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Heat Stress Induced by the Navy Fire Fighter's Ensemble Worn in Various Configurations

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Research Facility
and
U.S. Army Research Institute of
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13. ABSTRACT (Maximum 200 words) The Navy Clothing and Textile Research Facility conducted a laboratory evaluation to compare heat stress when the Navy Fire Fighter's Ensemble (NFFE) is worn in three configurations: 1) coverall "buttoned up" with anti-flash hood, helmet and gloves worn, 2) coverall unzipped with hood around neck and no helmet or gloves worn, and 3) coverall down around the waist with hood around neck and no helmet or gloves worn. The effectiveness of a selected cooling vest in reducing this heat stress was also examined. Nine test volunteers underwent six, 2-hour heat exposures (three NFFE configurations with and without the cooling vest). Environmental conditions were 90°F dry bulb temperature with 60% relative humidity. During the heat exposures, the test volunteers alternated seated rest with walking at 3.5 mph on a treadmill every 15 minutes. These conditions were chosen to simulate a training drill during which the level of physical exercise is low. Thermal strain, as measured by rectal temperature, skin temperatures, heart rate and sweating rate, was greatest when the NFFE was buttoned up. Unzipping the coverall resulted in a moderate decrease in thermal strain. When the coverall was worn down around the waist, all indicators of thermal strain were significantly reduced. Use of the cooling vest in both the buttoned up and unzipped configurations significantly reduced thermal strain. When the coverall was worn down around the waist, and the level of thermal strain was only moderate, the vest only slightly reduced heat stress.

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BACKGROUND

The Navy Fire Fighter's Ensemble (NFFE) including the non-aluminized damage control coverall (MIL-C-24935) was introduced to the Fleet in 1988. During the following year and a half, some instances of heat stress problems related to use of the NFFE were reported. These problems were reported through ship messages, the Damage Control/Fire Fighting Conference, Personnel Injury Reports from the Naval Safety Center, and Heat/Cold Injury Reports (Form NAVMED 6500/1). The ship messages described problems with heat stress primarily during main space fire drills when personnel were fully dressed out in the NFFE and, in some cases, were also using an Oxygen Breathing Apparatus. In February of 1990, the Navy Board of Inspection and Survey compiled a summary document of shipboard heat injuries related to wearing the NFFE (1). The source of information for this document was all Heat/Cold Injury Reports (Form NAVMED 6500/1) for injuries reported during a 16-month period from October 1988 through January 1990. A total of 63 reports from 37 ships were summarized. When the heat injuries occurred, the average length of time the NFFE had been worn was 36 minutes. Environmental conditions averaged 81^{o}F Wet Bulb Globe Temperature (1). The injuries occurred mostly during training drills when personnel were engaged in very low levels of physical activity (A. Dasler, INSURV, personal communication). In most cases, personnel had been completely dressed out in the NFFE (A. Dasler, INSURV, personal communication).

In response to these reports of problems with heat stress when the NFFE was worn, the Naval Sea Systems Command (55X24, Personnel Protection Branch) requested the Navy Clothing and Textile Research Facility conduct a laboratory evaluation of the NFFE. The primary purpose of the evaluation was to measure heat strain when the NFFE is worn in a "buttoned up" configuration and to determine to what extent wearing the NFFE in a more relaxed or standby configuration alleviates this heat strain. The secondary purpose of the study was to examine the effectiveness of a selected cooling vest in reducing heat strain when used with the NFFE.

(1) INSURV Report 01B/19 Feb 90.

METHODS

Test Design. Nine physically fit males (average age, 23 yr; height, 69 in; weight, 165 lbs) served as test volunteers. Testing was conducted during June in a Climatic Chamber at the Navy Clothing and Textile Research Facility (Natick, MA). The subjects were initially heat acclimated to a hot-humid environment by undergoing daily, 2-hour heat exposures in a 95°F dry bulb, 88°F wet bulb (75% relative humidity) environment for 6 days. During the heat exposures, subjects wore the Navy utility uniform and performed light-to-moderate treadmill exercise (walk at 3.5 mph with 5 minutes of seated rest every half hour; time-weighted metabolic rate approximately 360 watts). Following the heat acclimation, each subject was tested six times in random order:

1. Fire Fighter's Ensemble "buttoned up" *
2. Above plus cooling vest
3. Fire Fighter's Ensemble with coverall unzipped **
4. Above plus cooling vest
5. Fire Fighter's Ensemble with coverall down around waist ***
6. Above plus cooling vest

* "Buttoned up" = Coverall zipped, hood, helmet and gloves worn
** Unzipped = Coverall unzipped, anti-flash hood around neck, no helmet or gloves worn
*** Down around waist = Coverall down around the waist, hood around neck, no helmet or gloves worn

During all tests, the Navy utility uniform (denim trousers, T-shirt, chambray shirt) was worn under the fire fighter's coverall (MIL-C-24935). The basic outershell material of the coverall is a 60% para-aramid (Kevlar)/40% polybenzimidazole (PBI) blend with a water repellant finish. The quilted lining consists of a layer of aramid batting fibers and a layer of flame resistant aramid pajama check cloth. The interlining consists of a microporous expanded polytetrafluoroethylene (PTFE) film laminated to a flame resistant aramid pajama check cloth. In the "buttoned up" configuration, subjects also wore the anti-flash hood (MIL-H-24936), the MK II fire fighter's helmet and the structural fire fighter's gloves (MIL-G-24934). In all tests, the Type A-4 Oxygen Breathing Apparatus (OBA) was carried (15 lbs). (Under heat stress conditions, some individuals experience difficulty using an OBA. Since the primary purpose of this study was to compare heat strain induced by the NFFE worn in different configurations during a simulated training drill, the OBA was carried but not used.) To prevent blisters caused by walking on the treadmill each day, subjects wore athletic socks and sneakers instead of fire fighter's boots. When the cooling vest was used, it was worn over both the T-shirt and chambray shirt. The vest is made by Steele, Inc. (Kingston, WA). It has an insulated, cotton canvas vest (NSN 8415-01-289-9797) that holds 10 lbs of frozen gel packs (NSN 8415-01-289-9798) against the torso. Total weight is 11 lbs.

Environmental conditions during the tests of the NFFE were 90°F dry bulb, 79°F wet bulb (60% relative humidity), with a 2 mph wind. These conditions result in a Wet Bulb Globe Temperature (WBGT) Index of 82°F. This temperature was chosen to approximate the mean WBGT Index reported in the INSURV summary document (1). Each test of the NFFE was 2 hours, or until one

of the termination points described below was reached. During the heat exposures, subjects alternately sat for 15 minutes (metabolic rate approximately 105 watts) and walked on a level treadmill at 3.5 mph (approximately 500 watts). The time-weighted metabolic rate was approximately 300 watts. This work/rest cycle was chosen to simulate a training drill during which the level of physical activity is low (D. Spadone, NAVSEA, personal communication; A. Dasler, INSURV, personal communication). To prevent the development of significant hypohydration during the heat exposures, subjects were encouraged to drink water, and consumption was monitored. Criteria for early termination included: rectal temperature greater than 103.1°F, or heart rate greater than 180 b/min for 5 minutes continuously during exercise or 160 b/min during rest. A subject also would be removed if he exhibited signs of impending heat injury, such as syncope, dry skin, or other unusual distress, or was unable to continue walking unassisted. Each subject also had the right to withdraw voluntarily at any time.

Measurements. During all heat exposures, rectal temperature was measured using a thermistor inserted approximately 5 inches beyond the anal sphincter. Chest, arm, and leg skin temperatures were measured using thermocouples. To prevent direct contact between the chest thermocouple and the cooling vest, the chest thermocouple was shielded. Mean weighted skin temperature was calculated according to the formula: 0.50(chest) + 0.36(leg) + 0.14(arm). Rectal and skin temperatures were plotted and printed every 2 minutes on a computer-controlled data acquisition system. The electrocardiogram was obtained using chest electrodes (CM5 placement) and displayed on an oscilloscope and cardiotachometer unit. Heart rates were recorded every 15 minutes (at the end of each exercise and each rest bout). Total body sweating rate was calculated from pre- and post-test nude body weight, adjusted for water consumption.

