± 15

* = Significantly higher than 6-pack ($p<.05$)

Heat exposure produced average heat storage values of 1.48 ± 0.29 and 0.93 ± 0.23 $kcal \cdot kg^{-1}$ for the 4-pack and 6-pack vest configurations, respectively (Figure 5). For the control condition, the average HS was 1.27 ± 0.30, 1.88 ± 0.27, and 2.25 ± 0.17 $kcal \cdot kg^{-1}$ for tolerance times of 68 to 84 min, 99 to 101 min, and 120 min, respectively (Figure 5). The rate of HS over the entire heat exposure was significantly ($p<0.05$) different among the conditions. The respective rates were 48.5 ± 7.0, 35.0 ± 7.4, and 22.4 ± 5.7 $watts \cdot m^{-2}$ for control, 4-pack, and 6-pack vest conditions, respectively. The rates of HS during individual rest and exercise cycles were also significantly different among conditions (Table 4).

Table 4. Rates of Body Heat Storage (HS) ($watts \cdot m^{-2}$) during rest and exercise in the heat.

	Rest I	Exercise I	Rest II	Exercise II
Control (no vest)	13.4 ± 15.9* n = 12	71.6 ± 12.8* n = 12	53.2 ± 20.6* n = 12	55.1 ± 14.3 n = 6
4-pack cool vest	11.4 ± 11.8* n = 12	63.7 ± 20.1* n = 12	1.4 ± 8.2* n = 12	57.3 ± 18.2 n = 12
6-pack cool vest	4.1 ± 8.2* n = 12	46.8 ± 16.0* n = 12	-12.4 ±11.6* n = 12	45.6 ± 13.6 n = 12

* = Significantly different among all conditions ($p<.05$)

Fluid Loss.

The average total body sweat losses for the control group were 1627 ± 197 grams (g), 1907 ± 767 g, and 1503 ± 373 g for 120 min, 99 to 101 min, and 68 to 84 min tolerance times, respectively. The 4-pack and 6-pack vest conditions had total body sweat losses of 1659 ± 694 and 1497 ± 479 g, respectively (e.g., 6-pack sweat loss equivalent to 1.497 liter [l] or 3.3 pounds). The respective sweat rates for control, 4-pack, and 6-pack conditions were 1.09 ± 0.35, 0.83 ± 0.33, and 0.75 ± 0.24 $l \cdot hr^{-1}$. The sweat rate for control was significantly ($p<0.05$) higher than the 6-pack condition. The fluid balance ($l \cdot hr^{-1}$) was not significantly different among the conditions (-0.63 ± 0.45, -0.44 ± 0.29, and -0.48 ± 0.28 $l \cdot hr^{-1}$ for control, 4-pack, and 6-pack, respectively).

Perceived Exertion and TS.

The subjects' perceptions of TS and perceived exertion varied significantly ($p<0.05$) across time. RPE coincided with the cyclical changes in HR and energy expenditure during the rest/exercise cycles. RPE was similar among the conditions during the first rest/exercise cycle, but during the second cycle, the control condition had a significantly ($p<0.05$) higher RPE than both vest conditions (Table 5).

Table 5. Ratings of perceived exertion (RPE) during rest/exercise cycles.

	Rest I	Exercise I	Rest II	Exercise II
Control (no vest)	7.7 ± 2.1 n = 12	14.1 ± 3.2 n = 12	13.8 ± 3.6* n = 12	15.7 ± 4.2+ n = 3
4-pack cool vest	6.5 ± 0.8 n = 12	12.2 ± 2.4 n = 12	9.1 ± 2.6 n = 12	14.6 ± 2.9+ n = 12
6-pack cool vest	7.3 ± 1.6 n = 12	12.7 ± 1.8 n = 12	8.5 ± 2.0 n = 12	13.3 ± 2.3+ n = 12

* = $p<0.05$ (control vs. 4-pack and 6-pack vests)

+ = Subjects' time to exhaustion varied in Exercise II

Overall TS was significantly different over time for all conditions. Overall TS was significantly ($p<0.05$) higher for the control condition throughout heat exposure as compared to the two vest conditions which remained similar (Table 6). Regional TSs were similar among groups during the first rest/exercise cycle, with the exception of the chest. Chest TS was significantly ($p<0.05$) hotter throughout heat exposure for the control group compared to both vest conditions.

Table 6. Overall thermal sensation (TS) during rest/exercise cycles.

