NAVAL HEALTH RESEARCH CENTER

COOL VESTS WORN UNDER FIREFIGHTING ENSEMBLE INCREASES TOLERANCE TO HEAT

R. D. Hagan

K. A. Huey

B. L. Bennett

Report No. 94-6

NAVAL HEALTH RESEARCH CENTER
P. O. BOX 85122
SAN DIEGO, CALIFORNIA 92186 – 5122

NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
BETHESDA, MARYLAND

COOL VESTS WORN UNDER FIREFIGHTING ENSEMBLE INCREASES TOLERANCE TO HEAT

R. D. Hagan, Ph.D.[1]

K. A. Huey, M.S.[1]

B. L. Bennett, CDR, MSC, USN[2]

[1]GEO-CENTERS, INC.
Fort Washington, MD 20744

[2]Naval Health Research Center
P.O. Box 85122
San Diego, CA 92186-5122

Report Number 94-6, supported by the Naval Medical Research and Development Command, Department of the Navy, under work Unit No. 63706N M0095-004-6301. The views expressed in this paper are those of the authors and do not reflect official policy or position of the Department of the Navy, the Department of Defense, or the U.S. Government. Approved for public release, distribution unlimited.

The assistance of naval personnel as subject volunteers for this study is acknowledged and greatly appreciated. The authors also wish to thank HM3 Chris Parrish, USN and Ms. Michelle Held, San Diego State University Foundation student, for their technical assistance during data collection, and Ms. Marilyn Reddeg for her invaluable assistance during preparation of this manuscript.

SUMMARY

Problem.

Firefighting in the heavily insulated standard Navy protective ensemble prevents heat dissipation while exposure to high temperatures leads to progressive heat gain. In some instances, this can produce extreme elevations in body temperature and heart rate leading to heat strain disorders and complications. Consequently, an effective microclimate cooling system is needed to reduce heat strain and prevent heat causalities. Previous studies in warm air (up to 35°C) have shown that cool vests worn under the firefighting ensemble reduce heart rate, body temperatures, and heat storage. However, the effectiveness of torso cool vests on heat strain and tolerance time during exposure to hot and humid air are unknown.

Objective.

The primary objective of this study was to compare the effectiveness of a small 4-pack cool vest (CV_S) and a large 4-pack cool vest (CV_L) in minimizing heat strain and extending tolerance time in men dressed in the U.S. Navy firefighting ensemble and oxygen breathing apparatus, while resting and exercising in a hot/humid environment.

Approach.

Laboratory tests were conducted in an environmental chamber. The ambient conditions were 48±0.5°C (118±0.9°F) dry bulb (DB), 37±0.1°C (99±0.2°F) wet bulb (WB), and 41±0.2°C (104±0.4°F) wet bulb globe temperature (WBGT). The relative humidity equalled 50%.

Male volunteers (n=8) served as subjects. All subjects participated in three randomly ordered counterbalanced trials. The trials were: 1) no vest (NV), 2) small 4-pack CV (CV_S), and 3) large 4-pack CV (CV_L). Total weight of CV_S equalled 2.72 kg (5 lb), while CV_L weighed 3.63 kg (8 lb). CV_S contained four, 425 g (15 oz) gel packs and CV_L held four, 765 g (27 oz) gel packs. CV_S and CV_L were worn over dungarees and cotton shirts and under the single-piece U.S. Navy firefighting ensemble. During each heat exposure trial, the subject attempted to complete as many cycles as possible of 30 min seated rest and 30 min walking on a motorized treadmill (1.56 $km \cdot hr^{-1}$/2.5 mph, 0% grade). Heat exposure tolerance time was established when subjects desired to terminate heat exposure or after attainment of established medical termination criteria. Subjects were monitored continuously throughout heat exposure for rectal temperature (T_{re}), four skin temperatures (shoulder, chest, thigh, calf), and heart rate (HR). The skin temperatures were used to calculate mean weighed skin temperature (T_{msk}). Mean body temperature (T_{mb}) was calculated from T_{re} and T_{msk}. T_{mb} was used to calculated rate of heat storage (HS, $W \cdot m^{-2}$). Measures of oxygen uptake and carbon dioxide production (for calculation of energy expenditure in Watts), cardiac output (Q_c), stroke volume (SV), and subjective ratings of perceived exertion (RPE) and thermal sensation (TS) were recorded during each rest and exercise period.

Results.

Heat tolerance time for CV_S (58.2±15.8 min) and CV_L (60.1±10.4 min) were significantly longer ($p<.05$) than no vest (NV) (49.9±6.2 min). Only one NV subject finished the first 30 min exercise period compared to two and four subjects in the CV_S and CV_L trials, respectively. No subject in any trial exceeded 90 min of heat exposure. In 24 of 24 tests, tolerance time depended upon physical symptoms of general fatigue, headache, feeling "hot," or attainment of 90% of maximum HR.

Energy expenditure averaged 84±22 W during rest and 395±52 W during walking exercise. These responses were non-significant ($p>.05$) among all trials. HR rose slowly during the first rest period and rapidly during the first exercise period. However, peak HR during exercise was similar ($p>.05$) among trials (172±21 bpm).

During the first rest period, the rate of increase in T_{msk} exceeded the rate of increase in T_{re}. However, the rate of increase in T_{re}, T_{msk}, and T_{mb} were similar ($p>.05$) among all trials. During the first exercise period, rates of increase in T_{re} and T_{mb} were significantly higher ($p<.05$) for NV compared to CV_S and CV_L. Consequently, rate of heat storage was greater ($p<.05$) for NV (111.7±29.3 $W \cdot m^{-2}$) compared to CV_S (96.2±17.9 $W \cdot m^{-2}$) and CV_L (96.7±20.5 $W \cdot m^{-2}$).

Conclusions.