Self-ratings of physical symptoms were obtained using a condensed version of the Environmental Symptoms Questionnaire (ESQ, Appendix A) (2). Perceived well-being and estimated performance capabilities for military tasks and common activities were obtained using the Subjective States Questionnaire (SSQ, Appendix B) (3). The SSQ and the ESQ were administered during the first rest and exercise bouts (5 and 20 minutes), during the last rest and exercise bouts (95 and 110 minutes), and post-heat exposure (125 minutes). The questionnaires were administered verbally by a technician who announced each item and then paused briefly for the subjects to announce their ratings into a microphone. Each subject's response was recorded on a separate channel of an audio tape. The ESQ and the SSQ data were collected and analyzed by personnel from the U.S. Army Research Institute of Environmental Medicine.

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(2) Sampson, J. B., A. Cymerman, R. L. Burse, J. T. Maher, and P. B. Rock. Procedures for the measurement of acute mountain sickness. Aviat. Space Environ. Med. 54:1063-1073, 1983.

(3) Banderet, L. E., M. O'Mara, N. A. Pimental, R. H. Riley, D. T. Dauphinee, C. E. Witt, and R. M. Toyota. Subjective States Questionnaire: Perceived well-being and functional capacity. Proceedings, Military Testing Assoc., 1990, 339-344.

When the cooling vest was used, the gel packs were frozen in a blast freezer at -51°F and transferred to the test site in standard coolers. Upon removal from the freezer and during the transport time, the surface temperature of the gel packs rose rapidly to near freezing (32°F). During the 2-hour heat exposures in the present study, the packs did not require replacement due to melting.

Statistical Analysis. The data were statistically analyzed using repeated measures analyses of variance. Separate analyses were done on the data with and without the cooling vest for the three configurations of the NFFE. Additional analyses were also done on the data to compare cooling with no cooling when each of the three NFFE configurations was worn (separate analyses for each configuration). The sweating rate data were analyzed using one-way analyses of variance (NFFE configuration). The rectal temperature, skin temperature, and heart rate data were analyzed using two-way analyses of variance (NFFE configuration / time). Data points at 15-minute intervals were used (minutes 15, 30, etc., corresponding to the end of each rest and exercise bout). In the four instances where a subject was unable to complete the 120-minute heat exposure, the missing values were estimated using least squares, and the degrees of freedom were adjusted accordingly. Significance was accepted at the 0.05 level. Tukey's test was used to locate the significant differences.

Each item on the ESQ and the SSQ was analyzed with SPSS/PC+ (V3.0). A sensitivity analysis identified items that gave consistent significant differences for the different NFFE configurations compared with the NFFE buttoned up without cooling. Due to missing data caused by failures of the subjects to respond when they were uncomfortable or preoccupied with other activities (3), paired T-tests were used rather than analyses of variance. Outcomes were significant if $p<0.05$ (one-tailed).

RESULTS

Exposure Time. The total number of heat exposures was 54 (nine subjects x six tests). In four instances, a subject was unable to complete the 2 hours. This occurred three times when the ensemble was worn buttoned up without the cooling vest, and once when the ensemble was buttoned up with the vest. Tolerance times in those four cases ranged from 83-111 minutes. Early termination was due to reaching the heart rate limit (one case), or inability to continue walking due to nausea, cramps or weakness (three cases). In two of the three cases where an objective physiological limit was not reached, the subjects were within 0.6°F of the rectal temperature limit.

Rectal Temperature (Figures 1 and 2) - Comparison of NFFE Configurations. For the first 45 minutes of heat exposure, there were no significant differences in the rectal temperature response when the three configurations of the NFFE were worn without the cooling vest ($p>0.05$). From 60 minutes on, however, the rise in rectal temperature with the ensemble buttoned up was greater than with the coverall around the waist ($p<0.05$). By 90 minutes, rectal temperature increase with the ensemble buttoned up was also greater than with the coverall unzipped. From 75 minutes on, the rise in rectal temperature with the coverall unzipped was greater than with the coverall around the waist. After 2 hours of heat exposure, the increase in rectal

temperature averaged 3.3, 2.7 and 1.6°F with the ensemble buttoned up, unzipped, and around the waist, respectively. These differences were all statistically different from one another ($p<0.05$). When the cooling vest was used, there were no significant differences in the rectal temperature response among the three ensembles for the first 45 minutes of heat exposure. From 60 minutes on, the increase in temperature with the ensemble buttoned up was greater than with the coverall unzipped. From 90 minutes on, the increase in temperature with the ensemble buttoned up was also greater than with the coverall around the waist. After 2 hours, the increase in rectal temperature averaged 1.7, 1.3 and 1.2°F with the ensemble buttoned up, unzipped, and down around the waist, respectively.

Rectal Temperature - Comparison of Cooling vs. No Cooling. With the ensemble worn in the buttoned up configuration, there were no significant differences in the rectal temperature response between cooling and no cooling during the first hour of heat exposure. From 75 minutes on, however, the rise in rectal temperature was greater without the cooling vest than with the vest. After 2 hours of heat exposure, the rise in rectal temperature averaged 3.3°F without the cooling vest and 1.7°F with the vest. When the coverall was worn unzipped, the increase in rectal temperature from 45 minutes on was significantly greater without the vest compared with when the vest was used. After 2 hours, the rise in temperature averaged 2.7°F without the vest and 1.3°F with the vest. When the coverall was worn around the waist, there were no significant differences in the rectal temperature response except at the end of the 2 hours, when the increase in temperature without the vest was greater than with the vest by an average of 0.3°F.

Mean Weighted Skin Temperature (Figures 3 and 4) - Comparison of NFFE Configurations. When the cooling vest was not used, mean weighted skin temperature both with the ensemble buttoned up and with the coverall unzipped was greater than with the coverall around the waist, from 30 minutes on. From 75 minutes on, skin temperature with the ensemble buttoned up was also greater than with the coverall unzipped. Mean weighted skin temperature after 2 hours of heat exposure averaged 99.4, 97.7 and 95.8°F with the ensemble buttoned up, unzipped, and down around the waist, respectively. When the cooling vest was used, there were no statistically significant differences in mean weighted skin temperature among the three NFFE configurations during the 2-hour heat exposures. Skin temperature after 2 hours averaged 91.8, 89.5 and 88.6°F with the ensemble buttoned up, unzipped, and around the waist, respectively.

Mean Weighted Skin Temperature - Comparison of Cooling vs. No Cooling. When any of the three different NFFE configurations was worn, mean weighted skin temperature was significantly higher without the cooling vest compared with use of the cooling vest, at all time periods. With the ensemble buttoned up, mean weighted skin temperature after 2 hours averaged 99.4°F without the cooling vest and 91.8°F with the vest. With the coverall unzipped, skin temperature averaged 97.7°F without the vest and 89.5°F with the vest. When the coverall was worn down around the waist, skin temperature averaged 95.8°F without the vest and 88.6°F with the vest.

Heart Rate (Figures 5 and 6) - Comparison of NFFE Configurations. During the first rest and exercise bouts (15 and 30 minutes), there were no significant differences in heart rate responses among the three NFFE configurations when the cooling vest was not worn. At all other times, heart rate with the ensemble buttoned up was greater than with the coverall down around the waist. During the last three exercise bouts (60, 90 and 120 minutes) and during the last two rest periods (75 and 105 minutes), heart rate with the coverall unzipped was also greater than with the coverall around the waist. During the last rest period, heart rate with the ensemble buttoned up was greater than with the coverall unzipped. Heart rate at the end of the final rest period (105 minutes) averaged 120, 98 and 77 b/min with the ensemble buttoned up, unzipped, and around the waist, respectively. At the end of the final exercise bout (120 minutes), heart rate averaged 164, 151 and 125 b/min. When the cooling vest was used, heart rate was greater with the ensemble buttoned up than with the other two configurations during the first and last rest periods (15 and 105 minutes), and during the last two exercise bouts (90 and 120 minutes). Final heart rate during rest (105 minutes) averaged 84, 77 and 73 b/min with ensemble buttoned up, unzipped, and around the waist, respectively. Final heart rate during exercise (120 minutes) averaged 140, 129 and 125 b/min with buttoned up, unzipped, and around the waist, respectively.