	Rest I	Exercise I	Rest II	Exercise II
Control (no vest)	$5.0 \pm 0.8^*$ n = 12	$6.2 \pm 0.8^*$ n = 12	$6.6 \pm 0.8^*$ n = 12	$6.8 \pm 0.8^*+$ n = 3
4-pack cool vest	4.3 ± 0.4 n = 12	5.1 ± 0.8 n = 12	4.9 ± 0.7 n = 12	$5.8 \pm 0.7+$ n = 12
6-pack cool vest	3.8 ± 1.2 n = 12	5.1 ± 0.7 n = 12	4.0 ± 1.2 n = 12	$5.5 \pm 0.9+$ n = 12

* = Significantly higher than 4- and 6-pack conditions ($p<.05$)

+ = Subjects' time to exhaustion varied in Exercise II

The questionnaire completed at the end of the study indicated that all subjects, given the opportunity, would wear a cool vest during firefighting. Further, subjects felt that the vest would not prevent them from judging the intensity and potential danger of a fire. Subjects also indicated the 4-pack vest was superior with respect to fit and weight, while the 6-pack vest offered the most body cooling. The questions and answers are shown in Table 7.

Table 7. Post-heat strain study questions and answers.

Question	Answers		
In a large firefighting scenario, would you wear a cool vest to minimize heat strain?	Yes 12	No 0	
If yes, which vest would you wear?	4-pack 9	6-pack 2	Either 1
Do you think the use of a cool vest would prevent you from adequately judging the intensity and potential danger of the fire?	Yes 1	No 11	
From the standpoint of fit and weight, which cool vest was the most comfortable to wear?	4-pack 11	6-pack 1	Either 0
Which cool vest offered the most body cooling?	4-pack 0	6-pack 11	Either 1

DISCUSSION

This study demonstrates the effect of torso cooling vests on heat strain and tolerance in naval personnel while at rest and performing light to moderate exercise in a hot/humid environment. The torso cooling vests resulted in lower heat strain and completion of the two-hour test protocol. Other investigators have reported similar findings (Pimental et al., 1991).

<u>Effect of Cool Vests on Body Temperature Responses</u>.

Rest and exercise in a hot/humid environment while wearing the standard Navy firefighting protective ensemble leads to increases in core and peripheral body temperatures. Pimental et al. (1991) reported an average rise in T_{re} of 1.8°C in subjects wearing the standard Navy firefighting ensemble and performing rest/exercise cycles (15 min rest/15 min exercise) for two hours in 90°F and 60% RH. This rise is similar to our control subjects' rise of 1.8°C. However, our control subjects reached a higher T_{msk} Peak than observed by Pimental et al. (38.4 vs 37.4°C, respectively).

In our study, increases in core and peripheral body temperatures were lower for both the 4- and 6-pack cool vest conditions compared to the control condition. The 6-pack vest resulted in the smallest rise in both T_{re} and T_{msk}. T_{re} increased 0.8 ± 0.28°C which is comparable to the 0.9°C reported by Pimental et al. (1991) while wearing the 6-pack Steele vest. However, our T_{msk} peaks were greater than those reported by Pimental et al. for subjects wearing the 6-pack vest (36.8 ± 0.7 vs. 33.2°C, respectively). The difference in skin temperatures between these two studies may be due to the slightly higher air temperature and humidity confronting our subjects. When evaporative cooling is minimized by protective overgarments, skin temperature is closely related to ambient temperature. In addition, the subjects in the study by Pimental et al. were heat acclimated prior to heat-exposure tests. It is known that heat acclimatization is associated with greater sweat rate, and hence lower exercise skin temperatures (Wenger, 1988).

In our study, the 6-pack vest had a greater impact on reducing heat strain than the 4-pack vest in the second hour. The larger 6-pack vest was associated with lower core and skin temperature, suggesting a greater transfer of heat to the environment. The available surface cooling area of the 4-pack vest (1449 cm^2) is 52% of that in the 6-pack (2795 cm^2), while the weight of coolant in the 4-pack vest (1.8 kg) is 39% of that in the 6-pack vest (4.6 kg). The greater surface area and cooling capacity of the 6-pack vest (2.5 times greater) likely contributed to the differences in core and skin temperature.

HS During Heat Exposure.