CV_S and CV_L significantly increased tolerance time during rest and exercise in a hot/humid environment of 48°C and 50% rh. CV_S and CV_L also were associated with slower rates of increase in T_{re} and T_{mb} and rate of HS. However, the relative merits of the CV_S and CV_L could not be distinguished in this study perhaps as a result of the extreme environmental conditions and the prolonged rest and exercise phases of the exposure protocol. It is likely, that the initial 30 min rest period produced redistribution of blood to the skin and central hypovolemia, and a corresponding increase in heart rate during the initial exercise period. The rapid increase in heart rate during exercise resulted in a large percentage of terminations from heat exposure as a result of sustained elevations in HR. Despite this limitation, our findings indicate that cool vests worn over dungarees and under the firefighting ensemble delay the onset of heat strain and prolong heat exposure tolerance time in a hot/humid environment.

INTRODUCTION

High air temperatures and large amounts of steam often accompany U.S. Navy firefighting training and shipboard fire suppression activities. The performance of firefighting activities requires elevated energy expenditure as a result of wearing heavy protective clothing and carrying equipment. Thus, strenuous shipboard firefighting can produce rapid and large increases in heart rate (HR) and body temperatures (Bennett et al., 1993a). The extreme heat strain associated with firefighting indicates the need to investigate different countermeasures for use by damage control personnel during training and actual shipboard operations.

Passive torso cooling using a vest containing frozen gel-packs appears to be an effective countermeasure to heat strain in moderate to warm environments (Banta & Braun, 1992; Janik et al., 1987; Pimental et al., 1989; Speckman et al., 1988). Pimental et al., (1991) reported that a 6-pack cool vest (5.4 kg/12 lb) holding six 765 g gel packs reduced heat strain in individuals wearing firefighting clothing and exercising in 32°C heat. Similarly, Bennett and co-workers (1993b) reported that the same 6-pack cool vest and a 4-pack vest holding four, 425 g gel packs worn over dungarees and under the firefighting ensemble attenuated increases in body temperature and HR during rest and exercise in a warm humid environment of 35°C and 65% rh. However, the 6-pack vest is heavy and may not fit comfortably under the firefighting ensemble, while the smaller sized gel packs used in the 4-pack vest might not provide sufficient cooling at high temperatures. This suggests the possibility that using a larger 4-pack vest (3.6 kg/8 lb) capable of holding the larger 765 g gel packs might provide greater cooling capacity and still fit comfortably under the firefighting ensemble. Therefore, the purpose of this study was to evaluate and compare the effectiveness of a small 4-pack cool vest and large 4-pack cool vest, on heat strain reduction and tolerance time in men dressed in dungarees, firefighting ensemble (FFE), oxygen breathing apparatus while resting and exercising in a hot/humid environment.

METHODS

Subjects.

Eight males, experienced in U.S. Navy firefighting procedures and equipment, served as subjects (24±4 yrs; 174.2±6.4 cm; 73.3±7.4 kg; 1.88±.1 m^2; 13.4±4.1 % body fat; 41.5±4.0 $ml \cdot kg^{-1} \cdot min^{-1}$ VO_2max). Each subject gave informed consent prior to participation in the study.

Medical Screening.

Before the heat exposure trials, all subjects underwent medical screening which included a medical history questionnaire, body composition assessment, and resting electrocardiogram (ECG). Body surface area indicated in 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 at the neck and abdominal regions (Hodgdon & Beckett, 1984).

All subjects completed an incremental treadmill exercise test to voluntary exhaustion (Bruce et al., 1973). Skin surface ECG electrodes were placed on each subject's chest according to the Mason-Liker configuration. Two ECG electrodes were placed on the upper chest near the shoulders and two others on the waist towards the sides of the body. Six ECG electrodes were also placed on the chest around the lower border of the left pectoralis major muscle. Resting ECG and measures of heart rate (HR) and blood pressure were taken in supine, seated, and standing positions. Peak HR was recorded as the highest HR obtained during the graded treadmill exercise. Throughout walking recovery, the subject's HR and blood pressure were monitored until return to resting values. Pulmonary oxygen uptake (VO_2) and carbon dioxide production (VCO_2) were measured continuously during exercise using a breath-by-breath open circuit system (MedGraphics, Inc., St. Paul MN 55127).

Experimental Procedures.

The previous night and the morning of the heat exposure test, subjects were instructed to drink 1 liter of fluid (non-caffeinated beverages) to ensure normal body hydration. Euhydration was accepted if urine collected prior to each heat exposure trial possessed a specific gravity <1.030.

The ambient conditions were 48±0.5°C (118±0.9°F) dry bulb (DB), 37±0.1°C (99±0.2°F) wet bulb (WB), and 41±0.2°C (104±0.4°F) wet bulb globe temperature (WBGT). The relative humidity was 50%. During the heat exposure trials, each subject attempted to complete as many cycles as possible of 30 min seated rest and 30 min walking on a motorized treadmill at 1.56 $km \cdot hr^{-1}$/2.5 mph and 0% grade.

All subjects participated in three randomly ordered counterbalanced trials. The trials were: 1) no vest (NV), 2) small 4-pack CV (CV_S), and 3) large 4-pack CV (CV_L). Total weight of CV_S equalled 2.72 kg (5 lb), while CV_L weighed 3.63 kg (8 lb).

During each test, subjects wore the U.S. Navy dungaree uniform as the undergarment. This consisted of cotton T-shirt, long sleeve cotton shirt, denim pants, socks, and boondocker boots. The protective overgarment consisted of the standard U.S. Navy FFE. This ensemble included flash hood, hard helmet with plastic visor, gloves, single-piece fire-retardant suit, and an oxygen breathing apparatus (OBA). In the vest trials, the cool vest was worn over dungarees and under the FFE. The cool vests (Steele, Inc., Kingston, WA 98346) contained four gel thermostrips, frozen and maintained at -28°C until use. Each thermostrip for the CV_S weighed 425 grams (15 oz), while each thermostrip for the CV_L weighed 765 grams (27 oz). Both 4-pack vests had two thermostrips placed vertically on the front and two strips placed horizontally on the back. The pockets of each type of vest were insulated with Thinsulate.