Heart Rate - Comparison of Cooling vs. No Cooling. In the buttoned up mode, there were no significant differences in the heart rate response between cooling and no cooling during the first two rest bouts or during the first three exercise bouts. During the third and fourth rest periods (75 and 105 minutes) and during the last exercise bout (120 minutes), however, heart rate was significantly greater without the cooling vest than when the vest was used. Without the cooling vest, heart rate was greater than with the cooling vest by an average of 36 b/min during the final rest bout (105 minutes) and 24 b/min during the final exercise bout (120 minutes). When the NFFE was worn with the coverall unzipped, heart rate was significantly higher without the vest compared with use of the vest, from 60 minutes on. During the final rest and exercise bouts (105 and 120 minutes), heart rate was higher without the vest by an average of 21 and 22 b/min, respectively. When the coverall was worn down around the waist, there were no significant differences in the heart rate response between cooling and no cooling at any time period.

Sweating Rate (Figure 7). Total body sweating rate without the cooling vest was significantly greater with the ensemble buttoned up than with the other two configurations. Also, sweating rate with the coverall unzipped was greater than with the coverall down around the waist. Total body sweating rates averaged 688, 532 and 422 $g/m^2/h$ with the ensemble buttoned up, unzipped, and around the waist, respectively. When the cooling vest was used, sweating rate with the ensemble buttoned up was greater than with the coverall unzipped. Sweating rates averaged 403, 343 and 319 $g/m^2/h$ with buttoned up, coverall around the waist, and unzipped, respectively. With all three of the NFFE configurations, sweating rate was significantly higher without the cooling vest compared with use of the vest.

Environmental Symptoms Questionnaire (Figure 8). Different configurations of the NFFE resulted in different severities of symptoms. In general, the ensemble worn buttoned up (without cooling) produced more intense symptoms than when it was worn with the coverall unzipped, coverall around the waist, or coverall buttoned up with cooling.

Subjective States Questionnaire (Figure 9). Various configurations of the NFFE also resulted in different estimates of well-being and perceived capabilities for military tasks. The ensemble buttoned up without cooling resulted in lower estimates of well-being and performance capabilities than when it was worn with the coverall unzipped, around the waist, or buttoned up with cooling.

DISCUSSION

When the NFFE was worn in the "buttoned up" mode - with the coverall zipped and the anti-flash hood, helmet and gloves worn - the increase in rectal temperature after 2 hours in an 82°F WBGT environment was only 0.4°F lower than one of the physiological limits upon which the maximum safe exposure times of the Physiological Heat Exposure Limits (PHEL) curves are based (4). By unzipping the coverall and not wearing the hood, helmet or gloves, a moderate decrease in heat strain compared with wearing the NFFE in the buttoned up mode was obtained. Wearing the unzipped configuration for 2 hours, however, still resulted in a body core temperature that is associated with significant thermal discomfort and degradation in mental performance (5, 6). When the coverall was worn down around the waist, all indicators of thermal strain measured in this study - core temperature, skin temperatures, heart rate and sweating rate - were significantly reduced compared with the buttoned up and unzipped configurations. Core temperature after 2 hours of wearing the NFFE in this configuration was lower than the NIOSH Permissible Exposure Limit for an 8-hour period (7), and at a level normally associated with only slight decrements in mental performance (5, 6). From the observed rate of rise in temperature, it would be expected that the individual could continue under these conditions for at least 2 more hours before reaching the rectal temperature limit that was used as one criteria in the development of the PHEL curves.

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(4) Dasler, A. R. Heat stress, work function and physiological heat exposure limits in man. In: Thermal Analysis-Human Comfort-Indoor Environments, National Bureau of Standards, Washington, D.C., 1977.

(5) Blockley, W. V., and J. H. Lyman. Studies of human tolerance for extreme heat: III. Mental performance under heat stress as indicated by addition and number checking tests. Wright-Patterson AFB, OH: Technical Report 6521, 1951.

(6) Wilkinson, R. T., R. H. Fox, R. Goldsmith, I. F. G. Hampton, and H. E. Lewis. Psychological and physiological responses to raised body temperature. J. Appl. Physiol. 19: 287-291, 1964.

(7) Dukes-Dobos, F. N., and A. Henschel. Development of permissible heat exposure limits for occupational work. Am. Soc. Heat. Refrig. Air Cond. Eng. J. 15: 57-62, 1973.

In this study, there were no significant differences in the level of thermal strain during the first 30-45 minutes of heat exposure regardless of how the NFFE was worn. During this initial period of "obligatory" heat storage, there may be subjective differences in how comfortable or in how warm individuals wearing the ensembles feel. If physiological strain and not comfort is considered, it should be noted that there may be no differences between the configurations of the NFFE for short-term exposures of 45 minutes or less.

Symptomatology was less severe and estimates of well-being and performance capabilities were greater when the NFFE was worn unzipped, or worn around the waist, compared with when the coverall was worn buttoned up (without cooling). When the NFFE was buttoned up, use of the cooling vest resulted in decreased symptomatology, and improved ratings of well-being and performance capability compared with no cooling.

When the NFFE was worn buttoned up, and when it was worn in the unzipped configuration, use of the Steele cooling vest significantly reduced thermal strain. When the cooling vest was worn, the increase in core temperature after 2 hours of heat exposure was only half that of the uncooled conditions. Mean weighted skin temperature was significantly reduced, and heart rate was reduced by 21-36 b/min. Total body sweating rate was reduced by approximately 40%. When the coverall was worn around the waist, however, and overall thermal strain was only moderate, the vest further reduced heat stress only slightly. In that condition, the logistics involved in freezing and storing the gel packs probably do not warrant use of the cooling system.

In this evaluation, subjects were able to perform light exercise for about 2 hours while wearing the NFFE in a buttoned up configuration in an 82^{o}F WBGT environment. In the summary report of shipboard heat injuries when the NFFE was worn, average heat exposure time was only 36 minutes (1). There could be several reasons for this difference. There may have been differences in the initial physiological status of the laboratory test subjects compared with the shipboard personnel. The test subjects in the laboratory evaluation were heat-acclimated, well rested, and euhydrated before each test. During the heat exposures, water consumption was carefully monitored to prevent hypohydration. The shipboard personnel who were reported as heat injuries may not have been fully heat-acclimatized, may not have had adequate sleep (the average was 6 hours, with a range of 0-10 hours), may have performed other work before the fire fighting drill, or may have been hypohydrated. These factors alone or in combination impair heat tolerance. Some shipboard heat injuries that occurred after relatively short heat exposures may have been due to fainting. These drills may have involved standing for periods of time with no physical activity. Particularly in a hot environment, this results in venous pooling of the blood and can cause hypotension, which may lead to fainting. In the present study, the OBA was carried but not used. Use of a facemask or OBA by some individuals, particularly in hot environments, increases the likelihood of hyperventilation. If the OBA was in use during the shipboard training drills, it may have been a contributing factor in those cases where dizziness or fainting was reported. One further possibility for the difference in heat exposure time between the laboratory evaluation and the shipboard data is that different end-points were used to determine termination of the heat exposure. Under the controlled conditions

of the laboratory evaluation, termination criteria included rectal temperature above 103.1°F, or heart rate above 180 b/min for 5 minutes during exercise or 160 b/min during rest. During the shipboard drills when the NFFE was worn, the determination and subsequent reporting of heat injuries may have been because of other symptoms indicative of heat strain that occur before reaching those specific rectal temperature and heart rate criteria.