Convergence of skin and rectal temperatures has been postulated to be an indication of impending collapse (Pandolf and Goldman, 1978). This concept suggests that at thermal convergence the body can no longer transfer heat from its core to the skin for dissipation to the environment. However, Nunneley et al. (1992) reported that during exercise in hot and humid conditions, thermal convergence did not accurately predict heat tolerance or affect the rate of rise in temperature or HR. The majority of subjects in their study continued walking after attaining convergence until reaching a core temperature of 39.0 °C.

In our study, thermal convergence occurred in six of our nine control subjects terminating heat exposure before two hours. In the three control subjects who finished the entire protocol, only one showed brief periods of convergence. However, despite instances of thermal convergence, there was no heat illness observed in any of our subjects. Our findings suggest that thermal convergence is not a prelude to termination of heat exposure under these environmental conditions.

Heat tolerance may also be due to body heat accumulation (Shvartz and Benor, 1972; Henane et al., 1979). Shvartz and Benor reported that the maximum tolerable HS associated with exercise in the heat is 2.12 $kcal \cdot kg^{-1}$. However, for our control subjects completing between 63 and 84 min, average HS at termination was 1.26 ± 0.30 $kcal \cdot kg^{-1}$. The three control subjects who completed between 99 and 101 min HS averaged 1.88 ± 0.27 $kcal \cdot kg^{-1}$ while those who completed 120 min had an average heat storage of 2.25 ± 0.17 $kcal \cdot kg^{-1}$. All the control subjects (n=9) unable to complete the protocol complained of dizziness, light-headedness, and tingling sensations in their arms and hands. BP was monitored during recovery and all subjects had lower BP than pre-exposure values, suggesting that BP regulation was affected. These findings suggest that factors other than HS and/or thermal convergence contribute to heat intolerance.

Effect of Cool Vests on HR and RPE.

Higher HRs accompanied rest and exercise during the control condition compared to both vest conditions. During heat exposure and exercise, HR increases to maintain cardiac output and active muscle and skin blood flow. However, the increased skin blood flow leads to a reduction in cardiac filling pressure and stroke volume (Rowell, 1983; Nadel et al., 1979). The higher HR of the control condition compared to the vest conditions and the progressive increase in HR for all conditions with each respective rest and exercise period, suggests a greater need to dissipate body heat.

During exercise in normal environmental conditions (23°C, 50% RH), there is a high correlation between the level of physical exertion, RPE, and HR (Borg, 1982). In our study, RPE followed the HR response during rest and exercise in all conditions. Up to 90 min, the control condition had both the highest HR and RPE followed by the 4-pack and 6-pack vest conditions, respectively. However, during the final exercise period RPE was similar among the three conditions despite significantly higher average HR for the control and 4-pack conditions. Since the energy expenditure among the conditions was similar and HR results from brain commands and muscle reflexes (Mitchell, 1990), our findings suggest that RPE is a poor indicator of physical exertion.

Effect of Cool Vests on TS.

In our study, overall TS increased over time for all conditions in accordance with the increase in T_{re} and T_{msk}. In addition, overall TS and T_{msk} were higher for control compared to both vest conditions. This supports the concept that sensory perception closely parallels skin temperature during heat exposure (Gagge et al., 1967). The differences between the 4-pack and 6-pack conditions for both T_{re} and T_{msk} gradually became larger as heat exposure continued. However, TS remained similar between the two vest configurations. This suggests that the 1-to-8 numerical TS scale lacked the specificity to distinguish between the subjects' different physiological responses during the two vest conditions. Thus, the TS scale was only sensitive enough to detect the larger differences in body temperature between the control and vest conditions.

Effect of Cool Vest on Post-Heat Strain Questionnaire Responses.

Results of the post-test questionnaire showed that all subjects felt the cool vests were effective in reducing heat strain during rest and exercise in the heat. The subjects also felt that their ability to accurately judge the heat and potential danger of the fire would be maintained despite the cooling effect of the vests. This belief is supported by the first hour of subjective data which shows only small differences among conditions in some regional TSs such as head, arms, and legs. The 4-pack vest was most desirable in terms of fit and weight, while the 6-pack was desired for its' greater cooling capacity. These findings suggest that the cool vests would be accepted by fleet personnel employed in damage control operations in a hot environment.