Prior to each heat exposure test, subjects inserted a rectal thermistor to a depth of 20 cm in the rectum. Skin temperature thermistors were placed over the right deltoid, upper right pectoralis, mid-lateral vastus lateralis, and mid-lateral gastrocnemius muscles. Three ECG electrodes were placed on the chest to monitor HR. Rectal temperature (T_{re}), skin temperatures, and HR were recorded at one minute intervals by a portable data logger (Science/Electronics, Miamisburg, OH 45342). The data logger was worn outside the FFE. Heart rate was also recorded by a Polar Heartwatch (Polar, USA, Inc., Stamford, CT 06902).

Throughout each test, subjects were asked to rate their perception of physical exertion and thermal sensation at 15 min intervals. Subjects became familiar with the scales during pre-test briefings. Ratings of perceived exertion (RPE) were determined from the Borg 15 point scale (Borg, 1982), while ratings of thermal sensation (TS) were determined using an eight point scale (Young, 1987). TS included an overall body rating as well as ratings from five local body areas (head, neck, chest, arms, and legs).

Pulmonary VO_2 and VCO_2, and cardiac output (Q_c) were measured once in the middle of each rest and exercise period. The hard helmet and OBA were removed and the subject's pulmonary VO_2 and VCO_2 were measured for 2 min using a metabolic measurement system (Med-Graphics, Inc., St. Paul, MN 55127). Energy expenditure (W) was calculated from VO_2 and VCO_2. Cardiac Output was determined by the equilibration method (Winsborough et al., 1980). The rebreathing gas contained 12% CO_2 in a balance of oxygen. Heart rate was measured concurrently to determine stroke volume (SV) which was calculated by dividing Q_c by HR. Immediately after measurement of energy expenditure and Q_c, subjects were allowed to drink as much water as desired.

Mean skin temperature (T_{msk}) was calculated as the four skin temperatures (chest, shoulder, thigh, and calf) using a weighted equation (Ramanathan, 1964). Mean body temperature (T_{mb}) was calculated from T_{re} and T_{msk} according to a weighted equation (Stolwijk & Hardy, 1966). Body heat content (BHC) was calculated using T_{mb}, body weight in kilograms, and the specific heat of the body ($3.48\ kJ \cdot kg^{-1} \cdot {}^{\circ}C^{-1}$). Body heat storage (HS, $kJ \cdot kg^{-1}$) equalled the difference between peak and resting BHC values. Rates of HS were calculated, for each rest and exercise period, as the change in BHC ($W \cdot m^{-2}$) over time. Total body sweat loss, in liters, was calculated as the difference between pretest and posttest nude body weight with the posttest weight corrected for water intake and urine output. Fluid balance (Liters) was calculated as the sum of water intake, urine output, and sweat loss.

Removal of subjects from heat exposure and the recording of heat exposure tolerance time were based on the following criteria: 1) attainment of 39.5°C T_{re} during exercise, or 39.2°C T_{re} during rest; 2) rise in T_{re} of greater than 0.5°C per 5 min of exposure duration, excluding the initial 10 min of exercise; 3) HR greater than 80% and 90% of maximum for a 5 min period during rest and exercise, respectively; 4) absence of sweating or presence of chills, nausea, weakness, or dizziness; or 5) subject desired to terminate heat exposure.

Statistical Analysis.

Data was statistically analyzed by a one-way and two-way analysis of variance with repeated measures. In the presence of a significant omnibus F-ratio, comparison of means was conducted using the Newman-Keuls post hoc test. Significance is reported at $p<.05$.

RESULTS

Tolerance Time.

Heat exposure tolerance time for CV_S (58.3±15.6 min) and CV_L (60.1±10.4 min) were significantly ($p<.05$) longer than NV (49.9±6.2 min). Only one NV subject finished the first 30 min exercise period compared to two and four subjects for CV_S and CV_L, respectively. No subject for any trial reached 90 min of heat exposure. Tolerance time based on attaining 90% maximum HR, occurred in five of eight NV subjects compared to three of eight subjects for both CV_S and CV_L. Tolerance time based on physical symptoms of general fatigue, headache, and feeling very "hot" accounted for 13 of 24 terminations from heat exposure.

Energy Expenditure and Cardiovascular Responses.

Differences in energy expenditures among trials were non-significant during the first 30 min rest and exercise period averaging 84±22 W and 395±52 W, respectively. Differences in HR among trials were also non-significant during seated rest and exercise (Figure 1). During the first exercise period, differences in peak HR (172±21 bpm) among trials were non-significant. Q_c and SV were significantly ($p<0.5$) higher during exercise (12.2±2.3 $L \cdot min^{-1}$ and 79±17 $ml \cdot bt^{-1}$) compared to rest (4.5±1.2 $L \cdot min^{-1}$ and 54±13 $ml \cdot bt^{-1}$), but differences among trials were non-significant.

Body Temperature and Heat Storage.

During heat exposure, T_{re} (Fig. 2), T_{msk} (Fig. 3), and T_{mb} increased progressively. For all trials, the rate of increase in T_{msk} was greater ($p<.05$) than the increase in T_{re}, resulting in thermal convergence between 20 to 25 min of the first 30 min rest period. However, there was no difference among trials in the rate of rise of T_{re}, T_{msk}, and T_{mb} during the first rest period.

During the first 30 min exercise period, the rate of rise in T_{re} for NV averaged 3.3°C·hr^{-1} compared ($p<.05$) to a rate of 2.6°C·hr-1 for CV_S and CV_L. In contrast, differences in the rate of increase for T_{msk} during exercise were non-significant among trials and averaged 4.1±1.0°C·hr^{-1} for NV, CV_S, and CV_L. The rate of increase in T_{mb} for NV averaged 3.4±0.8°C·hr^{-1}, which was greater ($p<.05$) than the increase of 2.9±0.5°C·hr^{-1} for CV_S and CV_L. Consequently, the rate of increase in HS during exercise (Figure 4) averaged 111.7±29.3 W·m^{-2} for NV, which was greater ($p<.05$) than the rates of 96.2±17.9 W·m^{-2} for CV_S and 96.7±20.5 W·m^{-2} for CV_L.