CONCLUSIONS

The present study demonstrated that, if the Navy Fire Fighter's Ensemble (NFFE) is worn with the coverall down around the waist, heat stress is greatly reduced compared with wearing the coverall just unzipped, or with wearing the ensemble completely buttoned up. While personnel may need to practice donning and wearing the complete ensemble, in warm weather it should be worn in this configuration for very limited time periods only. To significantly reduce thermal strain and the likelihood of a heat injury, it is recommended that during training drills the NFFE be worn in a "relaxed" mode with the coverall down around the waist and without the anti-flash hood, helmet or gloves worn. If the coverall cannot be worn down around the waist, thermal strain can be significantly reduced by using the Steele cooling vest. While the vest may be effectively used to reduce heat strain during training drills, use of the vest may be an unsafe practice in an actual fire fighting situation. Because of the potential for a burn injury, exposure times for fire fighting personnel may be limited to very short periods during high intensity fires. In this case, use of an auxiliary cooling device such as an ice vest may reduce overall thermal strain but does not decrease the potential for a burn injury. Because of this, the added comfort provided by the cooling vest may result in a false sense of well-being if worn during actual fire fighting.

Appendix A. Condensed version of The Environmental Symptoms Questionnaire. (The Environmental Symptoms Questionnaire (2) has 68 statements. In this evaluation, statements 15, 28, 31 and 34-37, which assess "coldness", were omitted.)

Rating scale: 0 = Not at all; 1 = Slight; 2 = Somewhat; 3 = Moderate; 4 = Quite a bit; 5 = Extreme

1. I feel light-headed.
2. I have a headache.
3. I feel sinus pressure.
4. I feel dizzy.
5. I feel faint.
6. My vision is dim.
7. My coordination is off.
8. I'm short of breath.
9. It's hard to breathe.
10. It hurts to breathe.
11. My heart is beating fast.
12. My heart is pounding.
13. I have chest pains.
14. I have chest pressure.
16. I have muscle cramps.
17. I have stomach cramps.
18. My muscles feel tight or stiff.
19. I feel weak.
20. My legs or feet ache.
21. My hands, arms, or shoulders ache.
22. My back aches.
23. I have a stomach ache.
24. I feel sick to my stomach (nauseous).
25. I have gas pressure.
26. I have diarrhea.
27. I'm constipated.
29. I have to urinate less than usual.
30. I feel warm.
32. My feet are sweaty.
33. I'm sweating all over.
38. Parts of my body feel numb.
39. My skin is burning or itchy.
40. My eyes feel irritated.
41. My vision is blurry.
42. My ears feel blocked up.
43. My ears ache.
44. I can't hear well.
45. My ears are ringing.
46. My nose feels stuffed up.
47. I have a runny nose.
48. I've been having nose bleeds.

Appendix A. (continued)

49. My mouth is dry.
50. My throat is sore.
51. I've been coughing.
52. I've lost my appetite.
53. I feel sick.
54. I feel "hungover."
55. I'm thirsty.
56. I feel tired.
57. I feel sleepy.
58. I couldn't sleep well.
59. My concentration is off.
60. I'm more forgetful lately.
61. I feel worried or nervous.
62. I feel irritable.
63. I feel restless.
64. I'm bored.
65. I feel depressed.
66. I feel alert.
67. I feel good.
68. I am hungry.

Appendix B. The Subjective States Questionnaire (3).

Rating scale: 0 = Not at all; 1 = Slight; 2 = Somewhat; 3 = Moderate; 4 = Quite a bit; 5 = Extreme

1. I feel "overwhelmed."
2. I feel "vulnerable."
3. Right now, I could answer most promotion board questions.
4. It would be more difficult than usual to understand new concepts that are being taught in a military class.
5. My thinking and other mental processes are at their "max."
6. It would require more effort than usual to tell someone how to "shoot an azimuth."
7. My vision seems especially sharp and clear.
8. My thoughts seem complete.
9. I feel like spit shining my boots and polishing my brass.
10. My body feels clumsy and awkward in this situation.
11. I could complete gas mask confidence training, including unmasking in the "gas chamber" with no difficulty.
12. It would take more effort than usual to complete a land navigation course.
13. I feel "out of touch" with my surroundings.
14. I feel confused.
15. I could easily play a difficult video game for 20-25 minutes.
16. My thinking seems "sluggish."
17. I am having trouble remembering some things now.
18. Staying in this study hardly seems worth it.
19. Sending a grid coordinate by radio would require greater effort than usual.
20. If I were driving a motor vehicle, my actions would seem "jerky" and "unconnected."
21. I could properly camouflage myself and my equipment.
22. I could remember spoken directions to a store a few miles from here.
23. If I were driving an automobile, I might commit traffic violations or cause accidents.
24. I would have trouble running 2 miles in anything near my normal time.
25. I can talk freely without stuttering.
26. A 2-3 hour G.I. party might be difficult to "deal with."
27. Telling even a short joke would require more effort than usual.
28. If a "password" and "challenge" were changed every two hours, it might be difficult for me to remember them.
29. I would probably miss some information in military radio messages, without some "say agains."
30. I feel disoriented.
31. I am as aware of feelings in my arms, legs, and body as I usually am.

32. It would be hard to be up for 24 hours of guard duty now.
33. I could disassemble and reassemble an M-16 correctly within time limits.
34. Detecting a soldier in BDUs in tall brush would take more effort than it usually does.
35. I feel as good as I usually feel.
36. I would confuse some of the azimuths with the direction they represent.
37. I feel "ate up."
38. My memory is working as well as it usually does.
39. I feel good enough to max at least one part of the PT test.
40. I would find it more difficult than usual to find a landmark such as railroad tracks on a map.