In conclusion, 4-pack and 6-pack cool vests reduced heat strain during rest and exercise in a hot/humid environment. The cool vests were associated with significantly smaller increases in T_{re}, T_{msk}, and HR when compared to wearing no vest. In addition, HS, an important factor in heat tolerance, was lower when wearing a cool vest. The decreased heat strain when using a cool vest was accompanied by lower perceptions of physical exertion and TS. All subjects felt the cool vests were effective in reducing heat strain and all reported they would choose to wear a cool vest during active shipboard firefighting. These physiological, perceptual, and acceptance findings suggest that the cool vest is an effective countermeasure to heat strain for fleet personnel involved in damage control operations in a hot/humid environment.

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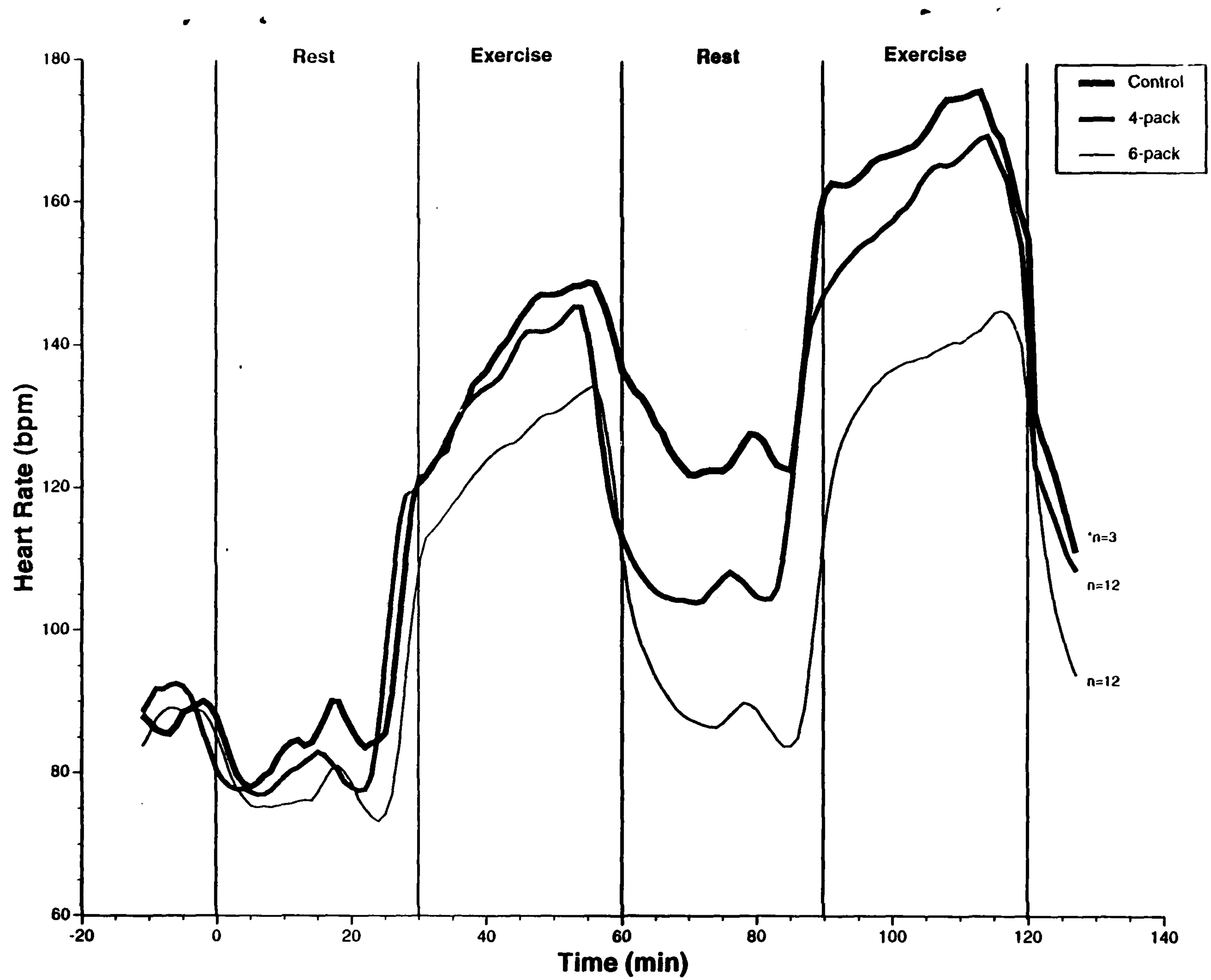

Figure 1. Average heart rates during rest and exercise in a firefighting ensemble at 95°F and 65% RH. *Three of the twelve control subjects completed the two-hour protocol.

