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THE EFFECTIVENESS OF ICE- AND FREON®-BASED PERSONAL COOLING SYSTEMS DURING WORK IN FULLY ENCAPSULATING SUITS IN THE HEAT*

Mary Kay White[a†]
S. Phillip Glenn[b]
Judith Hudnall[a]
Carol Rice[c]
Scott Clark[c]

[a]National Institute for Occupational Safety and Health, Division of Safety Research, 944 Chestnut Ridge Road, Morgantown, WV 26505; [b]U.S. Coast Guard, 8th Coast Guard District, 501 Magazine St., New Orleans, LA 70130-3396; [c]University of Cincinnati, 107 Kettering Lab, Cincinnati, OH 45267

The use of cooling garments in conjunction with fully encapsulating suits offers the potential for reducing the heat strain for workers at hazardous waste sites and chemical emergencies. This study examined the use of ice- and Freon®-based cooling garments during exercise in the heat while wearing a U.S. Coast Guard chemical response suit (CRS), a fully encapsulating, Teflon®-coated, Nomex® suit. Responses of nine healthy men (mean age 28.8 yr) were measured during moderate exercise at 30% of their maximal oxygen consumption in an environmental chamber maintained at 33.9°C (93°F) and 82% relative humidity. The four randomly assigned experimental conditions were (1) the CONTROL, consisting of a self-contained breathing apparatus (SCBA) worn in conjunction with shorts, shirt, helmet, and shoes; (2) the CRS, consisting of the Coast Guard CRS worn with shorts, shirt, SCBA, helmet, gloves, and boots; (3) the ICE, which was identical to the CRS ensemble, with the addition of an ice and water cooling system; and (4) the FREON, which was also identical to the CRS ensemble, with the addition of a Freon-based cooling system. To the authors' knowledge, this paper is the first to quantify and compare a Freon-based system with a circulating ice water system. The subjects performed repeated rest/work intervals for 45 min, followed by a 10-min recovery period. Measured physiological responses, including heart rate, skin, rectal, and axillary temperatures, were recorded at 1-min intervals during the tests. The results from this study indicate statistically significant reductions in mean skin temperature and heart rate ($p < 0.05$) in the trials where subjects wore the cooling garments. Significant differences were also seen in lower weight loss and shorter rectal temperature recovery time, indicating a physiological benefit from wearing cooling systems, despite their added weight. Under the conditions of this study, however, neither cooling system fully demonstrated an advantage over the other system.

The potential for developing problems associated with heat stress is increased dramatically when using chemical protective clothing.[1] Researchers have demonstrated that the microenvironment created within the suit eliminates heat loss by evaporation of sweat, reduces convective and conductive modes of heat exchange, and minimizes radiant heat losses.[2,3] The detrimental effects of chemical protective clothing during work are related to the permeability and thickness of the ensemble and result in a continuous and rapid rise in body temperatures and heart rate.[2,4–6]

Because the normal pathways for reducing and balancing heat are effectively eliminated by impermeable protective clothing, alternative solutions need to be addressed. These may include reductions in work schedules, outside engineering controls, or personal cooling systems.[7] This research addresses the effectiveness of personal cooling systems used inside fully encapsulating chemical response suits.

A variety of cooling garments have been used in industry and in space exploration to reduce the effects of thermal stress and have recently been applied to the field of chemical response. Detailed reviews of the use of water-cooled garments may be found in the literature.[8,9] Others[2,10–14] have investigated a variety of cooling systems, including ice, dry ice, and air-cooled and water-cooled modes of cooling. In general, this research indicates that the use of cooling systems may be advantageous under hot conditions and heavy work but may not be advantageous under mild climates and light work. Another study[15] found that when wearing chemical ensembles under the most severe envi-

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†Present Address: Lewis and Clark College, Portland, OR 97219

ronmental conditions, neither of two types of liquid cooling systems was successful in reducing heat strain. Under milder environmental conditions, differences were found between the cooling and noncooling garment conditions.

The purpose of this study was to compare the effectiveness of cooling garments in reducing heat strain during exercise in the heat while wearing a chemical response suit. A fully encapsulating, Teflon®-coated, Nomex® chemical response suit (CRS) was used with two types of cooling garments. One garment was a circulating ice water system and the other a Freon® system.

The chemical response suit selected for study was designed by the U.S. Coast Guard[16] and is representative of fully encapsulating suits currently on the market. Age, fitness level, and number of subjects (N) were within boundaries established by the National Institute for Occupational Safety and Health (NIOSH) Human Subjects Review Board. The study was jointly conducted by NIOSH and the Coast Guard.

METHODS

The physiological changes that were monitored included heart rate, skin temperature, rectal temperature, axillary temperature, and weight loss. Subjective data were also collected during and following the tests. Comparisons were made between a control, a CRS without a cooling garment, and a CRS with two types of cooling garments.

The subjects in this investigation were nine healthy male volunteers ranging in age from 23 to 35 yr (mean = 28.9 ± 4.1). Three of the subjects were active duty Coast Guard personnel, and the remaining six were civilian firefighters. All volunteers were nonsmokers and had prior experience using protective ensembles. The civilian volunteers were financially compensated for their participation. The percentage of body fat was estimated from the sum of four skinfold measurements (biceps, triceps, subscapular, and suprailiac).[17] The physical characteristics of the subjects were height: 181.2 ± 5.3 cm; weight: 76.8 ± 4.5 kg; body fat: 18.2 ± 3.2%; and peak oxygen consumption: 47.8 ± 3.9 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$.

Prior to inclusion in the study, subjects signed a NIOSH consent statement and were screened with a medical examination (including 12-lead electrocardiogram and pulmonary function tests) and an exercise tolerance test on a motor-driven treadmill.[18] After completing this preliminary testing, each subject was given training with the protective clothing and equipment to be used in the study and was thoroughly briefed on the details of the tests to be performed.

Four ensembles were selected for investigation in this study. The control ensemble (CONTROL) consisted of a self-contained breathing apparatus (SCBA) worn in conjunction with shorts, tee shirt, helmet, and running shoes. The SCBA used during this study was a 60-min, positive-pressure, open-circuit unit (Mine Safety Appliances Co., Pittsburgh, Pa.). The helmet used in the study

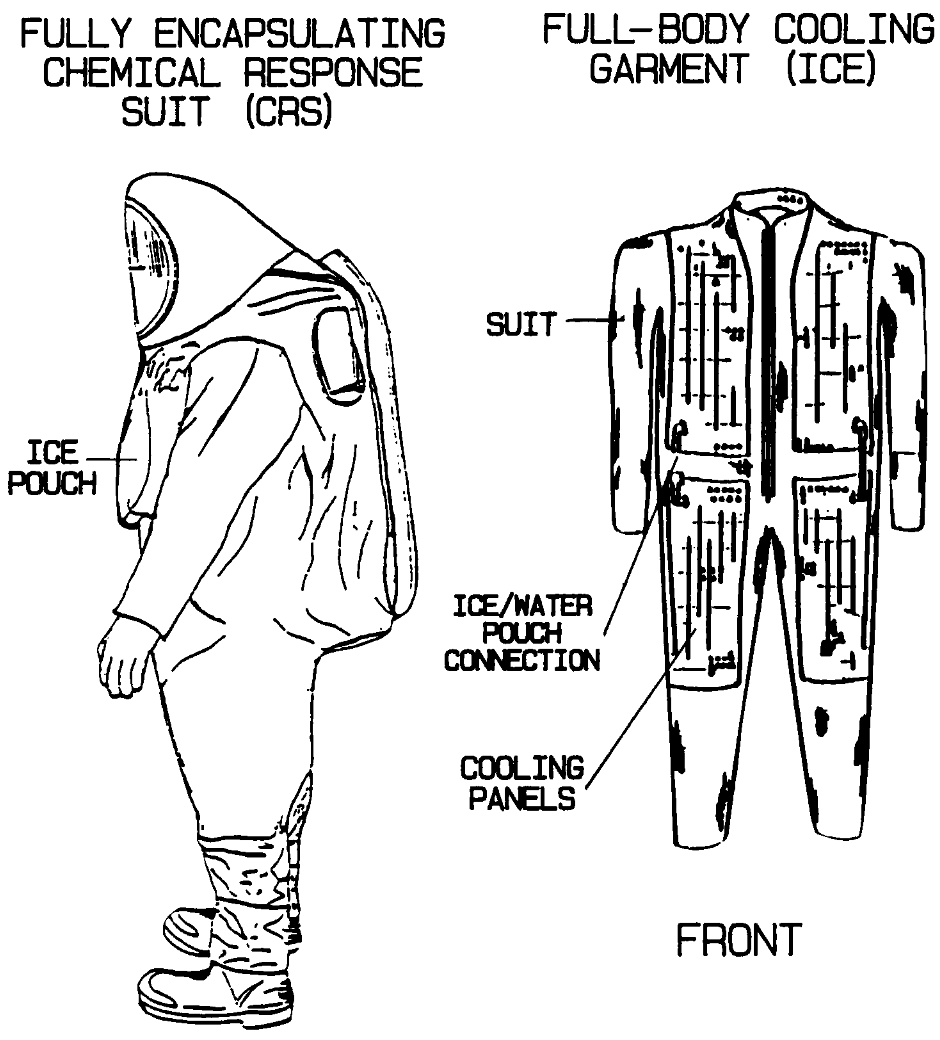

FIGURE 1. Diagram of CRS and ICE garments (two of the four test ensembles). To use the ICE cooling garment with the CRS, ice was placed in the outer pouch on the CRS and water in the inner pouch. The pouches are connected with a coil of copper tubing. Water is pumped through the coil, cooled by the ice, circulated through cooling panels on the undergarment, and then returned to the water pouch for recirculation.