Appendix C. Illustrations

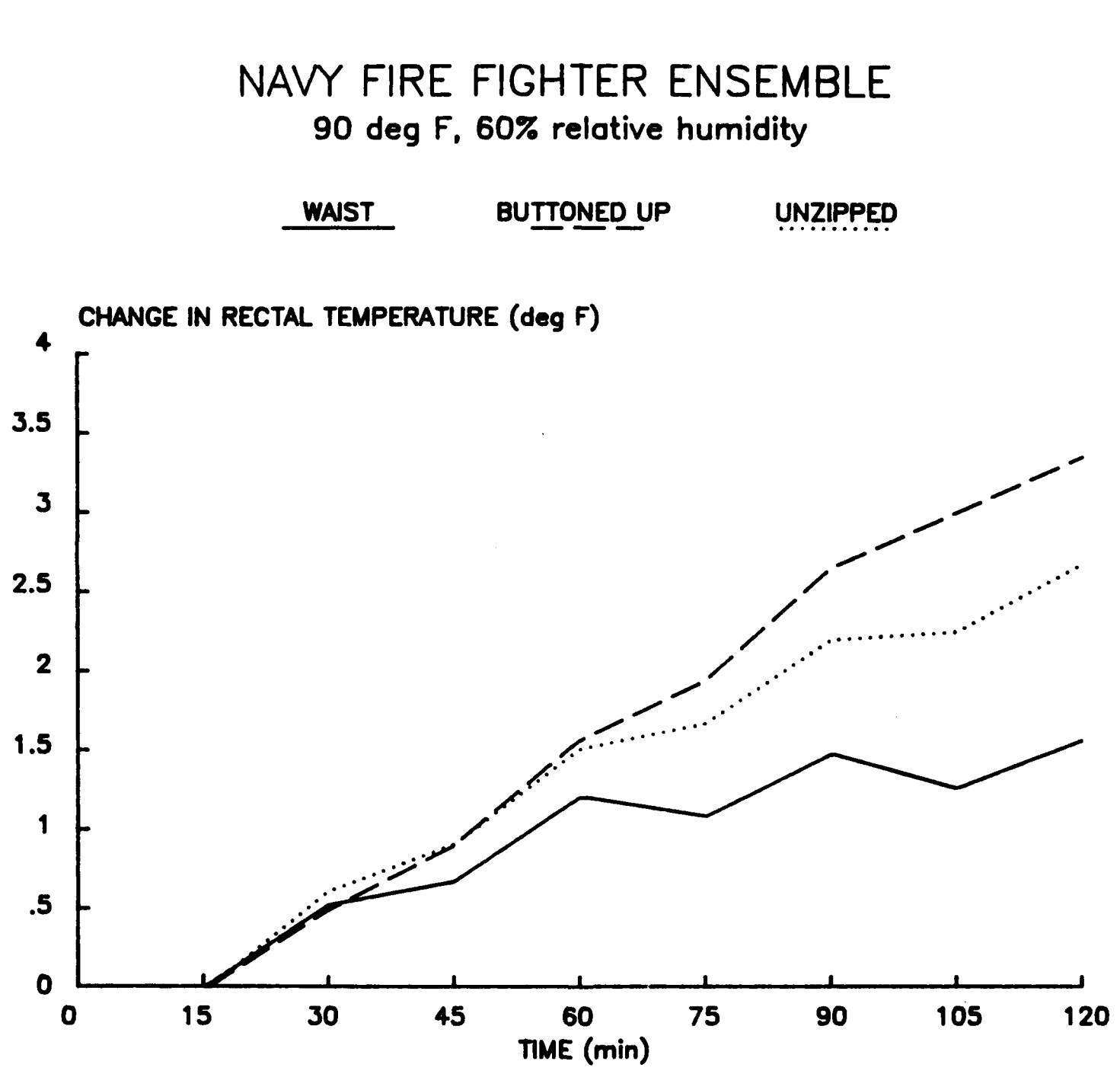

Figure 1. Change in rectal temperature when the fire fighter ensemble is worn.

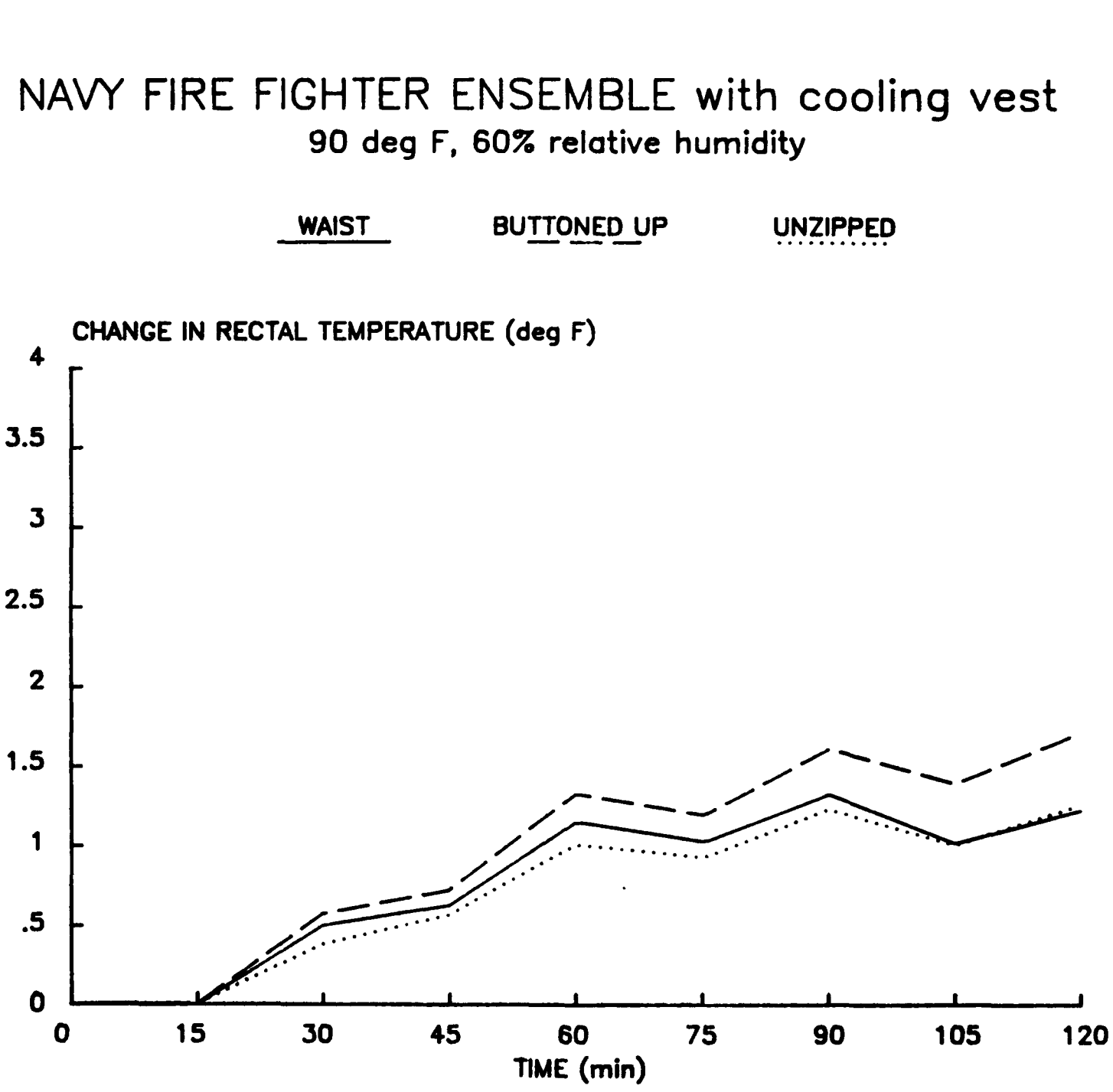

Figure 2. Change in rectal temperature when the fire fighter ensemble is worn with the cooling vest.