Despite differences in the rates of increase in T_{re} and T_{mb} during the first exercise period between NV and cool vest trials, differences among trials in peak values for T_{re} (38.3±0.5°C), T_{msk} (38.5±0.5°C), T_{mb} (38.3±0.4°C), and HS (6.53±1.2 kJ·kg^{-1}) were non-significant for NV, CV_S, and CV_L. Differences in total sweat loss (0.9±0.6 L) and fluid balance (-0.25±0.49 L) were non-significant among trials.

Rates of Perceived Exertion and Thermal Sensation.

RPE varied with HR and energy expenditure during rest and exercise. However, differences among trial for RPE were non-significant during rest (8.5±2.4) and exercise (14.0±2.6). Overall TS increased significantly overtime, but differences in responses among trials were non-significant for rest (4.8±0.7) and exercise (5.8±0.6). Chest TS was significantly ($p<.05$) reduced for both vest trials compared to NV, while all other differences in regional TS were non-significant among trials.

DISCUSSION

Effect of Cool Vests on Exposure Tolerance Time and Cardiac Responses.

Heat exposure tolerance times were significantly longer for both CV_S and CV_L compared to NV, but differences in tolerance time between the two vests were non-significant. The lack of difference between CV_S and CV_L is likely due to the impact of the hot/humid environment on HS relative to the heat absorption capacities of the frozen gel packs. Also, the prolonged rest and exercise phases of the exposure protocol likely had a profound impact on the demand for skin blood flow and HR predisposing the subjects to early attainment of medical termination criteria from heat exposure. This explanation is supported by the fact that 96% of terminations from heat exposure were due to general fatigue, headache, feeling "hot," or attaining a HR of 90% of maximum.

During the first rest period, HR increased slowly for all trials. During the first exercise period, HR increased rapidly for all subjects. However, the NV subjects experienced more terminations from heat exposure as a result of reaching 90% of HR maximum. The rapid increase in HR observed for all trials is likely due to a decrease in central blood volume and SV, and splanchnic and renal vascular vasoconstriction as a result of doubling skin blood flow (Rowell, 1983). In our study, exercise Q_c averaged 12.2 $L \cdot min \cdot .^{-1}$ This value is higher than the expected 10.5 $L \cdot min^{-1}$ value for exercise of a similar energy expenditure conducted in a thermoneutral environment (Nadel et al., 1979). Although Q_c and SV during rest and exercise, and peak HR during exercise were similar among trials, use of CV_S and CV_L reduced the number terminations from heat exposure due to elevated HR, and thus, contributed to a significant increase in heat tolerance exposure time.

Effect of Cool Vests on Body Temperatures and Heat Storage.

In this study, differences in peak T_{re}, T_{msk}, T_{mb}, and HS among trials were non-significant. HS for all trials averaged 6.5 $kJ \cdot kg^{-1}$ which was 27% below the predicted maximum tolerable level of 8.9 $kJ \cdot kg^{-1}$ (Shvartz and Benor, 1972). Thus, in this study, HS does not appear to have been a critical factor to tolerance time. However, during the first exercise period, the rate of HS was 16% greater for NV compared to CV_S and CV_L, suggesting that rate of body heat storage was a critical factor in heat exposure tolerance time. Thus, our findings suggest that CV_S and CV_L were responsible for the lower rate of HS, thus contributing to longer tolerance times.

The lower rate of heat storage during exercise, and overall similarity in physiological responses during heat exposure between CV_S and CV_L, may be related to the heat conduction capacities of the frozen gel packs and the amount of available cooling surface area of the vests. Heat conduction, defined as the transfer of energy arising from temperature differences between adjacent objects, is dependent upon surface area, temperature gradient, and thermal conductivity of the object with the lower temperature. Although the weight of the coolant (1.7 kg) in CV_S was 58% of CV_L gel packs (3.06 kg), the total cooling surface area for CV_S (1449 cm^2) was 78% of the surface of CV_L (1863 cm^2). Thus, the similar tolerance times for CV_S and CV_L appear to be related more to their similar surface areas than to the weight of the gel packs.

Effect of Cool Vests on RPE and TS.

In this study, differences among trials for RPE were non-significant during both rest and exercise. During seated rest, the relationship between RPE and HR was similar to exercise in thermoneutral environmental conditions (Borg, 1982), i.e., HRs of 75-95 bpm corresponded to "very light" RPE. However, walking at 395 W elicited HRs from 150 to 190 bpm and RPE responses of "somewhat hard" to "hard." In a thermoneutral environment, HRs of 150-190 usually produce RPE values of "hard" to "very very hard." Thus, during exercise RPE did not correspond to the normal HR-RPE regression formula. This alteration may be due to the higher Q_c and skin blood flow demanded by exercise in the hot/humid environment and weight distribution over the body of the 20 kg of protective clothing and OBA. This suggests that RPE is a poor indicator of physical exertion under these conditions. This finding is consistent with the findings from our previous study (Bennett et al 1993b). Thus, in this study, CV_S and CV_L had no effect on RPE values.

The perception of thermal sensation closely parallels skin temperature (Gagge et al., 1967). In this study, overall TS increased throughout heat exposure in accordance with the increases in T_{re} and T_{msk}. However, T_{msk} was similar among trials, so it is not surprising that overall TS and most of the regional TS responses were similar among trials. The significantly lower chest TS for both vest trials compared to NV is a reflection of the lower chest skin temperature as a result of wearing the cool vest. Thus, CV_S and CV_L had no effect on overall TS and TS values of regions not covered by the cool vests.