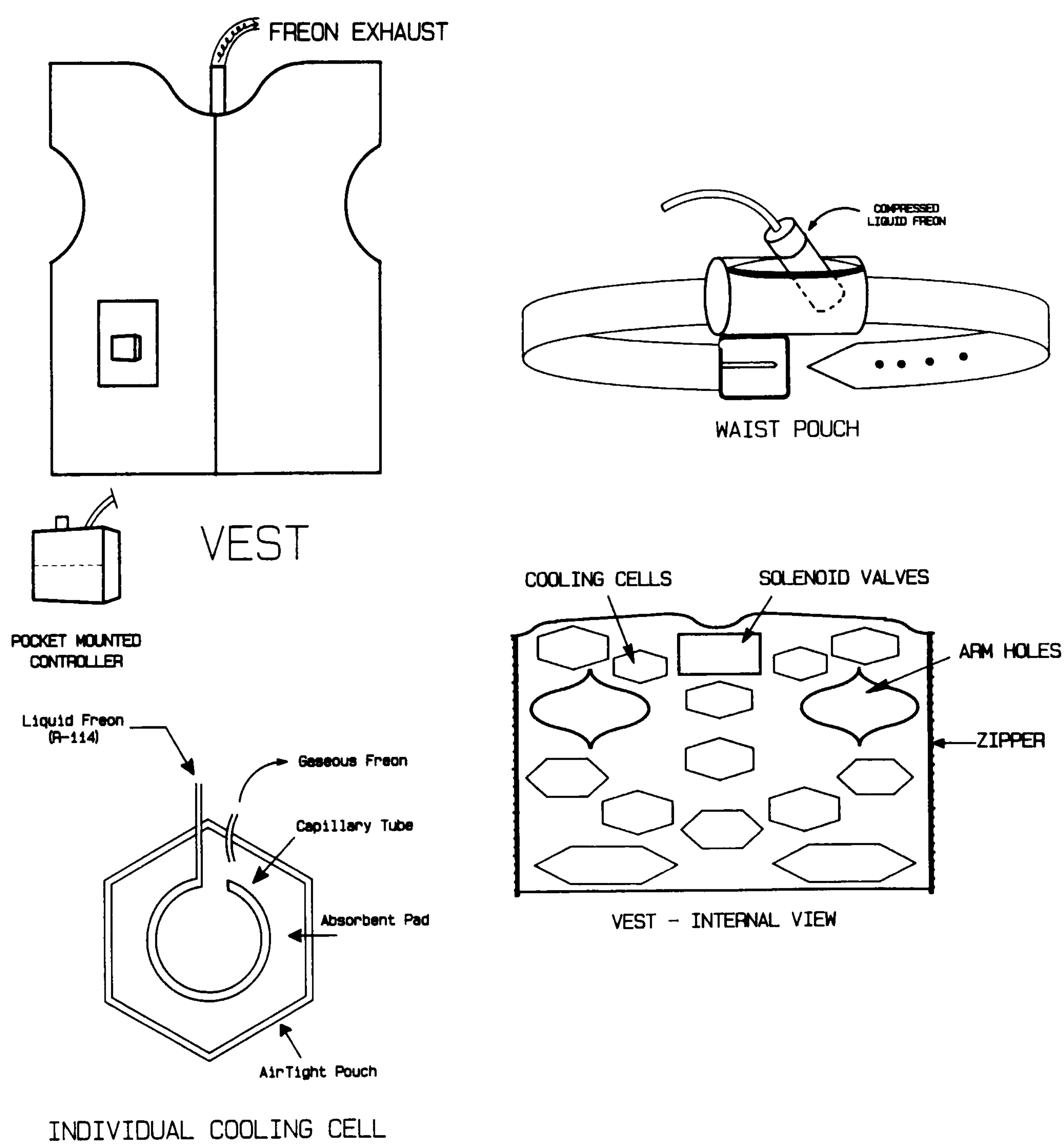

FIGURE 2. Piece diagram of FREON garment (one of the four test ensembles). Freon from a cylinder in the waist pouch is delivered to cooling cells in the vest via a solenoid valve operated by a pocket controller. Exhaust to the atmosphere is through tubing at the neck.

was a Bell bicycle helmet (Bell Helmets, Norwalk, Conn.). The second ensemble (CRS) consisted of the Coast Guard CRS worn with shorts, tee shirt, SCBA, helmet, butyl gloves, and neoprene overboots (Figure 1). The third ensemble (ICE) was identical to the CRS ensemble, with the addition of a closed-loop circulating ice and water Coast Guard cooling system. The system consisted of four major parts: a full-body undergarment, a heat exchanger, an ice water slurry reservoir, and a battery-operated centrifugal pump. The fourth ensemble (FREON) was also identical to the CRS ensemble, with the addition (Figure 2) of a Freon cooling system (Thermacor Technologies, Newbury Park, Calif.). This garment provided cooling by evaporating Freon R-114 in 16 flat, thin membrane capsules inside a stretch nylon sleeveless vest.

The CONTROL, CRS, ICE, AND FREON ensembles weighed 17.84, 24.48, 31.62, and 29.69 kg, respectively. The surface area covered by the ICE garment was approximately 0.62 m^2; that covered by the FREON garment was approximately 0.2 m^2.

Each subject then performed a series of four 45-min submaximal exercise tests in random order. A minimum of 24 hr separated each test. The study was conducted in the summer, and the subjects were considered to be partially acclimated to the heat. All subjects were instructed not to eat or ingest caffeine for at least 2 hr prior to each trial and to only drink water before the test condition. They were also asked to limit alcohol intake and heavy exercise for 24 hr prior to each test. After each test, subjects remained in a neutral environment until their rectal temperature recovered to 38°C.

Each test consisted of alternating work and rest periods performed in the heat for a total of 45 min (5 min of rest followed by 10 min of walking, repeated for 45 min), followed by a 10-min recovery period (2 min of slow walking followed by 8 min of doffing procedures). For safety reasons, the following test termination criteria were established:

- 90% of the individuals attaining maximum heart rate
- A rectal temperature of 39.0°C
- Mean skin temperature exceeding rectal temperature (provided that rectal temperature was above 38.0°C
- Objective or subjective signs of severe discomfort or fatigue

Tests were conducted in an Environmental Growth Chamber at an environmental temperature of 33.9°C (93°F) and 82% relative humidity. All tests were conducted on a Quinton motor-driven treadmill (Quinton Instruments, Seattle, Wash.) at an individualized workload equivalent to 30% of each subject's maximum aerobic capacity without protective clothing (treadmill elevation was adjusted for each subject, while the speed was a constant 4 kph). This speed was selected to maintain the comfort of the subjects wearing the fully encapsulating suit without markedly altering their stride or biomechanics. The work/rest regimen selected was also based on operational field experiences and paralleled the work levels chosen in other studies.[3,6] Work intensity averaged 312 kcal/hr (4.1 Mets).

A Hewlett Packard series 200 data acquisition system was used to acquire the physiological data obtained during the tests. Laboratory instrumentation was interfaced with the system, providing direct measurement of heart rate, skin temperatures, rectal temperature, axillary temperature, and chamber conditions at 1-min intervals. Heart rate was monitored continuously by a Physiocontrol (Redwood, Wash.) Life-Pak 6 telemetry system, interfaced to the Hewlett Packard system through the use of a CWE (Ardmore, Pa.) R-Wave detector.

Temperature measurement were obtained utilizing the thermocouple compensation features of the Hewlett Packard system. Skin temperatures were measured at six sites using uncovered copper-constantan thermocouples calibrated in distilled water ice baths to ±0.02°C. Mean weighted skin temperature was calculated in the following manner: $T_{skin} = 0.125\ (T_1) + 0.125\ (T_2) + 0.125\ (T_3) + 0.125\ (T_4) + 0.07\ (T_5) + 0.1\ (T_6)/0.67$, where T_1 = lateral thigh, T_1 = medial thigh, T_3 = back, T_4 = chest, T_5 = arm, and T_6 = cheek.[19] Axillary temperature was also measured using a single YSI thermister (Yellow Springs Instruments, Yellow Springs, Ohio) placed in the right axilla and secured with elastic and tape. It was not included in the mean weighted skin temperature calculation. Rectal temperature was measured using a flexible, vinyl-covered YSI probe inserted 10 cm into the rectum.

Total sweat production was estimated as the change in nude body weight, measured before and after the test session. A platform scale (GSE Inc., Farmington Hills, Mich.), accurate to ±5 g, was used for weighings.

The data were analyzed through a statistical analysis system (SAS) using general linear models at the $p < 0.05$ level of significance. Although data were collected and analyzed using analysis of variance (ANOVA) for each minute of the entire

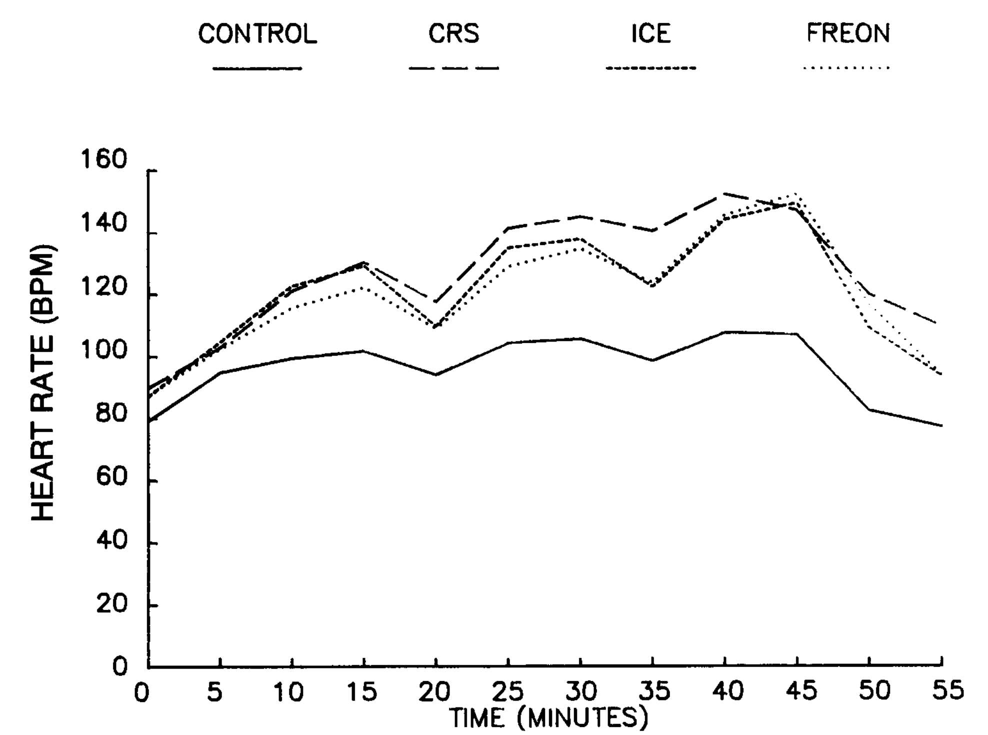

FIGURE 3. Mean heart rate observed in each of the four test conditions (N = 9)

TABLE I. Results of Selected Variables by Minute

		Minute (Mean ± Standard Deviation)					
		2	12	17	27	32	42
Condition	*Variable*	*At Rest*	*At Work*	*At Rest*	*At Work*	*At Rest*	*At Work*
CONTROL	HR	82(15)^{A,B,C}	101(10)^{A,B,C}	85(17)^{A,B,C}	105(10)^{A,B,C}	94(16)^{A,B,C}	110(12)^{A,B,C}
	T_{rectal}	37.05(0.39)	37.09(0.41)	37.11(0.42)^{B}	37.11(0.41)^{A,B}	37.10(0.43)^{A,B}	37.22(0.39)^{A,B,C}
	T_{skin}	34.57(0.31)^{B,C}	35.13(0.48)	35.30(0.42)^{B}	35.79(0.75)	35.85(0.90)	36.20(1.0)
CRS	HR	87(17)^{D}	125(17)^{D}	115(25)^{D}	145(20)^{B,C,D}	134(22)^{B,C,D}	151(23)^{D}
	T_{rectal}	37.14(0.30)	37.16(0.36)	37.20(0.36)	37.39(0.37)^{D}	37.53(0.36)^{D}	37.81(0.38)^{C,D}
	T_{skin}	34.54(0.69)^{B,C}	35.52(0.29)	36.06(0.34)	36.60(0.45)	36.97(0.48)	37.24(0.34)^{B}
ICE	HR	91(20)^{D}	126(10)^{D}	106(16)^{D}	138(12)^{A,D}	121(19)^{A,D}	146(13.5)^{D}
	T_{rectal}	37.15(0.29)	37.25(0.30)	37.33(0.33)^{D}	37.48(0.34)^{D}	37.55(0.35)	37.68(0.36)^{D}
	T_{skin}	33.76(0.53)	35.99(0.64)	34.45(0.74)^{D}	34.79(0.89)	35.10(0.97)	35.5(1.09)^{A,C,D}
FREON	HR	87(15)^{D}	120(13)^{D}	103(21)^{D}	133(13)^{A,D}	120(21)^{A,D}	149(19)^{D}
	T_{rectal}	37.04(0.26)	37.12(0.28)	37.16(0.31)	37.30(0.32)	37.38(0.33)	37.56(0.36)^{A,D}
	T_{skin}	33.94(0.74)	34.56(0.92)	35.02(0.93)	35.78(0.64)	36.31(0.59)	36.92(0.55)^{B}

^{A}Significantly different from CRS ($p < 0.05$).
^{B}Significantly different from ICE ($p < 0.05$).
^{C}Significantly different from FREON ($p < 0.05$).
^{D}Significantly different from CONTROL ($p < 0.05$).

45-min exercise (and the 10 min of recovery), only observations from Minutes 2, 12, 17, 27, 32, and 42 will be addressed in terms of statistical results and implications These time periods are representative of the entire test condition and include time periods from both rest and work routines.

RESULTS

Tolerance Time

Tolerance time was defined as the length of time the experiments progressed until terminated. Tolerance times (mean ± SD) were 45.0 (± 0.0), 43.3 (± 2.9). 45.0 (± 0.0), and 44.8 (± 0.6) min for the CONTROL, CRS, ICE and FREON conditions, respectively. No statistical differences were observed between ensembles. Out of the total 36 tests, 4 were terminated because of attainment of 90% of the maximal heart rate. Three of these early terminations occurred with the CRS ensemble (at Minutes 37, 40, and 43), while the fourth occurred with the FREON ensemble (at Minute 43). No tests were terminated for criteria other than heart rate.

Cooling Duration

The cooling duration for each of the cooling garments (which was obtained by subject notification and confirmed by an investigator) was also noted. The mean cooling time for the ICE system was 37.5 (± 2.7) min, and the FREON cooling time was 33.4 (± 8.3) min.

Heart Rate

Mean heart rate (HR) increased during all work periods across all four experimental conditions and decreased during the rest periods (Figure 3). The drops in HR during the 5-min rest periods resulted in only partial recovery, never returning to the original levels. In all cases, the peak HR occurred during the end of the last work period with the mean values of 107 (± 13.1), 147 (± 25.8), 146 (± 14.8) and 152 (± 20.1) beats per minute (bpm) for the CONTROL, CRS, ICE, and FREON conditions, respectively. These correspond to mean HR increases (peak HR minus HR recorded at Minute 1) of 28, 54, 57 and 68 bpm for each of the four conditions, respectively.

As shown in Table I, at Minutes 2, 12, and 17, HR showed a significant difference ($p < 0.05$) between the CONTROL condition and each of the other experimental conditions. No other differences were significant. At Minute 27 (17 min of actual treadmill walking) there was a significant HR difference observed between the CRS, ICE, and FREON conditions. At that time, the HR observed in the ICE and FREON conditions was significantly ($p < 0.05$) lower than those observed in the CRS condition. No significant differences were found between the two cooling garments. In the CONTROL condition, HR continued to increase at a much slower rate, remaining significantly lower than the other three conditions. This pattern continued until Minute 40, when the mean cooling durations of the garments had been surpassed. By Minute 42, no significant difference in HR between the CRS, ICE, and FREON conditions was apparent. HR for the CONTROL condition remained significantly lower than the other three ensemble conditions.

Rectal Temperature

The mean rectal temperatures in all experimental conditions showed gradual increases over time (Figure 4) and continued to rise through recovery and doffing procedures.

A summary of the findings is shown in Table I. Statistical analysis of the mean rectal temperatures at Minutes 2 and 12 indicated that there were no significant differences between any of the experimental conditions. Statistical differences between the four experimental conditions were first seen at Minute 15. At

Minute 17, significant differences ($p < 0.05$) were only observed between the CONTROL condition and the ICE condition. At Minute 27, the rectal temperatures were continuing to increase slowly, and the rectal temperature for the CONTROL condition was significantly lower than the CRS and ICE conditions. This general pattern continued until Minute 40.

By Minute 42, the CONTROL was significantly lower than each of the other three conditions; the FREON condition was significantly lower than the CRS condition; and no other differences were noted. These statistical trends continued throughout the remainder of the test. Peak rectal temperature values occurred during the recovery period.

The rectal temperature recovery time, the time it took the subjects to return to 38°C after exercise, was longest in the CRS condition. Mean times were 6.3 (± 12.5), 32.7 (± 23.0), 15.4 (± 21.2, and 22.0 (± 23.1) min for the CONTROL, CRS, ICE, and FREON conditions, respectively. The CONTROL recovery time was significantly ($p < 0.05$) shorter than both the CRS and the FREON conditions. Recovery time for the ICE condition was also significantly shorter than the CRS condition. No differences were observed between the ICE and FREON conditions, the CONTROL and ICE conditions, nor the CRS and FREON conditions.

Skin Temperature

Over the duration of the tests, mean skin temperature rose under all experimental conditions (Figure 5). The rate of increase was greatest in the CONTROL and CRS conditions. Maximum skin temperatures were reached at the end of the last work period and reflected increases (peak skin temperature minus skin temperature at Minute 1) of 1.82, 2.74, 2.03, and 3.25°C for the CONTROL, CRS, ICE, and FREON conditions, respectively.

A summary of the findings is shown in Table I. At minute 2, mean skin temperatures with the CONTROL and CRS ensembles were significantly higher than both the ICE and FREON ensembles. At Minutes 12, 17, 27, and 32 the ICE skin temperature was significantly lower than the other three conditions; the CONTROL and FREON temperatures were significantly lower than the CRS condition. At Minute 42, the ICE skin temperature was significantly lower than the other ensembles; the temperature with the FREON condition was not significantly different from the CRS condition; and the CONTROL condition was significantly lower than both the FREON and CRS conditions.

Gradient for Heat Exchange

In general, the largest gradient for heat exchange (mean rectal temperature minus mean skin temperature), indicating the least thermal stress[20] was seen in the ICE condition, while the smallest gradient was seen in the CRS condition, indicating the most stressful situation. Concentrating on the time period when the cooling garments were operating and producing the most effective cooling (Minutes 12–32) the gradient for heat exchange was greatest ($p < 0.05$) with the ICE condition. The gradient with the FREON ensemble was significantly higher than that seen with the CRS ensemble but showed no difference from the CONTROL. The mean gradients for heat exchange were 1.58, 1.03, 2.82, and 1.82°C for the CONTROL, CRS, ICE, and FREON conditions, respectively.

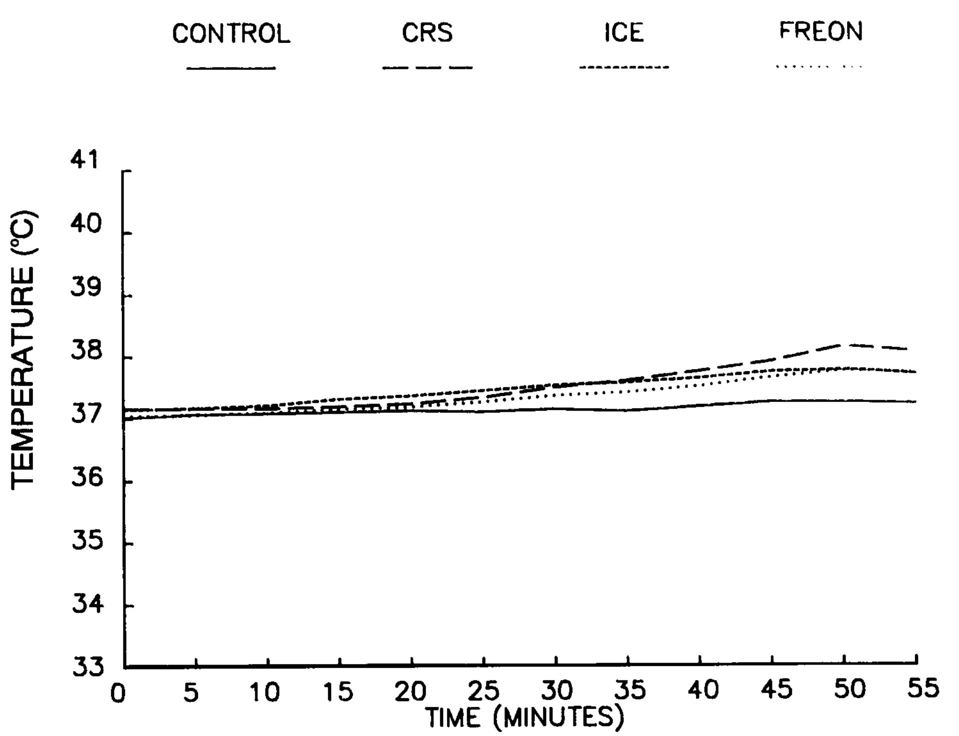

FIGURE 4. Mean rectal temperature observed in each of the four conditions (N = 9)

Axillary Temperature

Axillary temperature increased with exercise over the duration of the test and appeared to follow the general trends seen in skin temperature. A significant correlation was observed between axillary temperature and the mean skin temperature. This relationship, as indicated by the Pearson Correlation Coefficient (r) was strongest for the CRS ($r = 0.96$) followed by the FREON ($r = 0.93$), ICE ($r = 0.86$), and CONTROL ($r = 0.78$) conditions. No significant correlations were found between axillary and rectal temperature. The correlations for each of the four experimental conditions were –0.46 for the CONTROL, 0.43 for the CRS, 0.28 for the ICE, and 0.44 for the FREON.

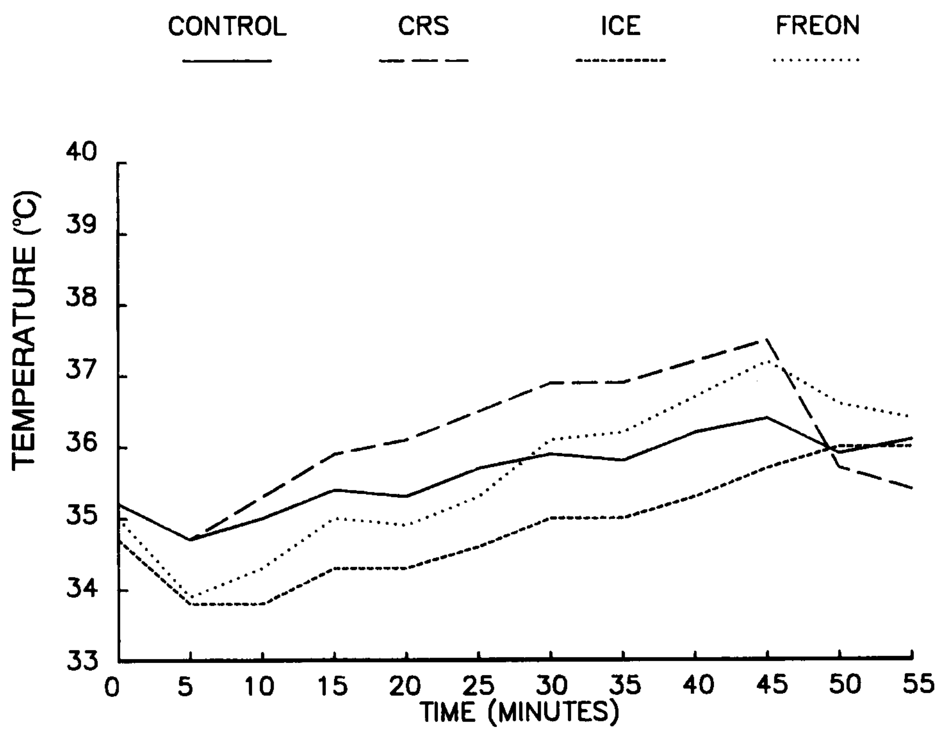

FIGURE 5. Mean skin temperature observed in each of the four test conditions (N = 9)

Weight Loss

The mean body weight loss was greatest in the CRS condition and least in the CONTROL condition. The average weight loss values were 0.61 (± 0.33), 1.00 (± 0.18), 0.69 (± 0.07), and 0.91 (± 0.15) kg for the CONTROL, CRS, ICE, and FREON conditions, respectively. ANOVA indicated that weight loss was significantly ($p < 0.05$) less in the CONTROL condition than in the CRS and FREON conditions. Weight loss was also significantly less with the ICE ensemble than with the CRS and FREON ensembles. No significant differences in weight loss were found between the CONTROL and ICE ensembles nor between the CRS and FREON ensembles.

Subjective Preference

The subjects were also asked for their subjective preferences during an exit interview conducted after all four experimental conditions were completed. Subjective preferences for the ensembles were as follows: eight of nine subjects rated the CONTROL as their most favorable experimental condition, seven of nine subjects rated the ICE ensemble as their next preference, six of nine subjects selected the FREON ensemble as their third choice, and seven of nine subjects rated the CRS as their least-preferred experimental condition.

DISCUSSION

Review and analysis of the data generated from this investigation indicate that significant physiological strain occurs with exercise in the heat while wearing the Coast Guard CRS, when compared to a CONTROL condition. This strain was reduced somewhat when using either of two types of cooling garments, but it was not reduced to a level equivalent to the CONTROL condition. When comparing the ICE and FREON conditions with the CRS conditions, significant differences ($p < 0.05$) were observed in heart rate, skin temperature, weight loss, gradient for heat exchange, and rectal temperature recovery time. Subjective preference of the users favored the use of cooling garments when performing work with the fully encapsulating CRS suit.

In terms of the physiological responses, no steady-state responses were observed under any of the experimental conditions in this study. Clearly, the most severe condition was the CRS and the most favorable was the CONTROL. The unique contribution of this study to the literature is that minimal differences were observed between the ICE and FREON ensembles. The differences noted between the two cooling garments may be more a measure of reliability and cooling duration than a clear physiological advantage of one system over another.

In this study, the most obvious and distinctive difference noted between the four experimental conditions was mean skin temperature. The results indicate that both the ICE and FREON ensembles were effective in reducing skin temperature and increasing the gradient for heat exchange. These differences were noticeable early in the testing and gradually diminished as the effectiveness of both the ICE and FREON cooling garments decreased. The lower mean skin temperatures observed in the ICE garment, compared to the FREON garment, may be the result of the larger surface area cooled by this design and the longer cooling duration that was seen in this particular study. Other researchers have demonstrated this decrease in mean skin temperature when comparing cooled and uncooled conditions.[15,21,22] However, this study is the first to quantify and compare differences between ice- and Freon-based cooling garments.

The conductive cooling provided by both the ICE and FREON cooling garments and subsequent reductions in mean skin temperature are also reflected in the reductions in sweat loss, expressed as a lower weight loss in this investigation. The cooler skin temperature provided by both cooling systems apparently inhibited sweat production at the area of skin surface covered by the cooling garment. Weight loss was greatest in the ICE ensemble, most likely because of the increased cooling surface area (approximately 0.4 m^2 greater than the FREON garment) and the slightly longer cooling duration.

Similar results were observed in the gradient for heat exchange. The largest gradient, indicating the most favorable condition from this perspective, was observed with the ICE condition. Clearly, the most severe condition was the CRS condition, demonstrating again a disadvantage to using the CRS ensemble without auxiliary cooling.

The use of heart rate as an indicator of heat strain has been widely accepted by researchers.[23] Heart rate is extremely sensitive to heat stress, as well as influences from exercise and anxiety. Its usefulness was supported in this study by the differences in mean heart rates between the four experimental conditions. Other researchers have noted that, under certain environmental conditions, cooling garments have very little effect on heart rate during the first hour of work[11] and under hot conditions (45°C).[15] In the present study, significant differences between the CRS, ICE, and FREON conditions were not observed until Minute 27 and then remained until Minute 40 (both garments had lost cooling power prior to Minute 40). With longer duration cooling systems, the heart rate differences would have likely remained significant until the end of testing. Significant differences in heart rate were also noted between the CONTROL and CRS conditions, clearly demonstrating the physiological strain of wearing fully encapsulating suits. Similar trends have been reported in other studies when chemical protective clothing was worn.[3,6]

The added weight from wearing cooling garments results in an increased metabolic heat production and could influence the choice of using cooling garments during short excursions. Physiological advantages in wearing such cooling garments becomes more apparent with time because of the influence of increased cooling. Longer duration studies to discover more profound differences may not be feasible for chemical response applications because of the limitation of breathing air time in fully encapsulating suits.

Although rectal temperature is used frequently as a diagnostic indicator by clinicians, it is often a poor indicator of heat strain under short-term experimental conditions. This measurement changes very slowly because of the insulating effects of the surrounding tissue.[24] Researchers have also noted that any benefit derived from a lower rectal temperature would be seen only after 1 hr of work.[11] These observations were supported by this study, which showed that mean rectal temperature rose only very gradually, producing significant differences only at the end of testing, even after cooling from the garments had stopped. The longest rectal temperature recovery time occurred with the CRS ensemble. Because of this time lag for rectal temperature recovery, consideration and caution is warranted under field or operational situations. It may be necessary to adjust work, recovery, and monitoring schedules to account for this relatively long recovery period.

None of the experiments were terminated because of rectal temperature criteria reaching 39°C. Temperatures above this level may lead to deleterious effects.[7] In a recent study using the Coast Guard CRS without cooling garments,[3] the maximum rectal temperature was 38.1°C, which compares favorably to the results from the CRS condition in this study (where the mean maximum rectal temperature reached 38.2°C).

In this study, axillary temperature correlated poorly with rectal temperature, indicating a low potential for using axillary temperature to approximate rectal temperature in field or operational situations. Axillary temperature did correlate well with the mean skin temperature and may provide a useful alternative to measuring six skin temperature sites in nonresearch or field conditions.

Weight loss indicated that the CONTROL condition was the least severe, the CRS the most severe, and the ICE and FREON conditions between these extremes. These trends were similar to those seen in heart rate and skin temperature responses. Similar differences in weight loss have been reported by other researchers.[3,6,15]

SUMMARY

In summary, this study indicated that wearing a CRS results in significant increases in strain over a CONTROL condition and that a cooling garment can effectively reduce the physiological strain under the experimental conditions selected in this investigation. The benefits of the cooling garments were manifested in reductions in physiological indicators of heat strain (skin temperature, heart rate, weight loss, gradient for heat exchange, and rectal temperature recovery time) and also in the subjective preferences of the users. Little difference was found between the two cooling garments (ICE and FREON), even though there were major design, engineering, and weight differences between the two systems. Under the experimental conditions of this study, neither cooling system fully demonstrated an advantage over the other system. Both the ICE and the FREON systems, however, were effective in minimizing the physiological strain seen with wearing fully encapsulating suits. More substantial differences may have been possible had the cooling systems delivered for the duration of the test. Neither of the cooling garments tested in this study reliably provided a sufficient cooling duration for the subjects (cooling for an average of 35 min out of the 45 min in the exercise period). Greater advantages in cooling versus noncooling, as well as differences between individual systems, may have been possible with more efficient and reliable cooling garments.

There is a need for the development of a simple and inexpensive cooling system that has a reasonable cooling duration with design features acceptable for fully encapsulating suits. Further testing of other commercially available products is warranted. The results from this study were taken from a single set of environmental conditions at a moderate work rate. The literature suggests that at certain critical temperatures and work rates the use of cooling systems may not be beneficial. Further experiments are necessary to clarify this relationship and provide the users of chemical protective clothing a more definitive guide to when and where the use of auxiliary cooling is helpful in reducing heat strain to the users.

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