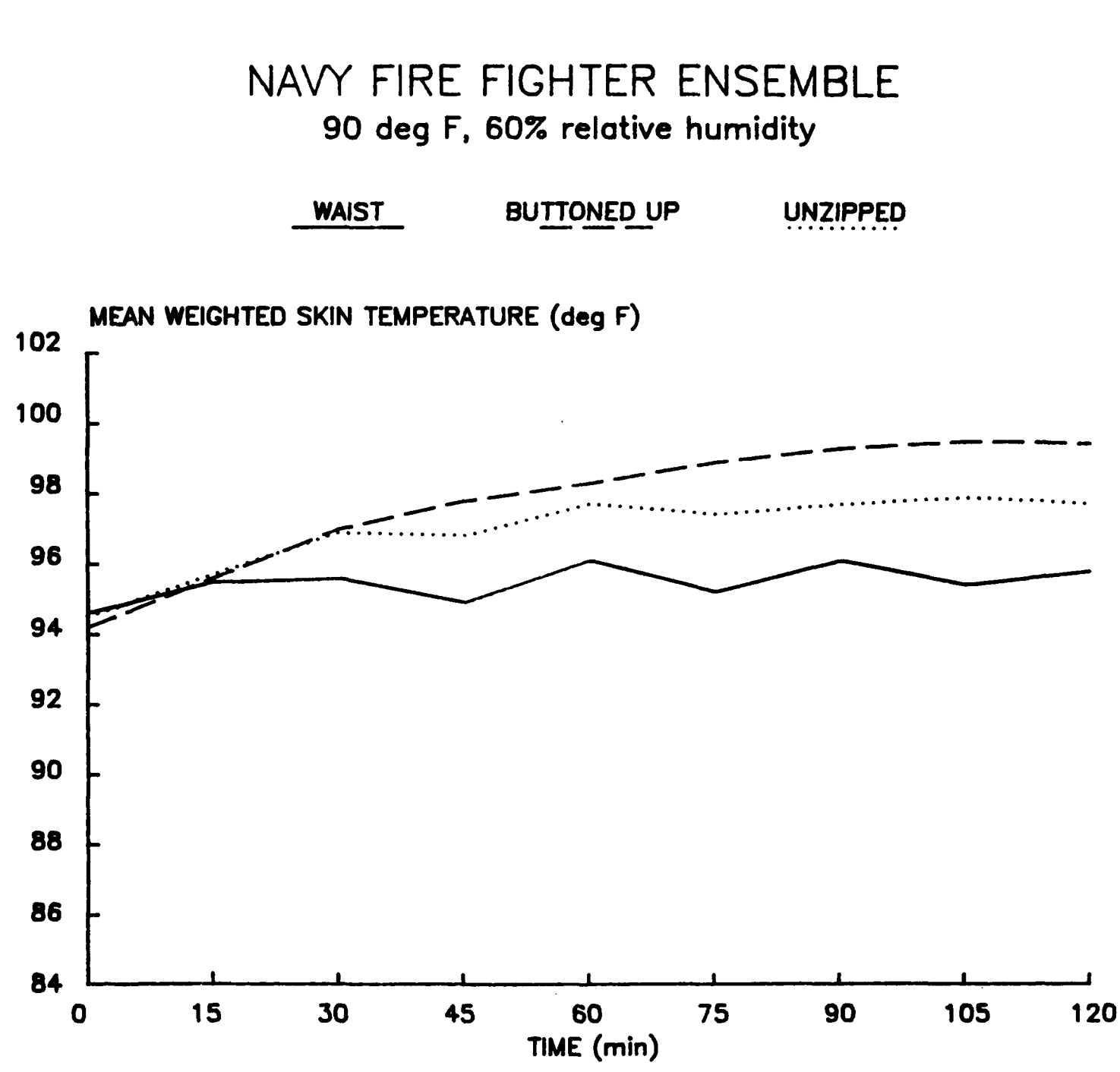

Figure 3. Mean weighted skin temperature when the fire fighter ensemble is worn.

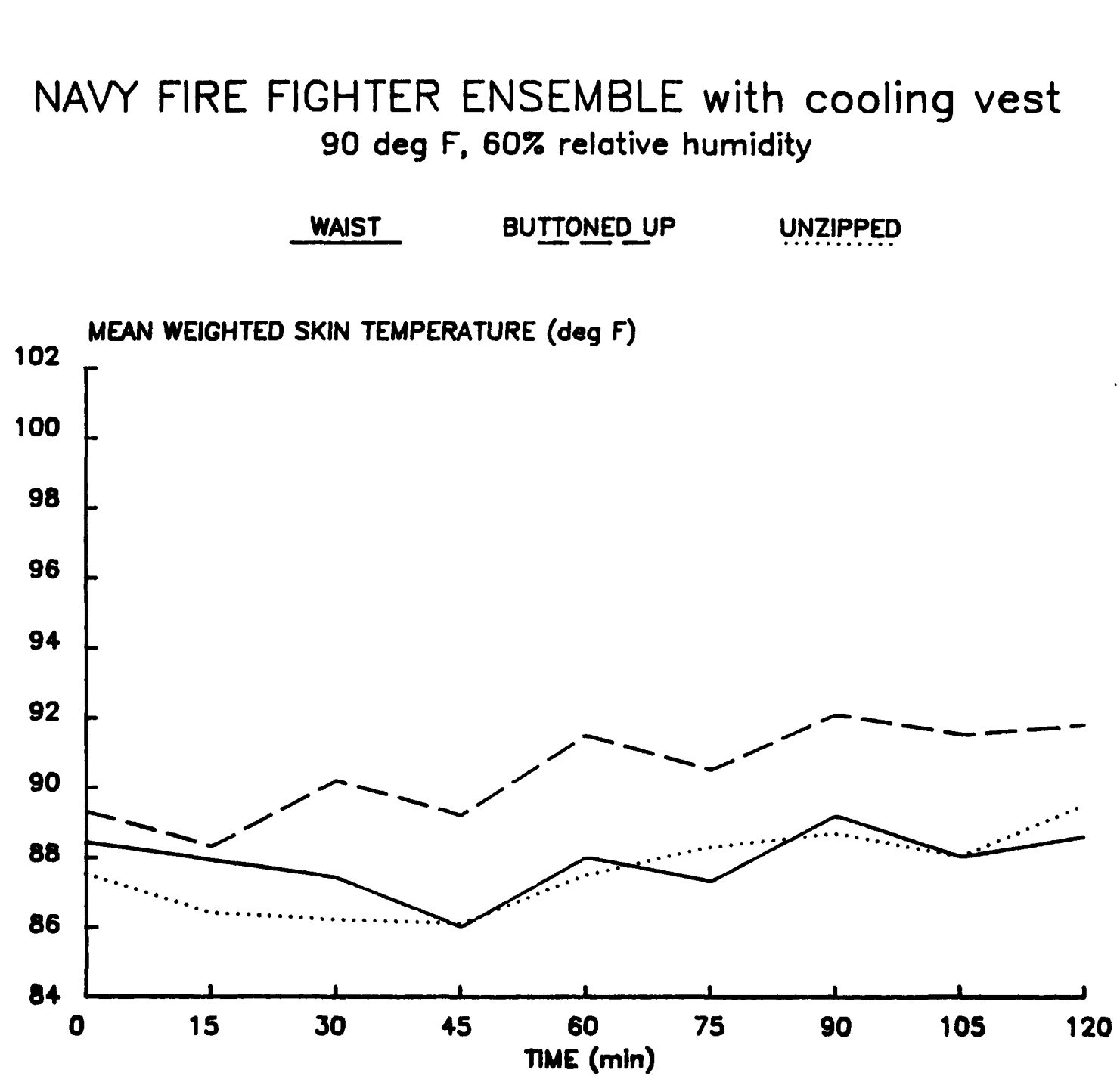

Figure 4. Mean weighted skin temperature when the fire fighter ensemble is worn with the cooling vest.

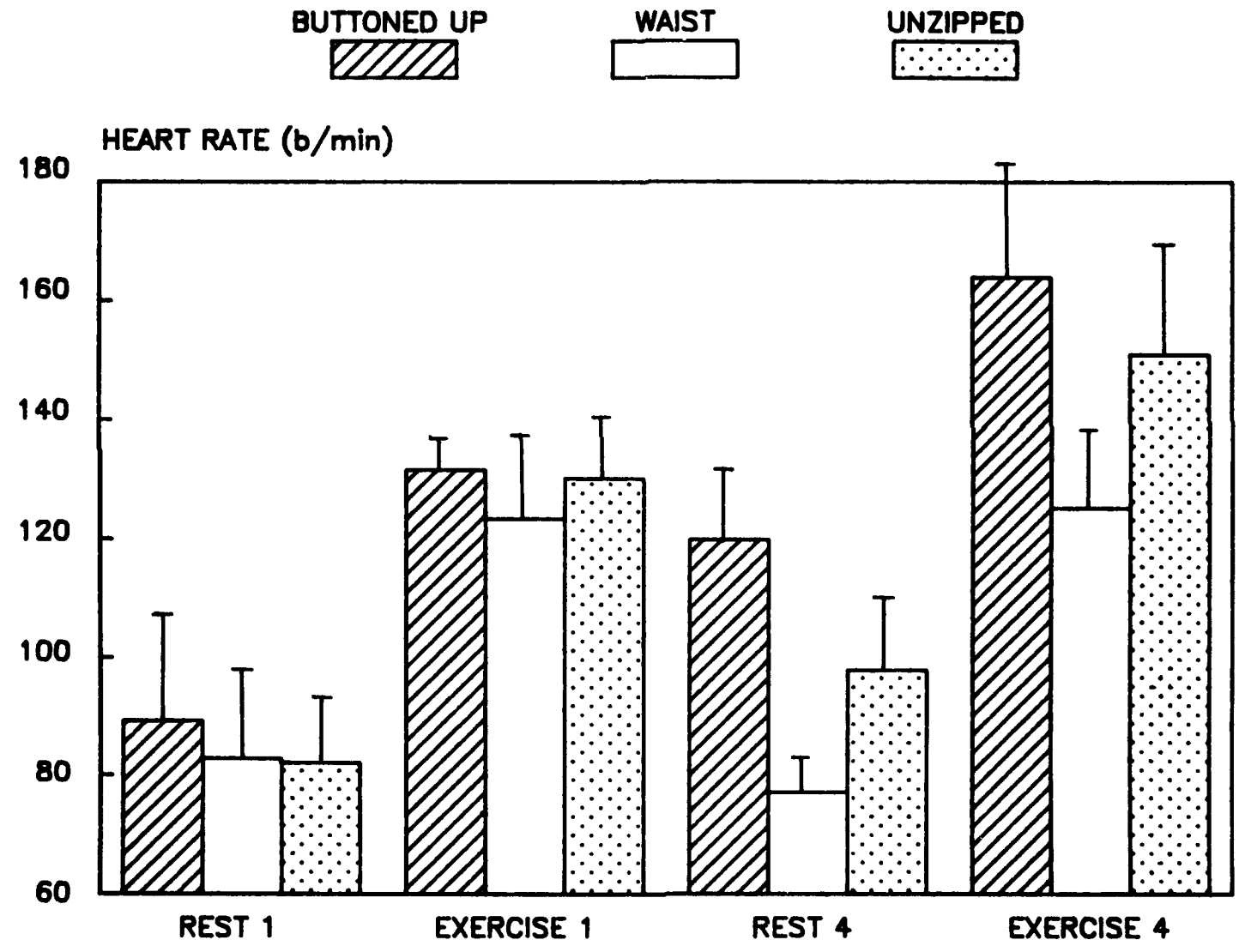

Figure 5. Heart rate response when the fire fighter ensemble is worn; T indicates S.D.

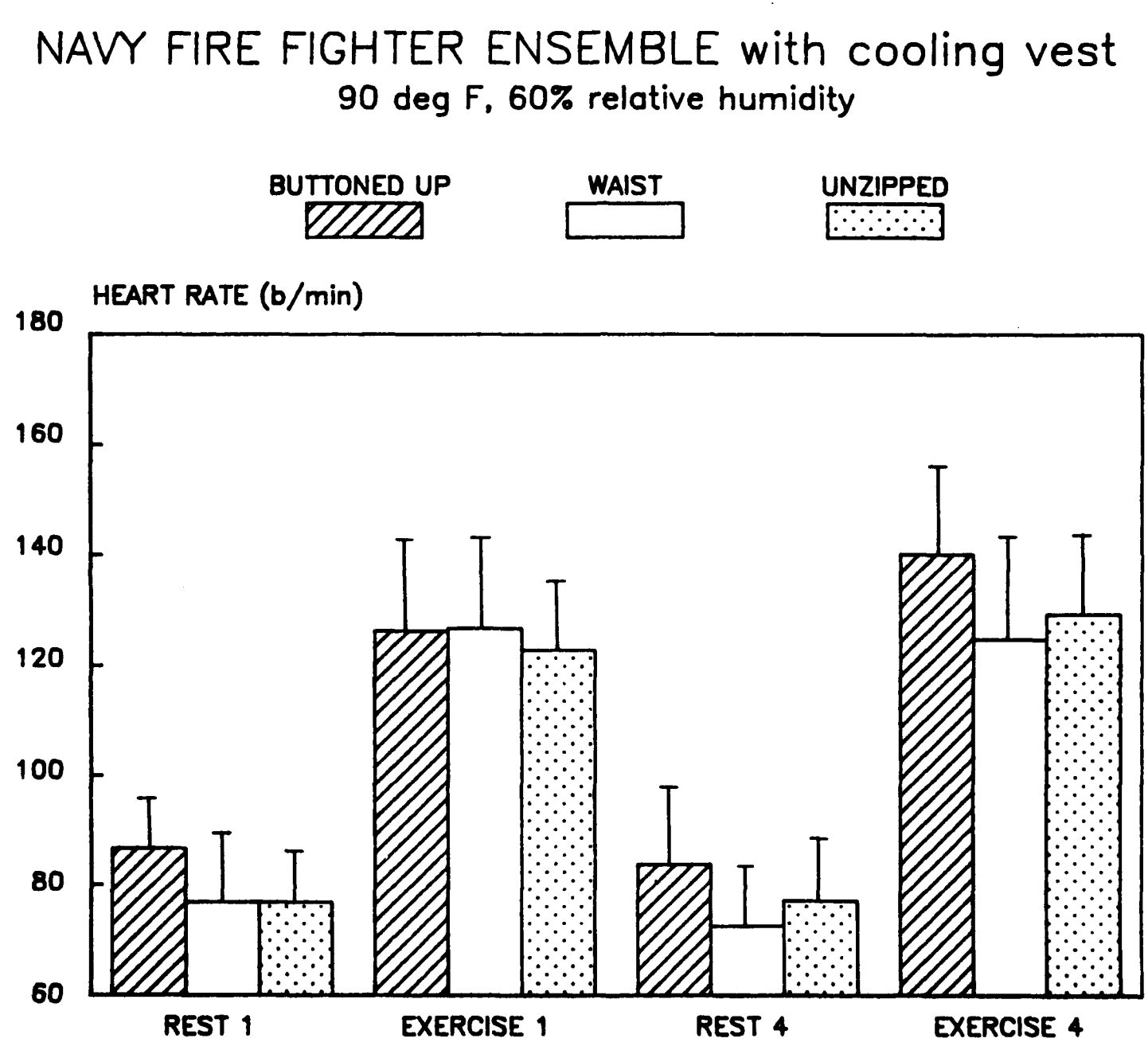

Figure 6. Heart rate response when the fire fighter ensemble is worn with the cooling vest; T indicates S.D.

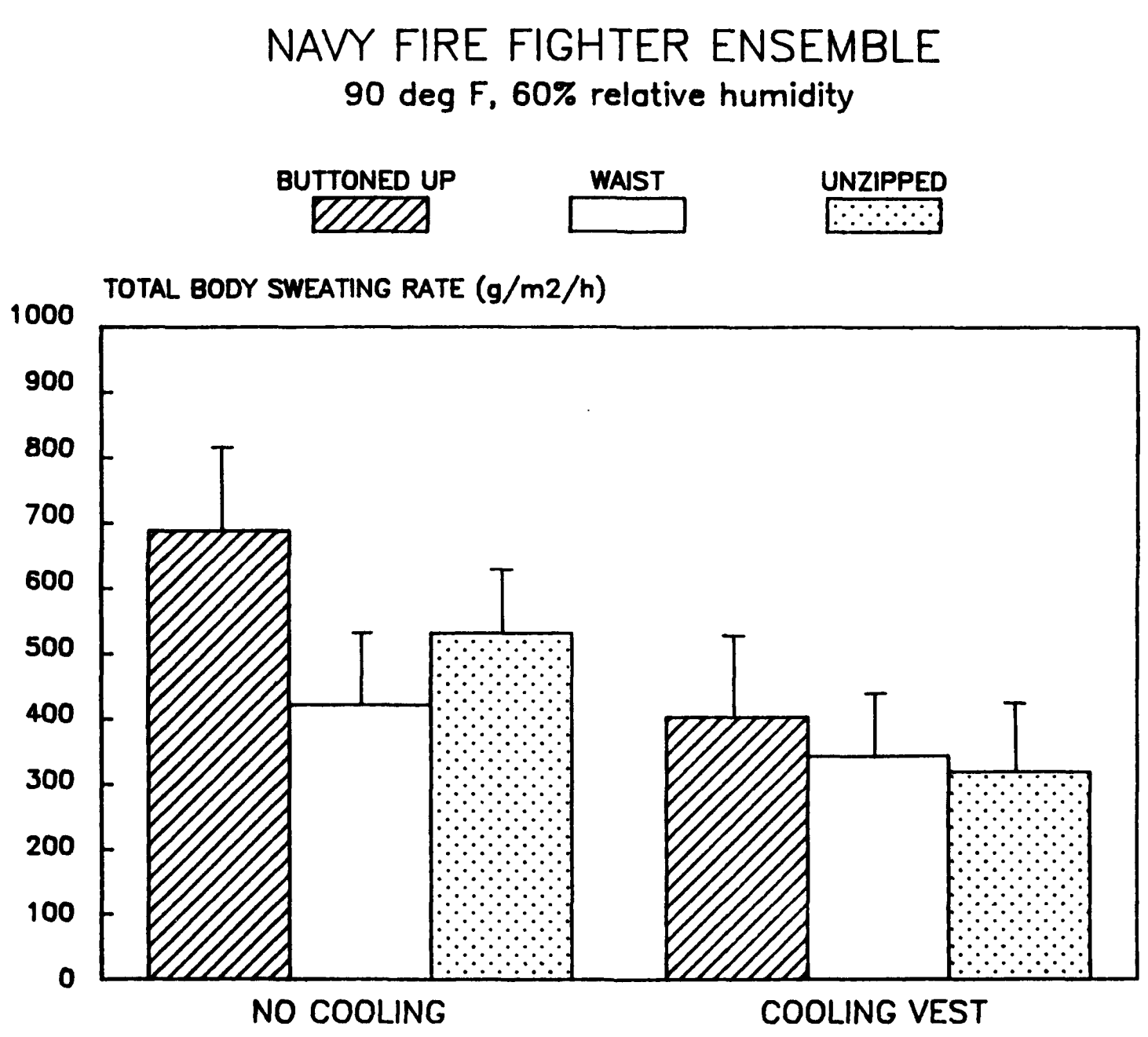

Figure 7. Total body sweating rate when the fire fighter ensemble is worn without and with the cooling vest; T indicates S.D.

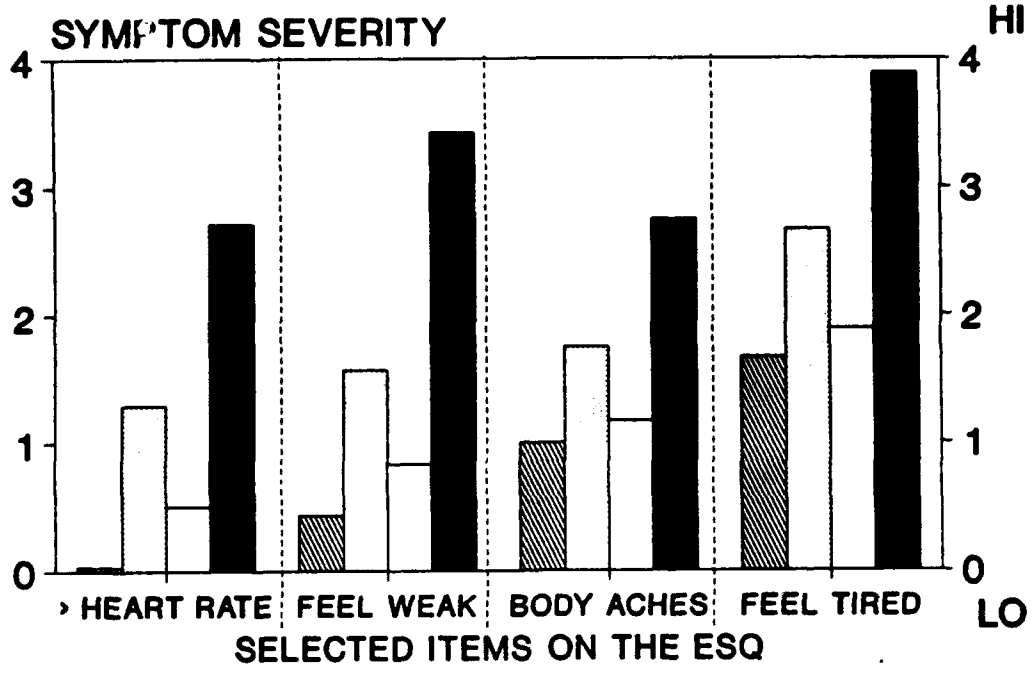

Figure 8. Symptom severity as measured by the Environmental Symptoms Questionnaire (ESQ) when the NFFE was worn in various configurations. The leftmost to rightmost bars for each statement are the average ratings when the coverall was worn around the waist (diagonal-lined bar), when the coverall was unzipped (dotted bar), when the coverall was buttoned up and the cooling vest was used (open bar), and when the coverall was buttoned up without the cooling vest (black bar). These statements (ESQ Items 11, 19, 21 and 56, left to right, respectively) were selected because they showed consistent differences in symptomatology for the various NFFE configurations. Ratings for the first three items were obtained during the last exercise bout (110 minutes). Ratings for the fourth item were obtained post-heat exposure (125 minutes). Symptom ratings when the coverall was worn buttoned up without cooling (black bars) were significantly greater compared with the other three NFFE configurations.

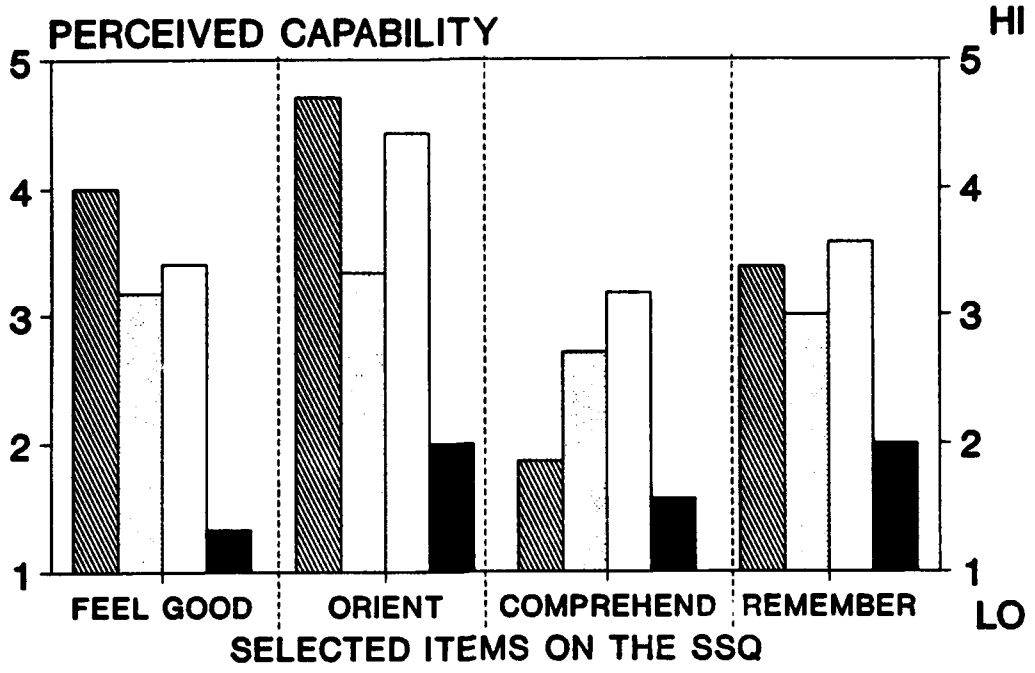

Figure 9. Perceived well-being and estimated performance capabilities as measured by the Subjective States Questionnaire (SSQ) when the NFFE was worn in various configurations. The leftmost to rightmost bars for each statement are the average ratings when the coverall was worn around the waist (diagonal-lined bar), when the coverall was unzipped (dotted bar), when the coverall was buttoned up and the cooling vest was used (open bar), and when the coverall was buttoned up without the cooling vest (black bar). These statements (SSQ Items 37, 30, 29, and 28, left to right, respectively) were selected because they showed consistent differences in perceived well-being and performance capabilities for the various NFFE configurations. All data were obtained during the last exercise bout (110 minutes). All NFFE configurations (except for the coverall around the waist for the "Feel Good" and "Orient" statements) produced greater estimates of well-being and performance capabilities than when the NFFE was worn buttoned up without the cooling vest.

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