SUMMARY

The CV_S and CV_L significantly increased tolerance time during rest and exercise in a hot/humid environment of 48°C and 50% rh. The CV_S and CV_L also were associated with slower rates of increase in T_{re} and T_{mb} and rate of body HS. However, the relative merits of the CV_S and CV_L could not be distinguished in this study, perhaps as a result of the extreme environmental conditions and prolonged rest and exercise phases of the exposure protocol. It is likely, that the initial 30 min rest period produced redistribution of blood to the skin and central hypovolemia, and a corresponding increase in heart rate during the initial exercise period. The rapid increase in heart rate during exercise resulted in a large percentage of terminations from heat exposure as a result of sustained elevations in HR. Despite this limitation, our findings indicate that small 4-pack and large 4-pack cool vests worn over dungarees and under the FFE attenuate the rate of increase in heat strain and prolong heat exposure tolerance time in a hot/humid environment.

REFERENCES

Banta, G. R. & Braun, D. E. (1992). Heat strain during at-sea helicopter operations and the effect of passive microclimate cooling. Aviation Space and Environmental Medicine, 63, 881-885.

Bennett, B. L., Hagan, R. D., Banta, G. R., & Williams, F. R. (1993a). Physiological responses during shipboard firefighting. (NHRC Technical Report 93-9). San Diego, CA: Naval Health Research Center.

Bennett, B. L., Hagan, R. D., Huey, K. A., Minson, C., & Cain, D. (1993b). Comparison of two cool vests on heat-strain reduction while wearing a firefighting ensemble in a hot/humid environment. (NHRC Technical Report 93-10). San Diego, CA: Naval Health Research Center.

Borg, G. A. V. (1982). Psychophysical bases of perceived exertion. Medicine and Science in Sports and Exercise, 14, 377-381.

Bruce, R. A., Kusumi, F., & Hosmer, D. (1973). Maximal oxygen intake and nomographic assessment of functional aerobic impairment in cardiovascular disease. American Heart Journal, 85, 546-562.

Carpenter, T. M. (1964). Tables, factors, and formulas for computing respiratory exchange and biological transformations of energy. (Publication 303C). Washington, DC: Carnegie Institution of Washington.

Gagge, A. P., Stolwijk, J. A. J., & Hardy, J. D. (1967). Comfort and thermal sensations and associated physiological responses at various ambient temperatures. Environmental Research, 1, 1-20.

Hodgdon, J. A., & Beckett, M. B. (1984). Prediction of percent body fat for U.S. Navy men from body circumferences and height. (NHRC Technical Report 84-11). San Diego, CA: Naval Health Research Center.

Janik, C. R., Avellini, B. A., & Pimental, N. A. (1987). Microclimate cooling systems: Shipboard evaluation of commercial models. (NCTRF Technical Report 163). Navy Clothing and Textile Research Facility.

Nadel, E. R., Cafarelli, E., Roberts, M. F., & Wenger, C. B. (1979). Circulatory regulation during exercise in different ambient temperatures. Journal of Applied Physiology, 46, 430-437.

Nunneley, S. A., Antunano, M. J., & Bomalaski, S. H. (1992). Thermal convergence fails to predict heat tolerance limits. Aviation Space and Environmental Medicine, 63, 886-890.

Pandolf, K. B., & Goldman, R. F. (1978). Convergence of skin and rectal temperatures as a criterion for heat tolerance. Aviation Space and Environmental Medicine, 49, 1095-1101.

Pimental, N. A. & Avellini, B. A. (1989). Effectiveness of three portable cooling systems in reducing heat stress. (NCTRF Technical Report 176). Navy Clothing and Textile Research Facility.

Pimental, N. A., Avellini, B. A., & Banderet, L. E. (1991). Comparison of heat stress when the Navy fire fighters ensemble is worn in various configurations. (NCTRF Technical Report 192). Navy Clothing and Textile Research Facility.

Ramanathan, N. L. (1964). A new weighing system for mean surface temperatures of the human body. Journal of Applied Physiology, 21, 1757-1762.

Rowell, L. B. (1983). Cardiovascular aspect of human thermoregulation. Circulation Research, 52, 367-379.

Shvartz, E. & Benor, D. (1972). Heat strain in hot and humid environments. Aerospace Medicine, 43, 852-855.

Speckman, K. L., Allan, A. E., Sawka, M. N., Young, A. J., Muza, S. R., & Pandolf, K. B. (1988). Perspectives in microclimate cooling involving protective clothing in hot environments. International Journal of Industrial Ergonomics, 3, 121-147.

Stolwijk, J. A. J., & Hardy, J. D. (1966). Partitional calorimetric studies of responses of man to thermal transients. Journal of Applied Physiology, 21, 967-977.

Wenger, C. B. (1988). Human heat acclimatization. In K. B. Pandolf, M. N. Sawka, & R. R. Gonzalez (Eds.), Human Performance Physiology and Environmental Medicine at Terrestrial Extremes. (pp. 153-197). Indianapolis, IN: Benchmark Press, Inc.

Winsborough, M., Miller, J. N., Burgess, D. W., & Laszlo, G. (1980). Estimation of cardiac output from the rate of change of alveolar carbon dioxide pressure during rebreathing. Clinical Science, 58, 263-270.

Young, A. J., Sawka, M. N., Epstein, Y., Decristofano, B., & Pandolf, K. B. (1987). Cooling different body surfaces during upper and lower body exercise. Journal of Applied Physiology, 63, 1218-1223.