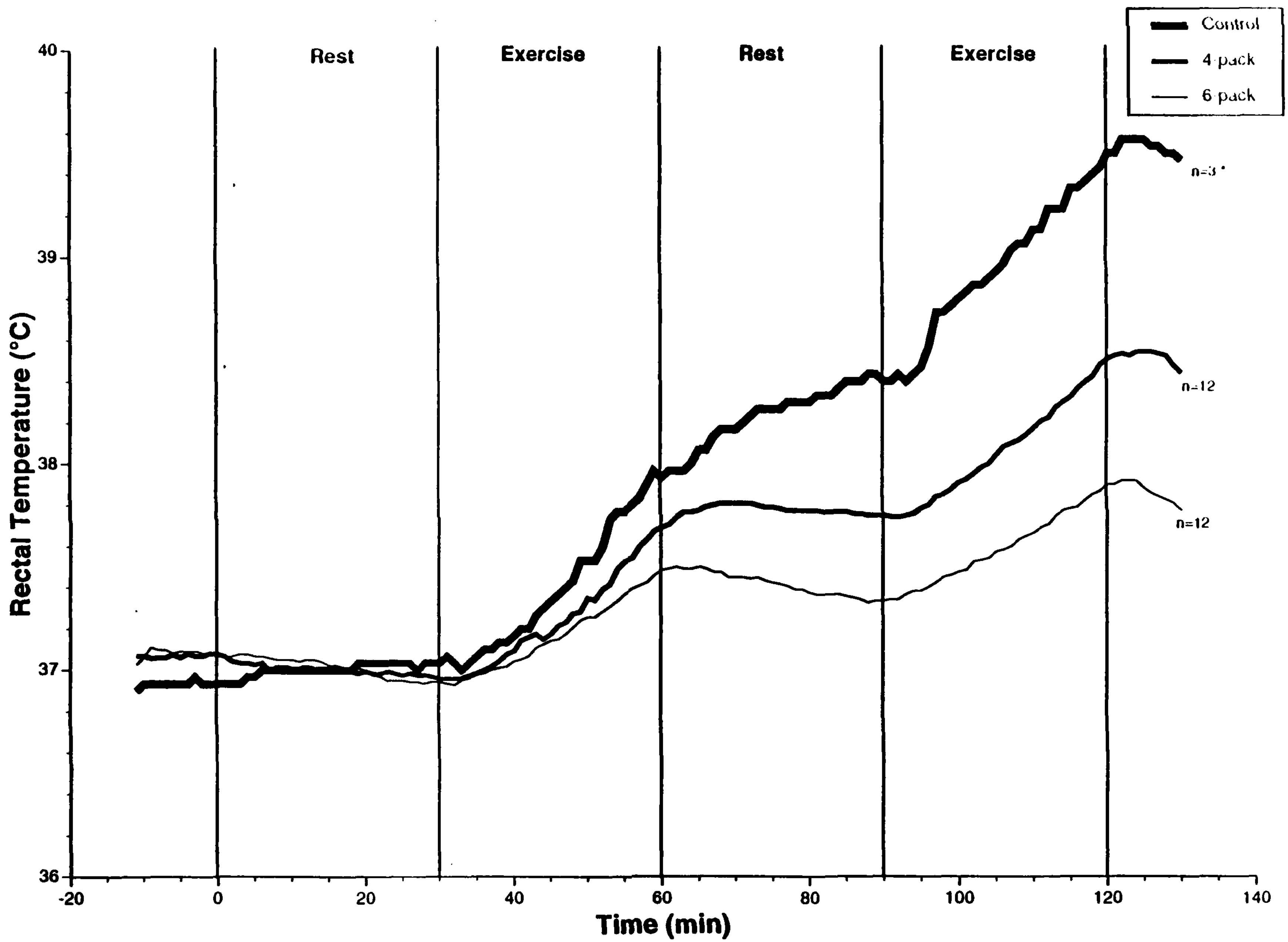

Figure 2. Average rectal temperatures during rest and exercise for subjects completing two-hour heat exposure. *Three control subjects completed the protocol.

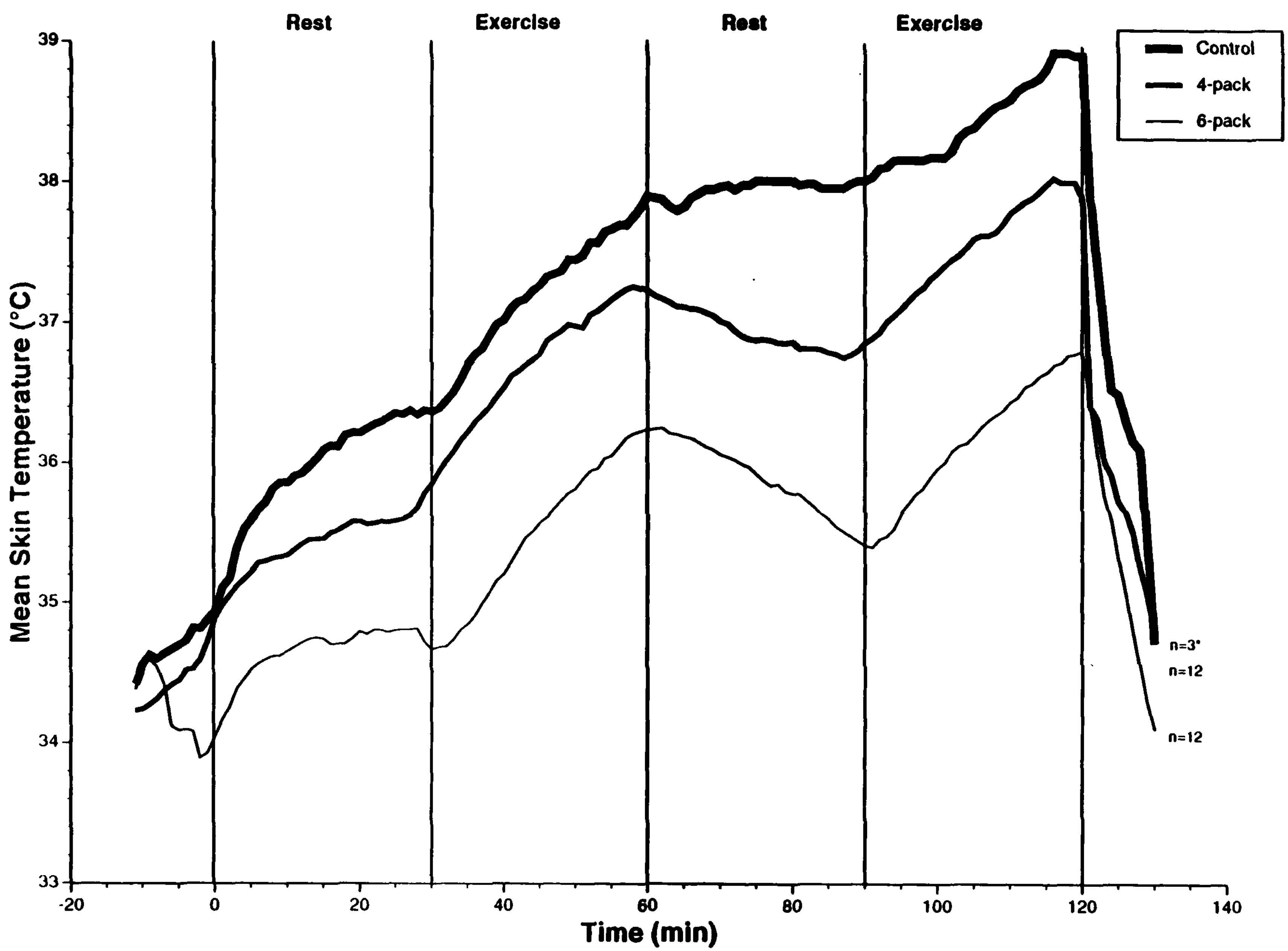

Figure 3. Mean skin temperatures during two hours of rest and exercise while wearing a firefighting ensemble in 95°C and 65% RH. *Three control subjects completed the two-hour protocol.

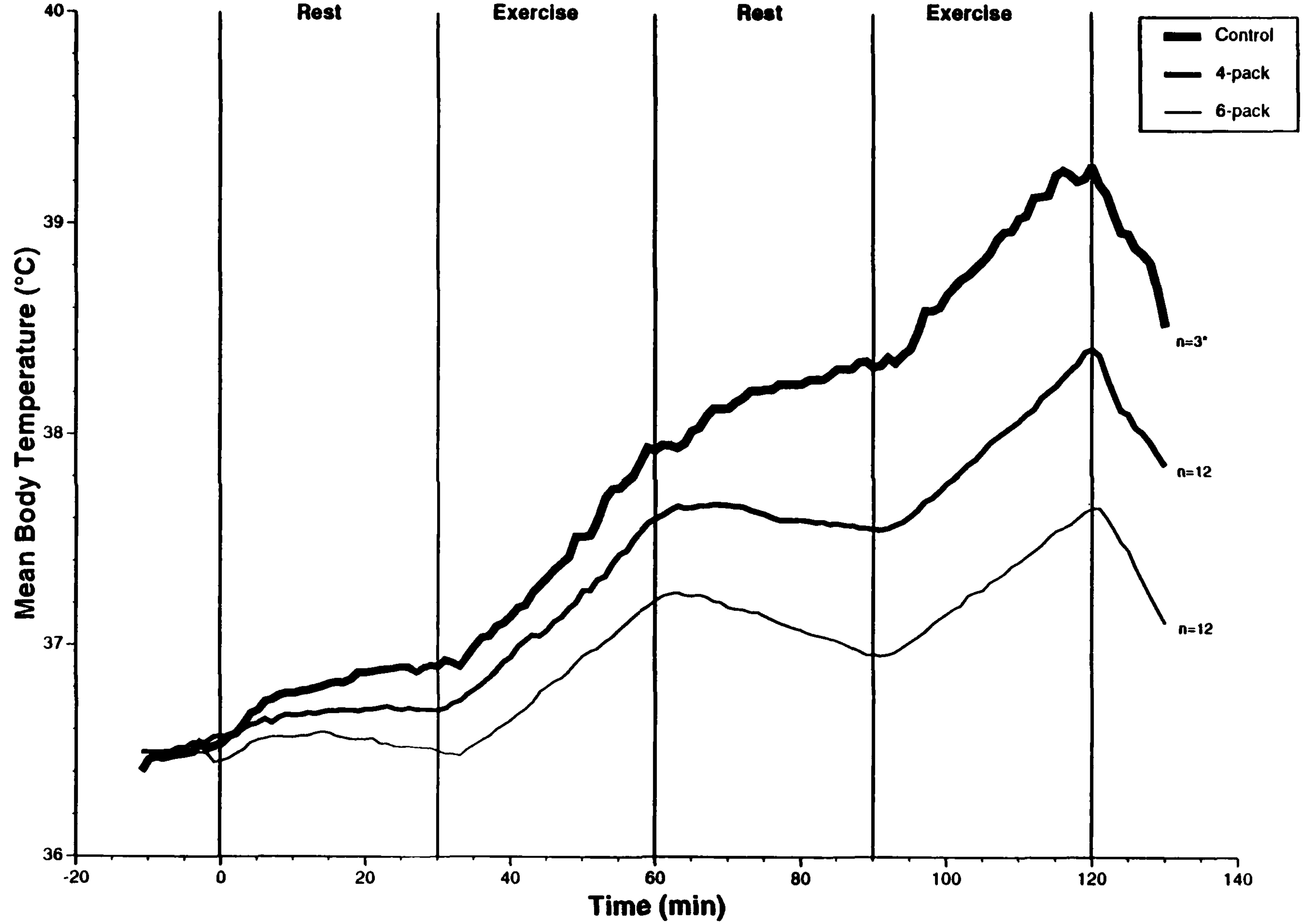

Figure 4. Mean body temperatures during rest and exercise for subjects completing the two-hour heat exposure.
*Three control subjects completed the protocol.

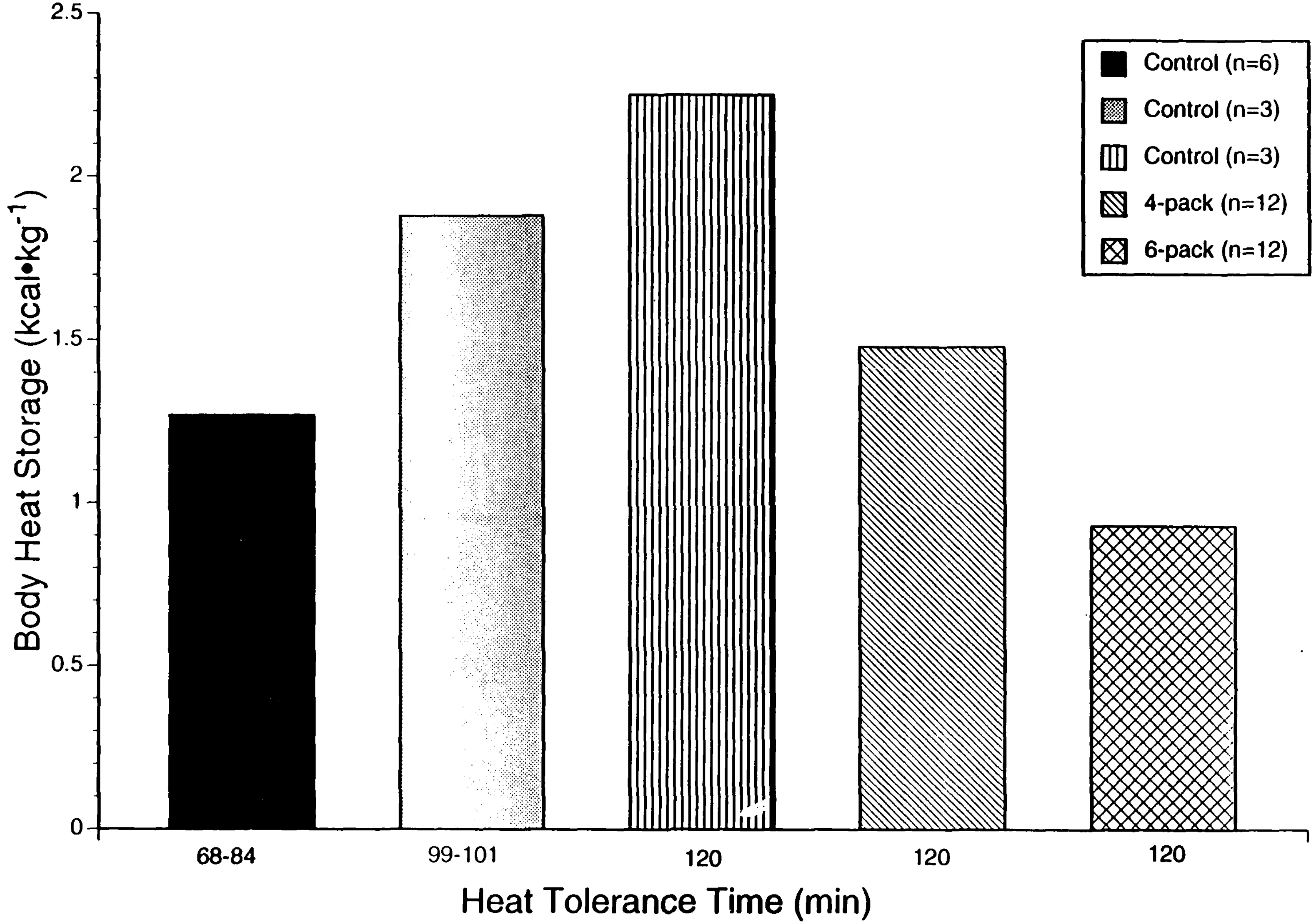

Figure 5. Mean body heat storage at the termination of heat exposure.

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13. ABSTRACT *(Maximum 200 words)*

Heat strain associated with firefighting training and shipboard firefighting is a significant problem for naval personnel. Previous studies suggest that torso cooling reduces heat strain, however, few studies exist on the effectiveness of different sized vests in reducing heat strain. Thus, the objective of this study was to evaluate the effectiveness of two cool vests worn underneath the Navy firefighting ensemble in reducing heat strain in men resting and exercising in a hot/humid environment (94°F/65% RH). Male volunteers (n=12) attempted to complete two cycles of 30 min seated rest and 30 min treadmill walking (120 min total) during three heat exposure tests (control, 4-pack, and 6-pack cool vests). Measurements included rectal and mean skin temperatures, and heart rate. Tolerance time was significantly less for control condition (92.8 min) compared to the two vest conditions (120 min). Peak values for body temperatures were lower with the cool vests. Peak values for rectal temperature were 38.9 ± 0.5°C for control, 38.6 ± 0.4°C for 4-pack and 38.0 ± 0.3°C for 6-pack. Peak values for mean skin temperature were 38.4 ± 0.5°C for control, 38.1 ± 0.5°C for 4-pack, and 36.8 ± 0.7°C for 6-pack. Energy expenditure and heart rate varied in response to the rest/exercise cycles. Our findings indicate that wearing a cool vest underneath the Navy firefighting ensemble can reduce heat strain in individuals resting and working in a high heat environment.

14. SUBJECT TERMS
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