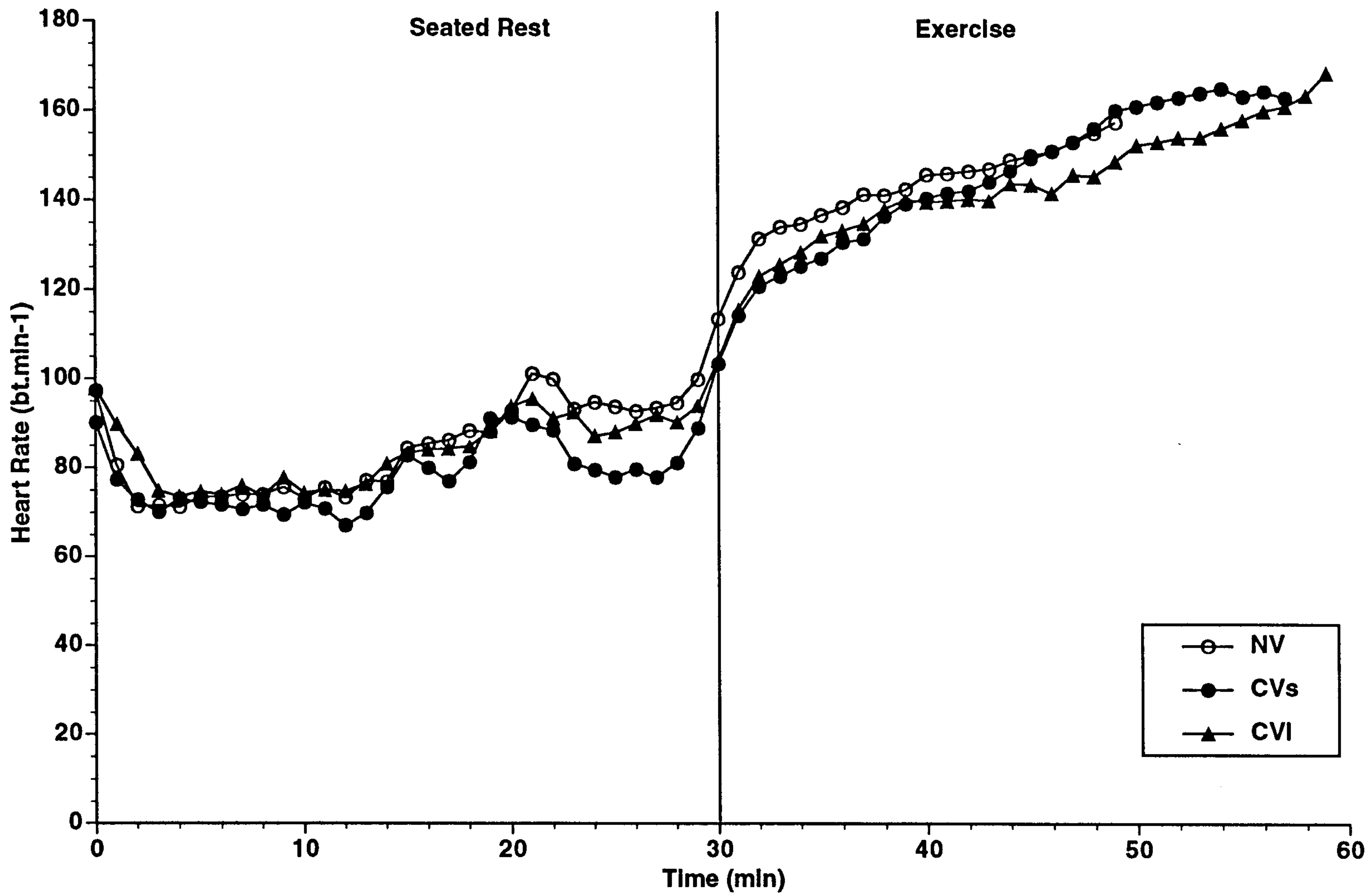

Figure 1. Heart rate during rest and exercise.

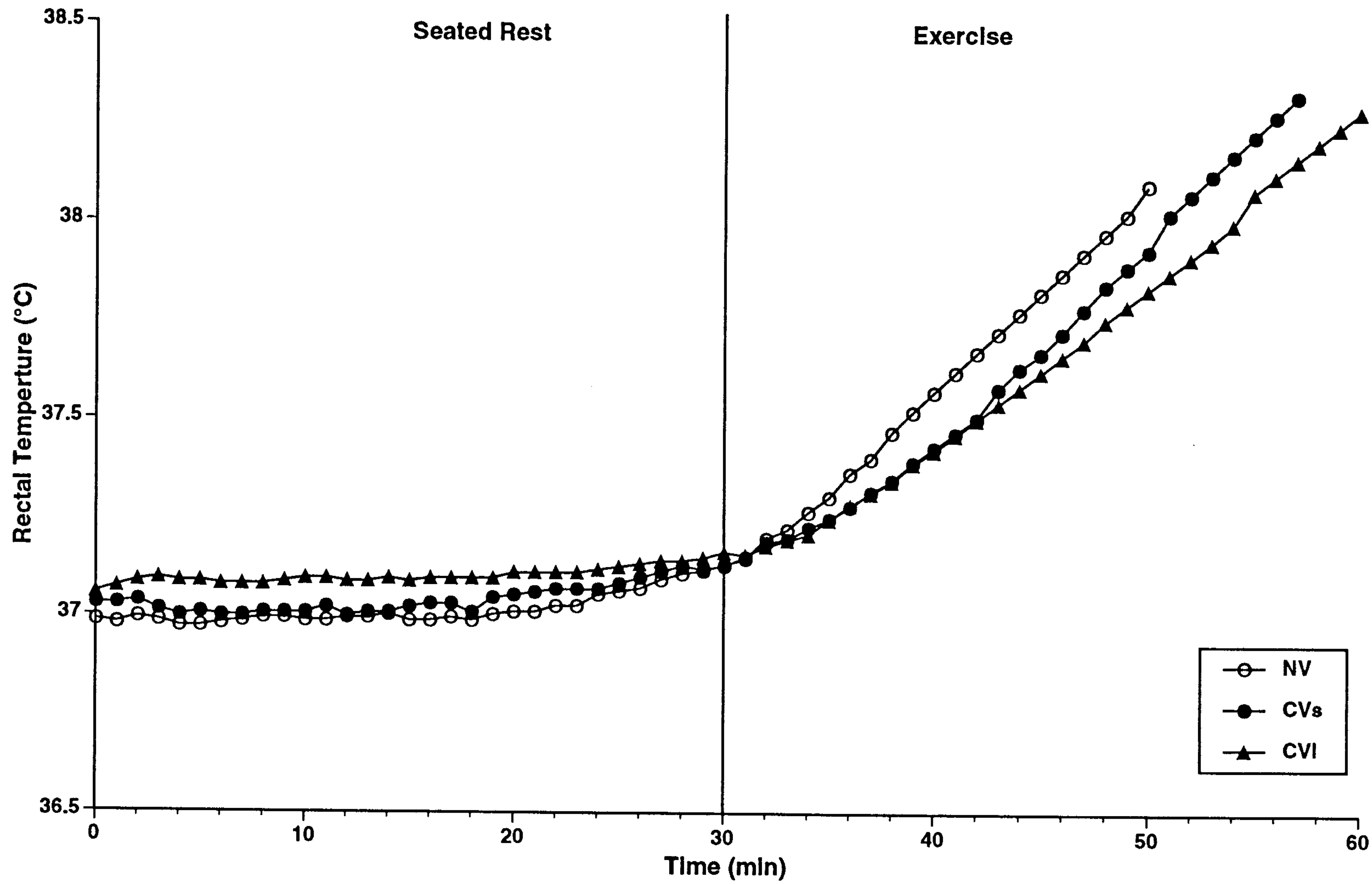

Figure 2. Rectal temperature during seated rest and exercise.

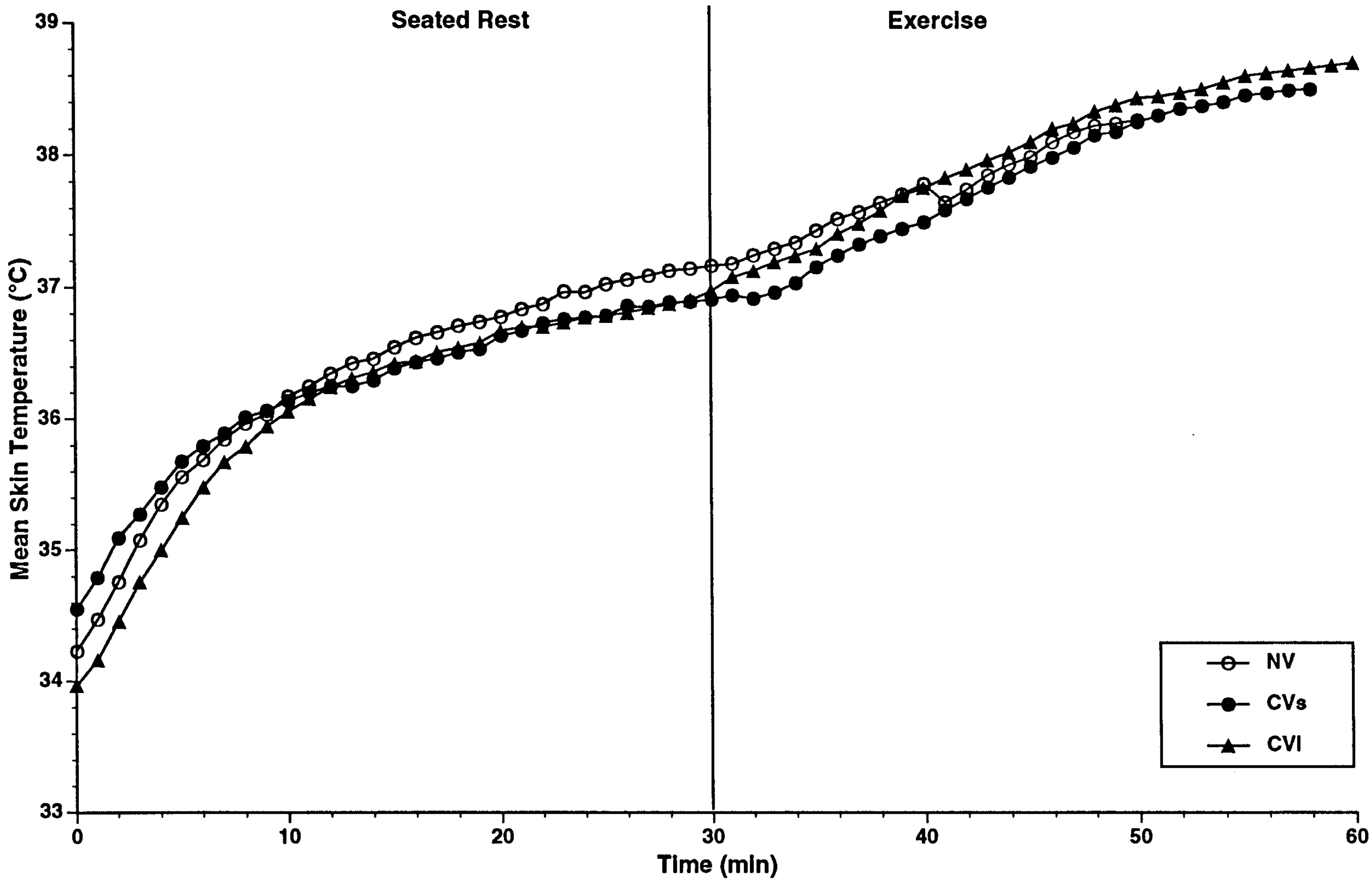

Figure 3. Mean skin temperature during seated rest and exercise.

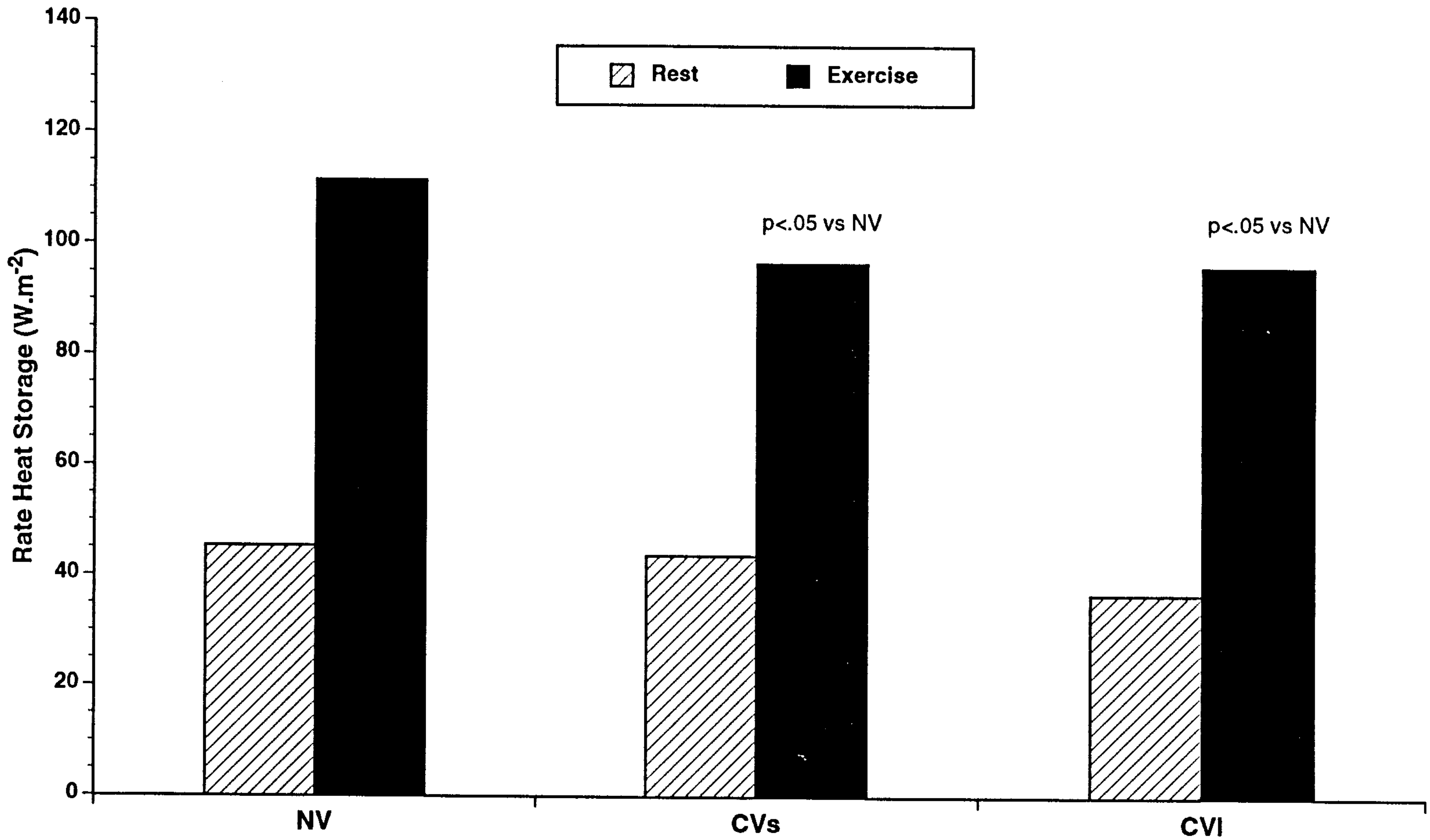

Figure 4. Comparison of rate of heat storage during rest and exercise.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1994

3. REPORT TYPE AND DATE COVERED
New Feb 93 - Sep 93

4. TITLE AND SUBTITLE
Cool Vests Worn Under Firefighting Ensemble Increase Tolerance to Heat

5. FUNDING NUMBERS
Program Element: 63706N
Work Unit Number: M0096-004-6301

6. AUTHOR(S)
R.D. Hagan, Ph.D., K.A. Huey, M.S., CDR B.L. Bennett, MSC, USN

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Health Research Center
P. O. Box 85122
San Diego, CA 92186-5122

8. PERFORMING ORGANIZATION
Report No. 94-6

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Medical Research and Development Command
National Naval Medical Center
Building 1, Tower 2
Bethesda, MD 20889-5044

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Firefighting in the Navy firefighting ensemble (FFE) prevents heat dissipation while exposure to high temperatures leads to progressive heat gain. Previous studies in air up to 35°C show that cool vests worn under FFE reduce heat strain. However, the effectiveness of cool vests on heat strain during exposure to hot/humid air is unknown. The purpose of this study was to compare a small 4-pack vest (CV_S) and a large 4-pack vest (CV_L) in minimizing heat strain in men dressed in the Navy FFE, while resting and exercising in hot/humid air (48°C/118°F, 50% rh). Eight males attempted to complete as many cycles as possible of 30 min rest and 30 min walking during three trials (no vest, CV_S, and CV_L). Measurements included rectal and four skin temperatures, and heart rate. Tolerance time for CV_S (58.2±15.8 min) and CV_L (60.1±10.4 min) were longer ($p<.05$) than NV (49.9±6.2 min). During the first exercise period, rate of heat storage was greater ($p<.05$) for NV (111.7±29.3 $W \cdot m^{-2}$) compared to CV_S (96.2±17.9 $W \cdot m^{-2}$) and CV_L (96.7±20.5 $W \cdot m^{-2}$). Our findings indicate that cool vests worn under the firefighting ensemble attenuate rate of heat storage and prolong heat exposure tolerance time in a hot/humid environment.

14. SUBJECT TERMS
Heat Strain, Heat Strain Countermeasures, Firefighting Protective Clothing

15. NUMBER OF PAGES
18

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited