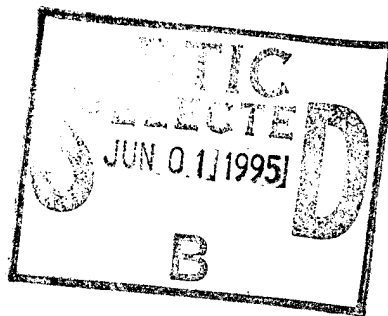# NAVAL HEALTH RESEARCH CENTER

COOL VESTS WORN UNDER FIREFIGHTING ENSEMBLE

REDUCES HEAT STRAIN DURING EXERCISE AND RECOVERY

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HEAT STRAIN DURING EXERCISE AND RECOVERY

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Summary

<u>Problem</u>.

The findings from previous studies suggest that cool vests worn under the firefighting protective ensemble reduced heat strain during exercise in warm/humid and hot/humid environments. However, the impact of cool vests on recovery from heat strain and subsequent return to work in hot environments is not established.

<u>Objective</u>.

The purpose of this study was to evaluate the effectiveness of a torso cool vest to minimize heat strain during exercise and heat exposure, facilitate heat loss during recovery, and minimize heat strain during subsequent return to exercise and heat exposure.

<u>Approach</u>.

Male subjects (n=12) were evaluated for heat strain during 20-min periods of rest, exercise, recovery, exercise, and recovery (total time=100 min). The rest and recovery periods occurred in warm/humid air (29°C/65% relative humidity [rh]), while exercise (treadmill walking at 1.12 $m \cdot s^{-1}$ and 0% grade) occurred in hot/humid air (48°C/50% rh). Subjects completed two tests: no vest (NV) and 4-pack (weighing 3 kg) cool vest (CV) worn over dungarees and under the U.S. Navy firefighting ensemble and oxygen breathing apparatus. Total clothing weight equaled 18.3 kg for NV and 21.3 kg for CV. Measures included heart rate (HR), rectal temperature (T_{re}), and skin temperatures from the upper chest (T_{ch}), upper arm (T_{ar}), thigh (T_{th}), and calf (T_{ca}). The effect of CV on dependent measures was examined using repeated-measures analysis of variance.

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Results.

All subjects in the NV and CV trials completed the 100-min test. For CV and NV, HR increased during both exercise periods and declined during both recovery periods. However, differences in HR between CV and NV were nonsignificant.

T_r increased progressively during both exercise periods and declined slightly during the recovery periods for both NV and CV. T_{ch}, T_{ar}, T_{th}, and T_{ca} increased during the initial rest period and throughout both exercise periods, and then declined during the recovery periods for both CV and NV. Throughout the tests, CV produced significantly lower T_{re}, T_{ch}, T_{ar}, and T_{th}, while differences in T_{ca} between CV and NV were nonsignificant.

Differences in total-body sweat loss, urine output, and fluid balance between CV and NV were nonsignificant, while ad libitum water intake was significantly ($p<.05$) less for CV compared to NV. Differences in ratings of perceived exertion (RPE) between CV and NV were nonsignificant, while ratings of thermal sensation (TS) for the head, neck, chest, and arms were significantly lower for CV compared to NV.

Conclusion.

CV minimized heat strain during exercise in hot/humid air, hastened recovery from heat strain in warm/humid air, and attenuated heat strain during subsequent exercise in hot/humid air. These findings have application to fleet personnel involved in damage control training and shipboard operations during heat exposure.

Introduction

Heat strain, dehydration, and fatigue are major problems for naval personnel engaged in shipboard firefighting activities (Bennett et al., 1993a). Fleet doctrine guidelines attempt to minimize these problems by having damage control teams use short-term work-recovery cycles to perform fire suppression activities. However, conformation of the usefulness of work-recovery cycles is lacking for few studies have investigated the impact of work-recovery cycles on personnel wearing firefighting protective clothing during exposure to hot environments.

Evidence from previous research suggests that torso cool vests can reduce heat strain in personnel dressed in protective firefighting clothing. Pimental et al. (1991), Bennett et al. (1993b), and Hagan et al. (1994) reported that cool vests worn under the firefighting protective ensemble reduced heat strain during exercise in warm/humid and hot/humid environments. However, a major question concerns the impact of cool vests on recovery from heat strain and subsequent return to exercise in hot environments. Thus, the purpose of this study was to evaluate the effectiveness of a cool vest to minimize heat strain during exercise and heat exposure, facilitate heat loss during recovery, and to determine the impact of heat strain reduction during recovery on minimizing heat strain during subsequent return to exercise and heat exposure.

Methods

The protocol and procedures used in this study were approved by the Committee for the Protection of Human Subjects of the Naval Health Research Center.

Subjects.

Twelve males served as subjects. The physical characteristics of the subjects were 27.6

± 4.7 years, 178.6 ± 5.5 cm, 79.2 ± 10.8 kg, 1.98 ± 0.5 m^{-2}, and 17.1 ± 6.1% body fat. Bruce (Bruce et al., 1973) maximum treadmill performance time averaged 12.4 ± 1.3 min; the estimated peak oxygen uptake was 47 ± 5 ml•kg^{-1}•min^{-1}. All subjects were trained in shipboard firefighting procedures and use of firefighting equipment. All subjects performed occupational activities in warm/hot environments 5 days a week. The amount of time spent in these environments ranged from 1 to 2 hr.

<u>Medical screening.</u>

Each subject gave their informed consent prior to participation in testing. All subjects underwent medical screening which included a medical history questionnaire, body composition assessment, and a resting 12-lead electrocardiogram (ECG). Body surface area (m^2) was calculated according to the height and weight regression equation of DuBois (Carpenter, 1964). A U.S. Navy regression equation was used to calculate percent body fat using height and measures of neck and abdomen circumference (Hodgdon & Beckett, 1984).

ECG electrodes were placed on each subject's chest in the Mason-Liker configuration. Two electrodes were placed on the upper chest near the shoulders (infraclavicular fossa), and two others slightly above the waist at the base of the legs. Six electrodes (V_1-V_6) were also placed on the chest in the precordial position around the lower border of the left chest. Resting ECGs and blood pressures (BP) were taken in supine, seated, and standing conditions. All subjects completed an incremental treadmill exercise test (Bruce protocol) to voluntary exhaustion. Maximum treadmill performance time was used to estimate peak oxygen uptake from a regression equation (Bruce et al., 1973). Peak heart rate (HR) was determined as the highest HR obtained during the test. Each minute of recovery, the subject's HR and BP were monitored until

they returned to resting values.

Experimental procedures.

All subjects participated in two test trials: control, no vest (NV) and 4-pack cool vest (CV) worn under the firefighting protective ensemble (FFE). The tests were administered in a counterbalanced order. During each test, subjects wore a T-shirt, long-sleeved cotton shirt, jeans (Navy dungarees), socks, and boondocker boots as the basic undergarment, and the standard U.S. Navy FFE: flash hood, helmet, gloves, and single-piece Nomex firefighting protective suit. Subjects breathed oxygen, independent from ambient room air oxygen, using an oxygen breathing apparatus (OBA) (NAVEDTRA 465-09-00-81). In the CV trial, a torso cool vest was worn over undergarment clothing and under the FFE. The cool vest (Steele, Inc., Kingston, WA 98346) contained four (765 g each) frozen gel thermostrips, which were kept frozen at -28°C until use. The 4-pack CV had two strips placed vertically on the front and two strips placed horizontally on the back. Each pocket of the CV was insulated with Thinsulate. Average total clothing and OBA weight was 18.3 kg for NV and 21.3 kg for CV.

The previous night and the morning of the heat-exposure test, subjects were instructed to drink generous amounts (at least 1 L) of fluid (noncaffeine beverages) to ensure normal body hydration. Hydration status was determined by measuring the specific gravity of urine samples obtained prior to the test.

The test protocol used in this study was designed to simulate an activity pattern similar to a shipboard fire suppression operation requiring repeated cycles of work and recovery. The protocol consisted of 20-min periods of seated rest, exercise, seated recovery, exercise, and seated recovery. During exercise, subjects breathed oxygen from an OBA. The ambient environment

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during the initial seated rest period and during the two recovery periods was 29°C/65% relative humidity (rh), while the ambient environment during walking exercise was 48°C/50% rh. Exercise consisted of walking on a motorized treadmill at 1.12 m•s^{-1} and 0% grade. During the initial rest period, subjects sat in a chair with the FFE completely zipped and buttoned-up, while during the recovery period, subjects sat with the FFE open and off the shoulders to the waist. During the initial rest and recovery period, subjects breathed room air. Approximately 3 min prior to starting the first and second exercise periods, subjects stood, zipped- and buttoned-up the FFE, and strapped on and activated the OBA.

Measurements.

Prior to the test, subjects inserted a rectal thermistor to a depth of 20 cm in the rectum for measurement of rectal temperature (T_{re}). Skin temperatures, using thermistors, were measured from the upper right chest (T_{ch}), right upper arm (T_{ar}), right mid-lateral thigh (T_{th}), and right mid-lateral calf (T_{ca}). Three ECG electrodes were placed on the chest to monitor HR. HR, T_{re}, T_{ch}, T_{ar}, T_{th}, and T_{ca} were recorded at 1-min intervals by a portable Squirrel data logger (Science/Electronics, Miamisburg, OH 45342) worn outside the ensemble. Another thermistor was place inside a chest pocket of the cool vest between the gel pack and chest to record changes in surface temperature of a gel pack. HR was also recorded by a Polar Heartwatch System (Polar, USA, Inc., Stamford, CT 06902). Pre- and posttest nude body weights as well as fluid intake and output were recorded to determine change in body weight. During the initial rest, exercise and recovery periods, subjects were allowed to drink as much water (water temperature=21°C) as desired.

During each 20-min period of the tests, subjects were asked to rate their perceived exertion

(RPE) and thermal sensation (TS) at 10-min intervals. RPE was determined using the Borg 15-point (6-20) scale (Borg, 1982). For ratings of TS, an eight-point scale (1-8) was used (Young, 1987). Ratings of TS were obtained from five local body areas (head, neck, chest, arms, and legs).

The following criteria were used for removal of the subject from heat exposure: T_{re} of 39.5°C; systolic BP of 29.3 Kpa (220 mmHg) or diastolic BP of 16 Kpa (118 mmHg); HR of 85% of predicted maximum or greater for 20 min; absence of sweating or presence of chills, nausea, weakness, or dizziness; or subject desiring to terminate the test.

Total-body sweat loss was calculated as the difference between pretest and posttest body weight with the posttest weight corrected for fluid input and urine output. Fluid balance ($L \cdot h^{-1}$) was calculated as the sum of fluid intake, urine output, and sweat loss. Other calculations included, mean skin temperature ($\bar{T}_{sk}$) calculated from T_{ch}, T_{ar}, T_{th}, and T_{ca} using a weighted equation (Ramanathan, 1964).

Statistical analysis.

HR, T_{re}, T_{ch}, T_{ar}, T_{th}, and T_{ca} were analyzed for the main effects of time (100 min), vest (NV and CV), and the interaction of time and vest by repeated-measures analysis of variance (ANOVA). Post-hoc analyses in the presence of a significant omnibus F-ratio included Student-Newman-Keuls comparisons to evaluate significant differences between CV and NV means during time of the tests. Differences between CV and NV for fluid dynamic measure were analyzed by Student's t-test. The significance level was set at $p < .05$.

Results

All subjects in the NV and CV trials completed the 100-min test. No subject in either vest trial developed physical symptoms of fatigue or feeling "hot." ANOVA results describing the impact of time, vest, and interaction of time and vest on HR, T_{re}, T_{ch}, T_{ar}, T_{th}, and T_{ca}, are shown in Table 1.

Table 1. Analysis of main and interaction effects on HR and body temperatures.

Variable	Time	Vest	Time x Vest
HR	n.s	n.s.	n.s.
T_{re}	p=.0001	p=.0094	p=.0073
T_{ch}	p=.0141	p=.0016	n.s.
T_{ar}	p=.0001	p=.0045	n.s.
T_{th}	p=.0001	p=.0098	n.s.
T_{ca}	p=.0001	n.s.	n.s.

<u>Heart Rate Response.</u>

HR increased steadily during both exercise periods for both CV and NV, and declined rapidly during both recovery periods for both CV and NV (Fig. 1). However, there were no time, vest, or time by vest interactions for HR (Table 1).

Body temperatures.

Time, vest, and the interaction of time and vest had a significant effect on T_{re} (Table 1). T_{re} increased progressively during both exercise periods and declined slightly during the recovery periods (Fig. 2). T_{re} for CV was significantly lower compared to NV starting at minute 42 of the first recovery period and extending through the remainder of the test. During the two recovery periods, T_{re} increased slightly and then declined slowly for both NV and CV.

T_{ch}, T_{ar}, T_{th}, and T_{ca} showed significant time effects (Table 1). These temperatures progressively increased during the initial rest period and throughout both exercise periods for both CV and NV (Fig. 3, 4, 5, 6).

T_{ch}, T_{ar}, and T_{th} varied significantly between NV and CV, and became significantly lower with CV compared to NV starting midway through the initial rest period, while T_{ar} and T_{th} became significantly lower during the first minutes of the first recovery period. Consequently, T_{ch}, T_{ar}, and T_{th} for CV remained significantly lower for the remainder of the test protocol. During the two recovery periods, T_{ch}, T_{ar}, and T_{th} declined rapidly for both CV and NV with the rate of decrease for T_{ch}, T_{ar}, and T_{th} greater for CV. T_{ca} values tended to be lower for CV compared to NV, but the difference was nonsignificant.

Fluid dynamics.

Differences in total-body sweat loss, urine output, and fluid balance between CV and NV were nonsignificant, while water intake was significantly ($p<.05$) less for CV compared to NV (Table 2).

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Table 2. Comparison of measures of fluid dynamics between NV and CV.

Variable	NV	CV	Comparisons
Water intake (ml)	1288 ± 615	936 ± 381	p=.04
Urine output (ml)	148 ± 250*	249 ± 412*	n.s.
Sweat Loss (ml)	1650 ± 425	1323 ± 583	n.s.
Fluid Balance (ml)	-510 ± 590	-637 ± 613	n.s.

*n=5 for NV and CV.

Ratings of perceived exertion and thermal sensation.

ANOVA results of time, trial, and interaction of time and trial on RPE and regional TS are shown in Table 3. Plots of RPE and TS response for CV and NV are shown as follows: RPE, Fig. 7; head TS, Fig. 8; neck TS, Fig. 9; chest, Fig. 10; arms, Fig. 11; and legs, Fig. 12.

Table 3. Analysis of main and interaction effects on RPE and overall and regional TS.

Variable	Time	Trial	Time x Trial
RPE	p=.0001	n.s.	n.s.
head TS	p=.0001	p=.008	n.s.
neck TS	p=.0001	p=.0009	n.s.
chest TS	p=.0001	p=.0001	p=.0004
arms TS	p=.0001	p=.0003	n.s.
legs TS	p=.0001	n.s.	n.s.

RPE increased during initial rest and the two exercise periods and decreased during both recovery periods. RPE recorded during exercise contributed to a significant time effect on RPE. However, differences in RPE between CV and NV were nonsignificant. Differences in the y-intercepts and slopes of the RPE-HR relationship for CV and NV were nonsignificant. Linear regression equations relating HR to RPE were: RPE = -0.07 + 0.08(HR) for CV; and RPE = 0.09 + 0.08(HR) for NV.

Perceptions of TS of various regional values increased during exercise and decreased during recovery. However, all TS responses increased significantly overtime, primarily as a result of responses during exercise. Differences in TS of the head, neck, chest, and arms between CV and NV were significant, while differences in TS for the legs was nonsignificant. Differences in TS between CV and NV were greatest for the chest region followed in order by

the arms, neck, head, and legs. Only TS for the chest showed a significant interaction effect of time and trial. Post-hoc analysis indicated that significant differences in chest TS between CV and NV were evident during rest and both exercise and recovery periods. Post-hoc analysis also revealed that significant differences in TS for the neck and arms occurred during rest and both exercise periods, while significant differences for head TS occurred only during the second exercise period.

Discussion

The major finding of this study is that CV worn under the U.S. Navy FFE effectively decreases heat strain during exercise, facilitates heat loss during recovery from exercise, and attenuates heat strain upon subsequent return to exercise and heat exposure.

Effect of cool vest on body temperatures.

Increases in T_{re}, T_{ch}, T_{ar}, and T_{th} were lower for CV compared to NV. Lower heat strain for CV appeared midway through the initial rest period when differences in T_{ch} between NV and CV first became significant. The impact of CV on heat strain was also evident during the first exercise period as indicated by lower T_{ch} values for CV. Also, during the first recovery period, CV significantly lowered T_{re}, T_{ch}, T_{ar}, and T_{th}. The lower T_{re}, T_{ch}, T_{ar}, and T_{th} for CV recorded during the first recovery period helped minimize increases in these temperatures during the second exercise period, and likely contributed to the significant time and trial interaction effect on T_{re}. Thus, use of CV resulted in lower heat strain during all phases of the 100-min test protocol.

The lower T_{re}, T_{ch}, T_{ar}, and T_{th} for CV throughout the duration of the tests suggests that

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CV reduces heat storage. T_{ch} is lower because the frozen gel packs of CV covered the torso. The lower T_{ar} and T_{th} for CV may be lower because the gel packs absorbed both body heat and heat close to the skin thereby lowering skin temperatures in areas other than the torso.

The lower skin temperatures for CV can be explained by the heat conduction and heat storage capacity (HSC) 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. HSC is due to the heat capacity of the solid gel pack, heat of fusion of the gel pack, and heat capacity of the liquid portion of the gel pack. The CV had a total surface area of 1863 cm^2, gel-pack weight of 3.06 kg, and heat storage capacity of 2.8 J•gr^{-1}. Prior to the test, the gel-packs were frozen to -28°C, and during the 100-min test, gel-pack surface temperatures increased from -5°C to 10°C. This suggests that the gel packs were absorbing heat. Since the environmental conditions during the hot/humid phases of the test were above body temperatures, the increase in gel-pack surface temperatures reflects heat gain from both the subject's body and ambient air. Thus, it is likely the lower heat strain associated with CV is due to conduction of heat from both environment and body surface to the CV and the HSC of the gel-packs.

<u>Effect of cool vest on heart rate.</u>

In the present study, differences in HR between CV and NV across all phases of heat exposure were nonsignificant. This occurred despite significantly greater water intake for NV (1288 ml) compared to CV (936 ml). Available evidence suggests, in comparison to no water intake, that regularly scheduled water intake during exercise and heat exposure decreases HR

(Frances, 1979), possibly as a result of an increase in plasma volume (Bothorel et al., 1990). However, while water intake was greater for NV, differences in fluid balance between CV (-510 ml) and NV (-637 ml) were nonsignificant suggesting that differences in plasma volume between CV and NV were minimal. Also, these amounts of water intake for CV and NV may have been inadequate to produce a significant difference in HR, since Montain and Coyle (1992) reported decreases in exercise HR in a warm environment required a fluid intake of at least 1400 ml.

In addition, the lack of significant differences in HR between CV and NV remain despite significantly lower T_{re}, T_{ch}, T_{ar}, and T_{th} for CV. This is in contrast to our previous findings (Bennett et al., 1993b), showing significantly lower HR, T_{re}, and $\bar{T}_{sk}$ during exercise and recovery in a warm/humid environment. Also, since active muscle blood flow is maintained during heat exposure (Nielson et al., 1990), lower skin temperatures fostered by use of CV should reduce skin blood flow (Nadel et al., 1979; Rowell, 1983), thereby increasing cardiac filling pressure (Nose et al., 1994) and reducing HR (Shaffrath & Adams, 1984). However, the lack of effect of CV on HR evident in the present study may be due to magnitude of body temperature reduction associated with wearing CV.

In a previous study (Bennett et al., 1993b), $\bar{T}_{sk}$ for a small 4-pack CV ranged on average from 0.5 and 1.0°C below that of NV throughout two cycles (180 min) of rest and exercise in a warm/humid environment. In the present study, CV lowered $\bar{T}_{sk}$ from 0.3 to 0.6°C throughout two cycles (120 min) of exercise and recovery. Thus, our findings suggest that small differences in T_{re}, T_{ch}, T_{ar}, and T_{th} may not attenuate HR during exercise and recovery in a hot/humid environment. The similar HR response between NV and CV supports a role for central command in the overall regulation of cardiovascular function during exercise and heat strain (Mitchell, 1990).

Effect of cool vest on fluid dynamics.

In the present study, it was not possible to determine either the water loss due to pulmonary respiration or insensible perspiration because of the high atmospheric relative humidity which ranged from 50 to 65%. However, since CV and NV both consumed ambient air during rest and recovery, and ventilated on an OBA during exercise, it is likely that respiratory water loss was similar between CV and NV. In addition, mean total sweat loss was higher for NV (1650 ml) compared to CV (1323 ml), but the difference was nonsignificant. The slightly higher sweat loss for NV could be due to the significantly higher T_{re} for NV, and a resetting of the central set-point temperature (Nielsen, 1984).

Use of CV was associated with a significantly lower intake of water. Greenleaf (1982) reported in heat acclimatized subjects, that water intake is highly related to sweat rate during exercise in the heat. However, our subjects were not heat acclimatized. Also, the amount of dehydration experienced by our subjects was not corrected by ad libitum water intake, a finding often shown by others (Rothstein et al., 1947). Greenleaf et al. (1985) has suggested that decreases in body fluid compartment volumes and stimulation of the renin-angiotensin II system are associated with increases in water intake during exercise in the heat. Unfortunately, we did not evaluate neuroendocrine mechanisms regulating fluid intake. Despite this limitation, our findings suggest that the lower water intake for CV is related to lower body temperatures. Lower body temperatures would reduce sympathetic drive, stimulation of the renin-angiotensin system, and thirst.

Effect of cool vest on ratings of perceived exertion.

In the present study, differences in RPE between NV and CV were nonsignificant. This

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finding is contrary to that reported by Bennett et al. (1993b) for exercise of the same intensity (395 W) in a warm/humid environment, but similar to that of Hagan et al. (1994) for exercise of the same intensity in a hot/humid environment. Our finding suggests that RPE and HR are related during exercise and recovery in air temperatures up to 48°C. A similar finding was reported by Potteiger and Weber (1994) for exercise in a warm environment. Thus, our findings suggest that RPE is unaffected by CV during cycles of exercise and recovery in warm/humid and hot/humid environments, respectively. However, cycles of exercise and recovery in hot/humid environments may alter the intercept and slope of the RPE-HR relationship.

In the RPE scale developed by Borg (1982), RPE values range from 6 to 20 to correspond to HR values 60 to 200 bt•min⁻¹. This relationship represents a y-intercept equal to zero and a slope of 0.1. In the present study, differences in the y-intercepts and slopes of the RPE to HR relationship between CV and NV were nonsignificant. However, the RPE-HR relationship for both CV and NV had a y-intercept of 0.09 and a slope of 0.08. Thus, the cycles of exercise and recovery in combination with the hot/humid environment altered the RPE-HR relationship such that RPE values from 6 to 20 represented HR of 80 to 260 bt•min⁻¹. In the study by Potteiger and Weber (1994), the y-intercept and slope of the RPE-HR relation also appears to have been altered by exercise and heat exposure. Thus, our findings argue that RPE is more dependent upon energy expenditure, while HR is controlled by central and peripheral factors affecting arterial pressure and muscle and skin blood flow.

Effect of cool vest on thermal sensation.

TS of the head, neck, chest, and arms were significantly lower for CV compared to NV. Significant differences in chest TS between CV and NV occurred during rest and both exercise

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and recovery periods. Significant differences in TS for the neck and arms occurred during rest and both exercise periods, while head TS was lower for CV during the second exercise period. In addition, differences in TS values between CV and NV were greatest for the chest region followed by the arms, neck, and head. The differences in chest, neck, and arms TS between CV and NV, and the rank order of the magnitude of the differences among the various regions, appears to be a direct result of the localization of CV on the torso. For CV, lower TS values for the head, neck, chest, and arm regions are related to significantly lower T_{ch} and T_{ar}. The lack of difference in leg TS between CV and NV may be related to the small differences in T_{th} and T_{ca} between CV and NV. Despite the presence of significantly lower T_{th} for CV, the lack of association between T_{th} and leg TS suggests that skin temperatures are not always related to perception of TS (Gagge et al., 1967). Despite these discrepancies, our findings indicate that upper body regional TS values are significantly reduced by CV during cycles of exercise and recovery in warm/humid and hot/humid environments, respectively.

In conclusion, CV was accompanied by significantly smaller increases in T_{re}, T_{ch}, T_{ar}, and T_{th} and lower perceptions of regional TS compared to NV. CV minimized heat strain during exercise in hot/humid air, hastened recovery from heat strain in warm/humid air, and attenuated heat strain during subsequent exercise and hot/humid air. These physiological and perceptual findings suggest that CV is an effective countermeasure to heat strain during exercise and heat exposure and promotes recovery. These findings have application to fleet personnel involved in damage control training and shipboard operations during heat exposure.

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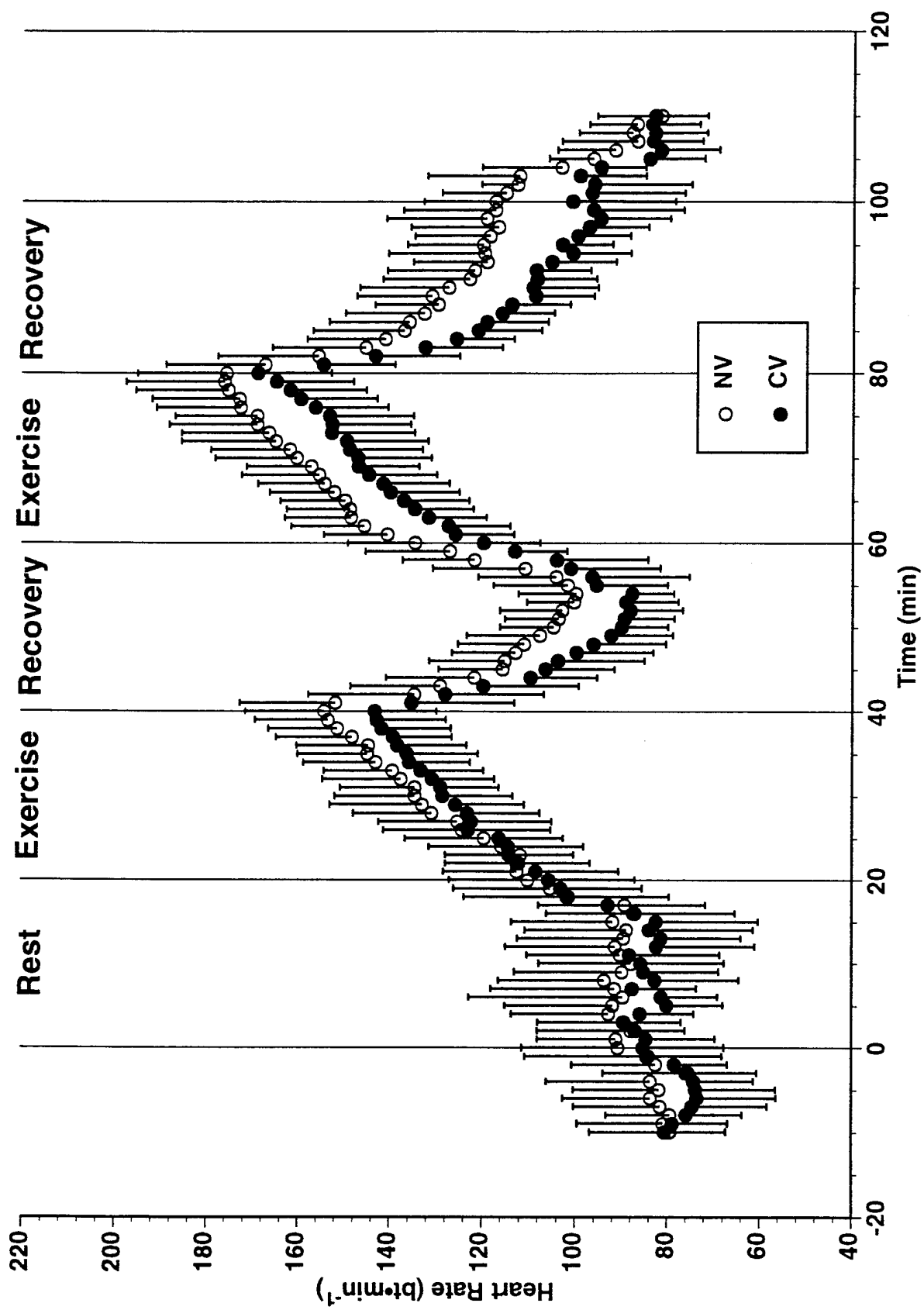
Figure 1. Mean heart rates for CV and NV during rest and two cycles of exercise and recovery. Differences in heart rate response between CV and NV were non-significant.
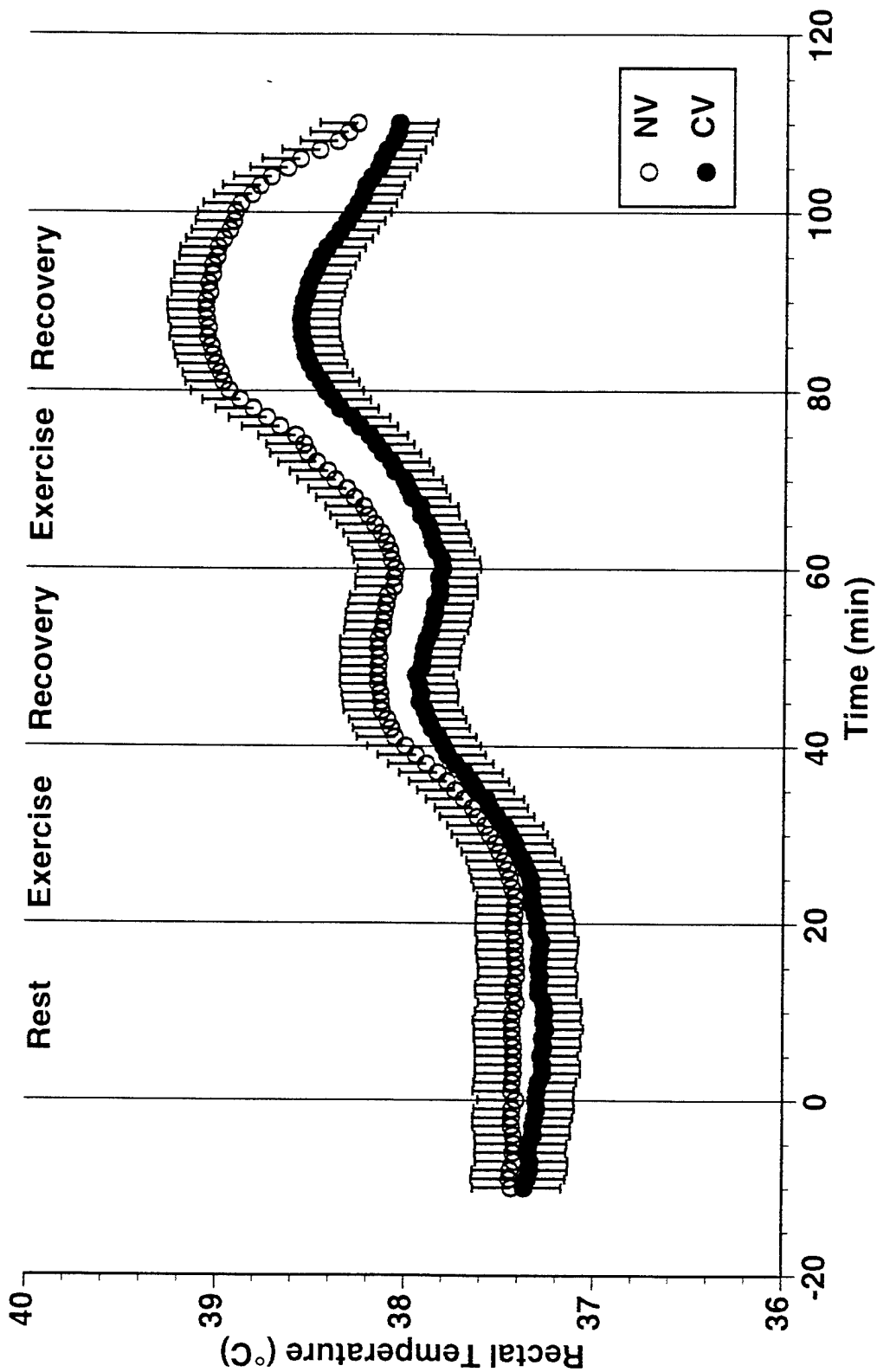
Figure 2. Mean rectal temperatures for CV and NV during rest and two cycles of exercise and recovery. Significantly lower rectal temperature for CV started at minute 42 of the first recovery period and continued significantly lower through the remainder of the test.
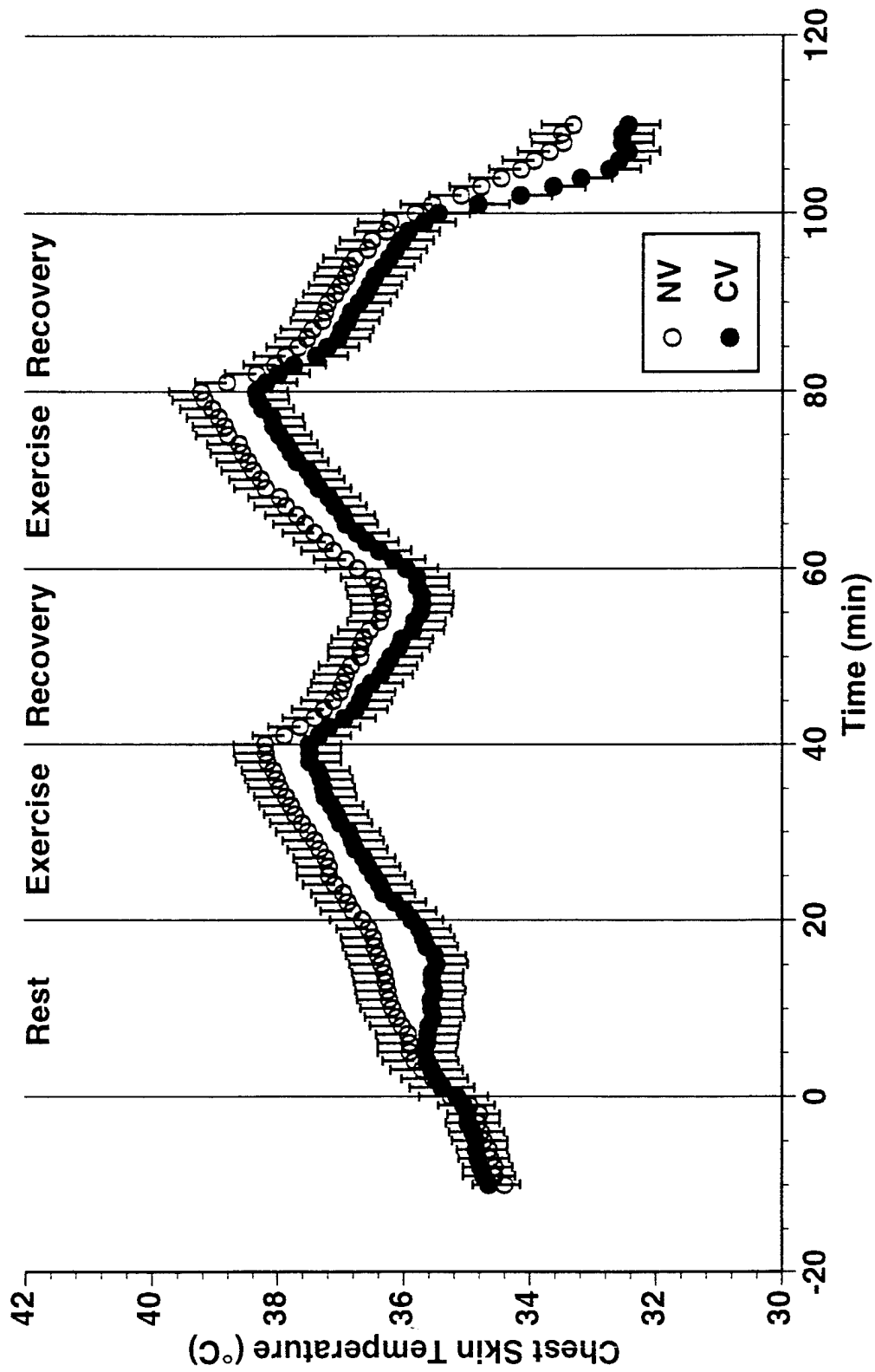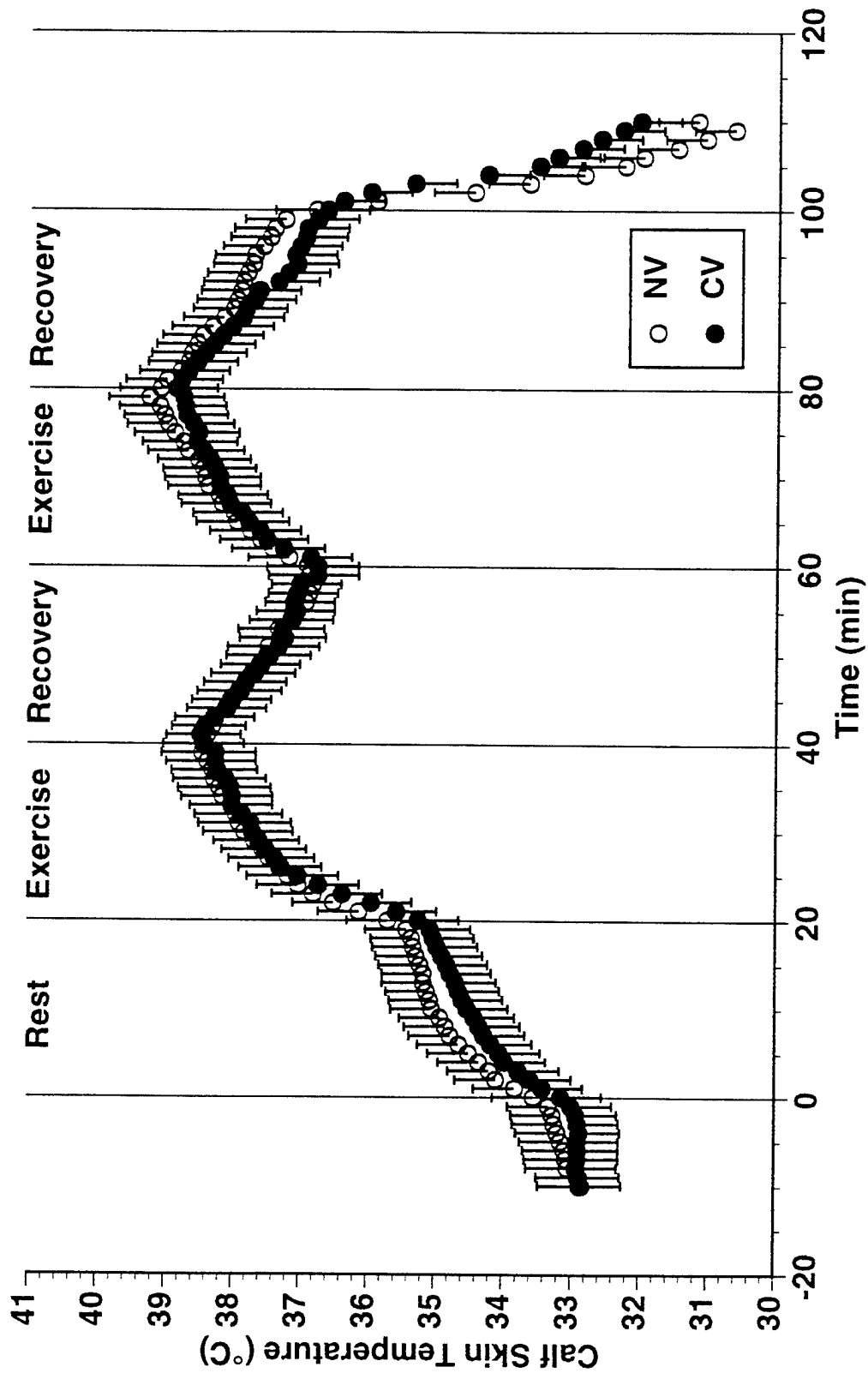
Figure 3. Mean chest skin temperatures for CV and NV during rest and two cycles of exercise and recovery. Significantly lower chest temperature for CV started midway through the initial rest period and continued significantly lower through the remainder of the test.
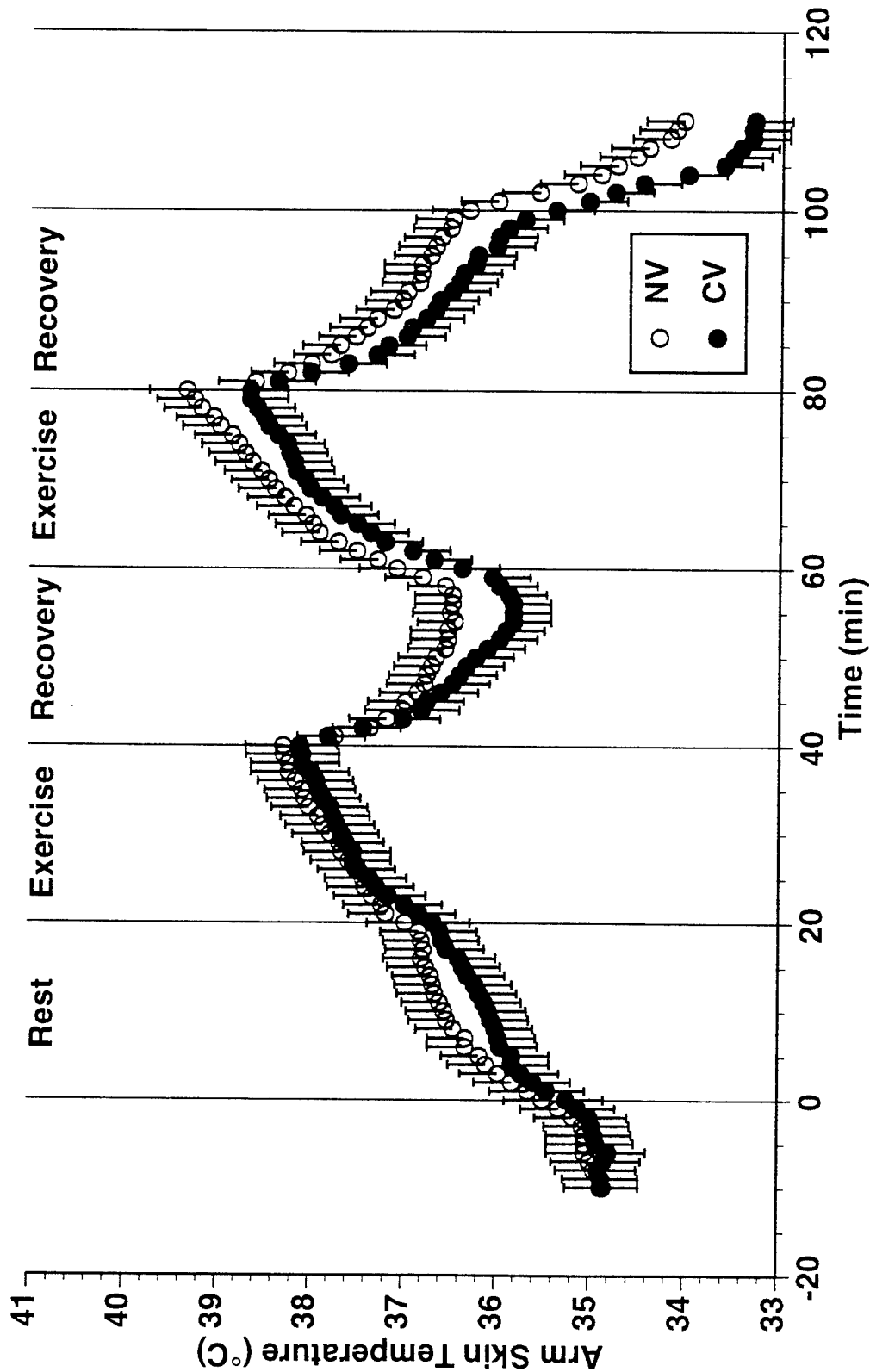
Figure 4. Mean arm skin temperatures for CV and NV during rest and two cycles of exercise and recovery. Significantly lower arm temperature for CV started midway through the first recovery period and continued significantly lower through the remainder of the test.
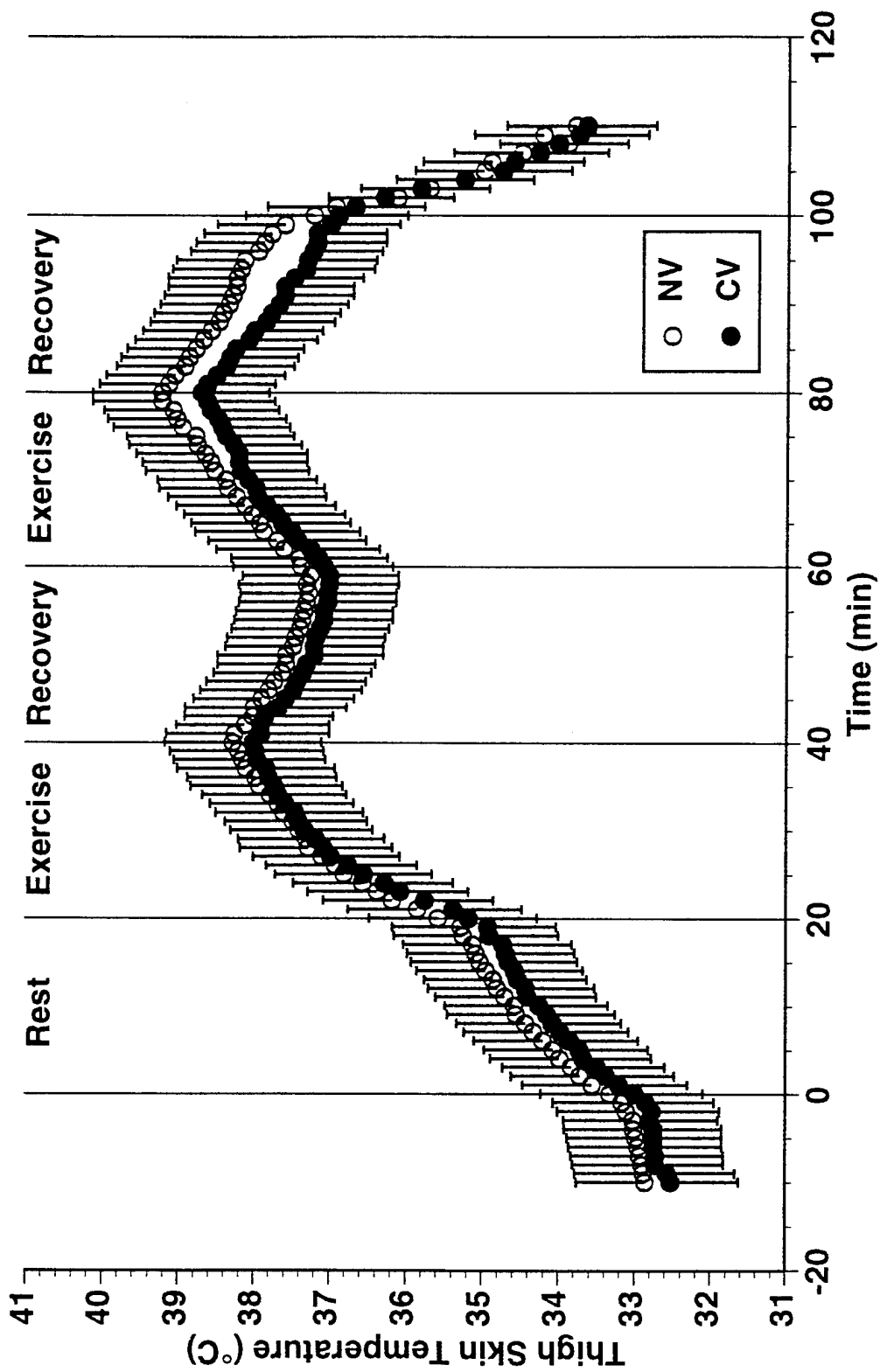
Figure 5. Mean thigh skin temperatures for CV and NV during rest and two cycles of exercise and recovery. Significantly lower thigh temperature for CV started midway through the first recovery period and continued significantly lower through the remainder of the test.

Figure 6. Mean calf skin temperatures for CV and NV during rest and two cycles of exercise and recovery. Differences in calf temperature between CV and NV were nonsignificant.
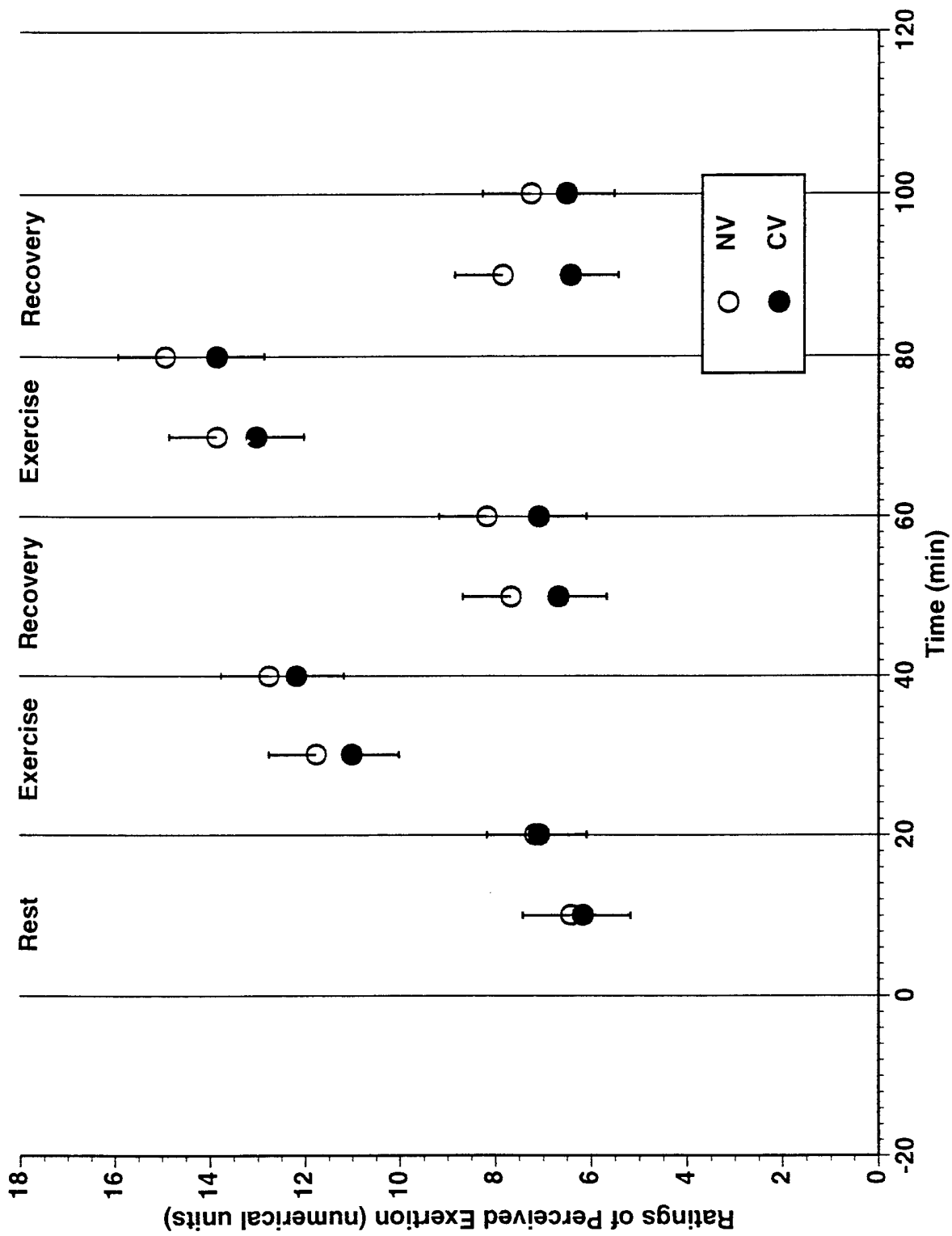
Figure 7. Average Ratings of Perceived Exertion (RPE) for CV and NV during rest and two cycles of exercise and recovery. Differences in RPR between CV and NV were nonsignificant.
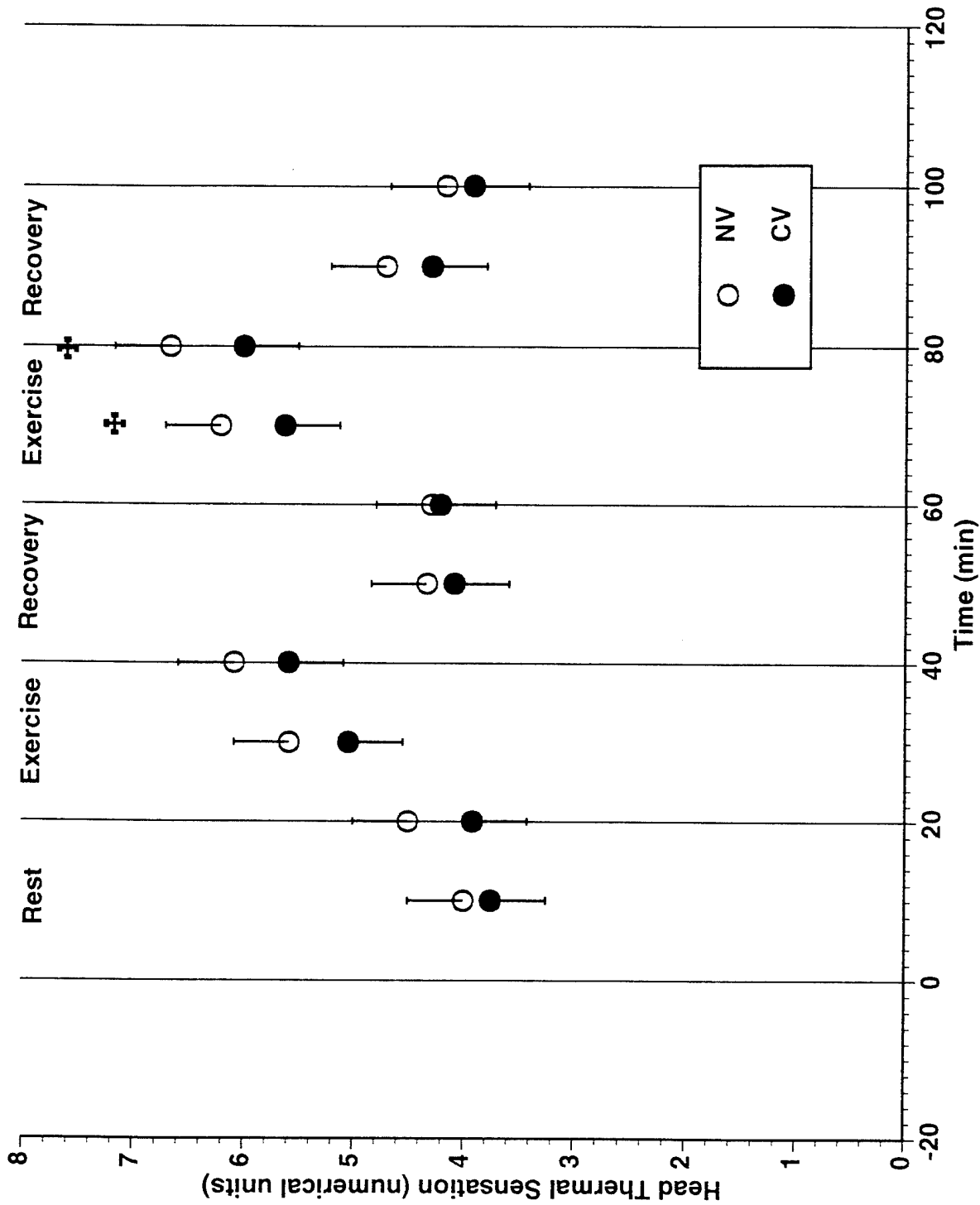
Figure 8. Average ratings of thermal sensation (TS) of the head for CV and NV during rest and two cycles of exercise and recovery. ✚TS significantly lower for CV compared to NV.
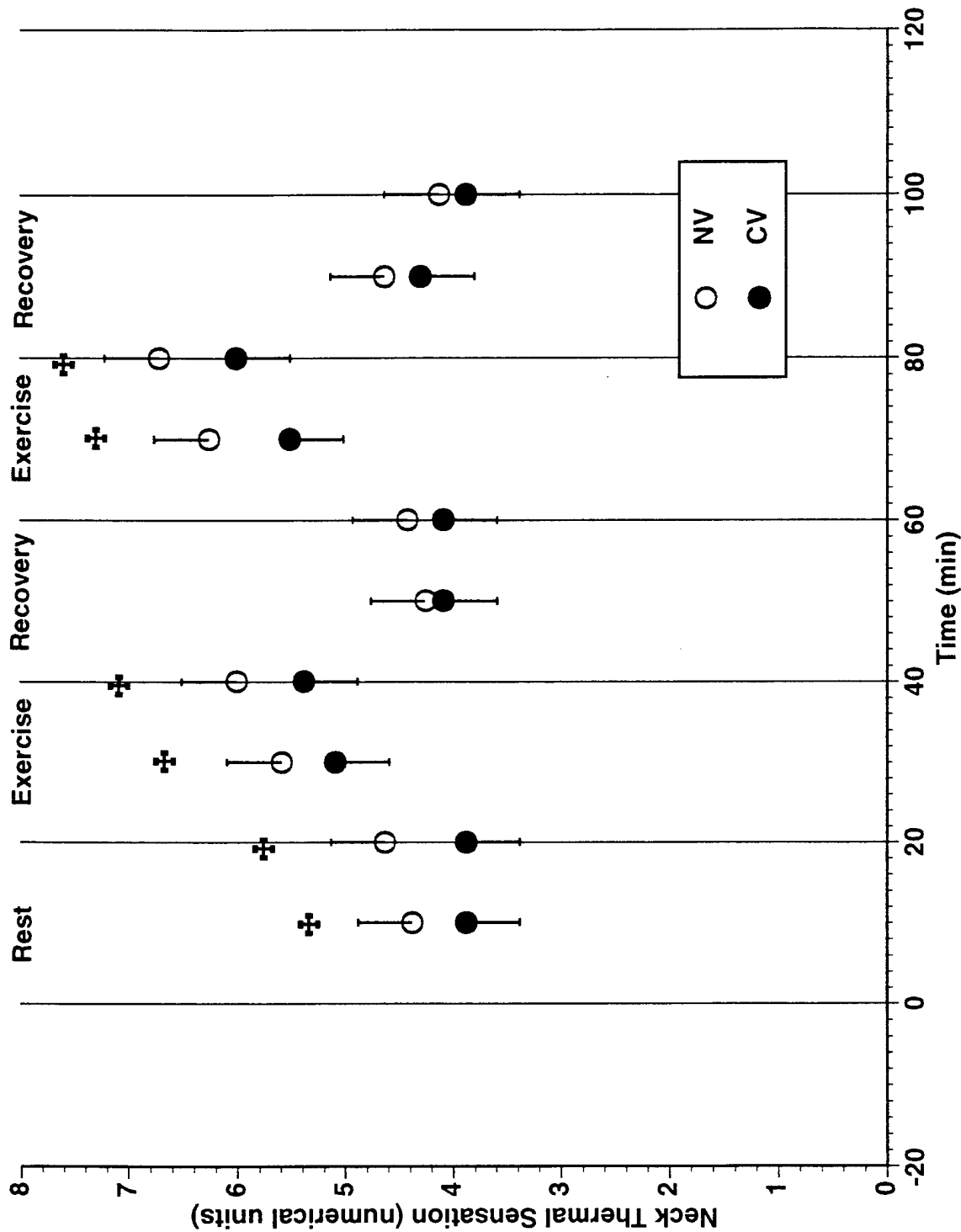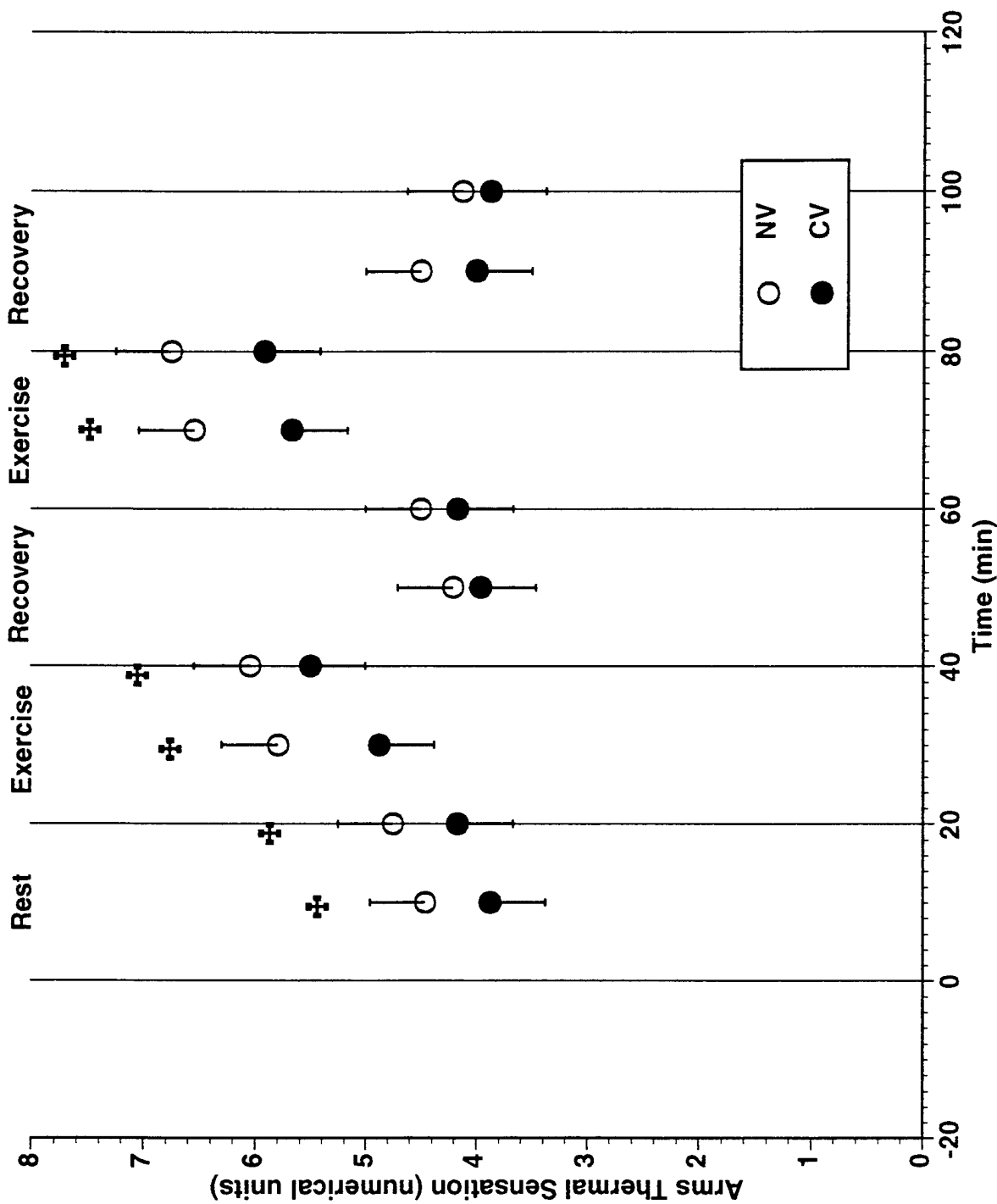
Figure 9. Average ratings of thermal sensation (TS) of the neck for CV and NV during rest and two cycles of exercise and recovery. ╬TS significantly lower for CV compared to NV.
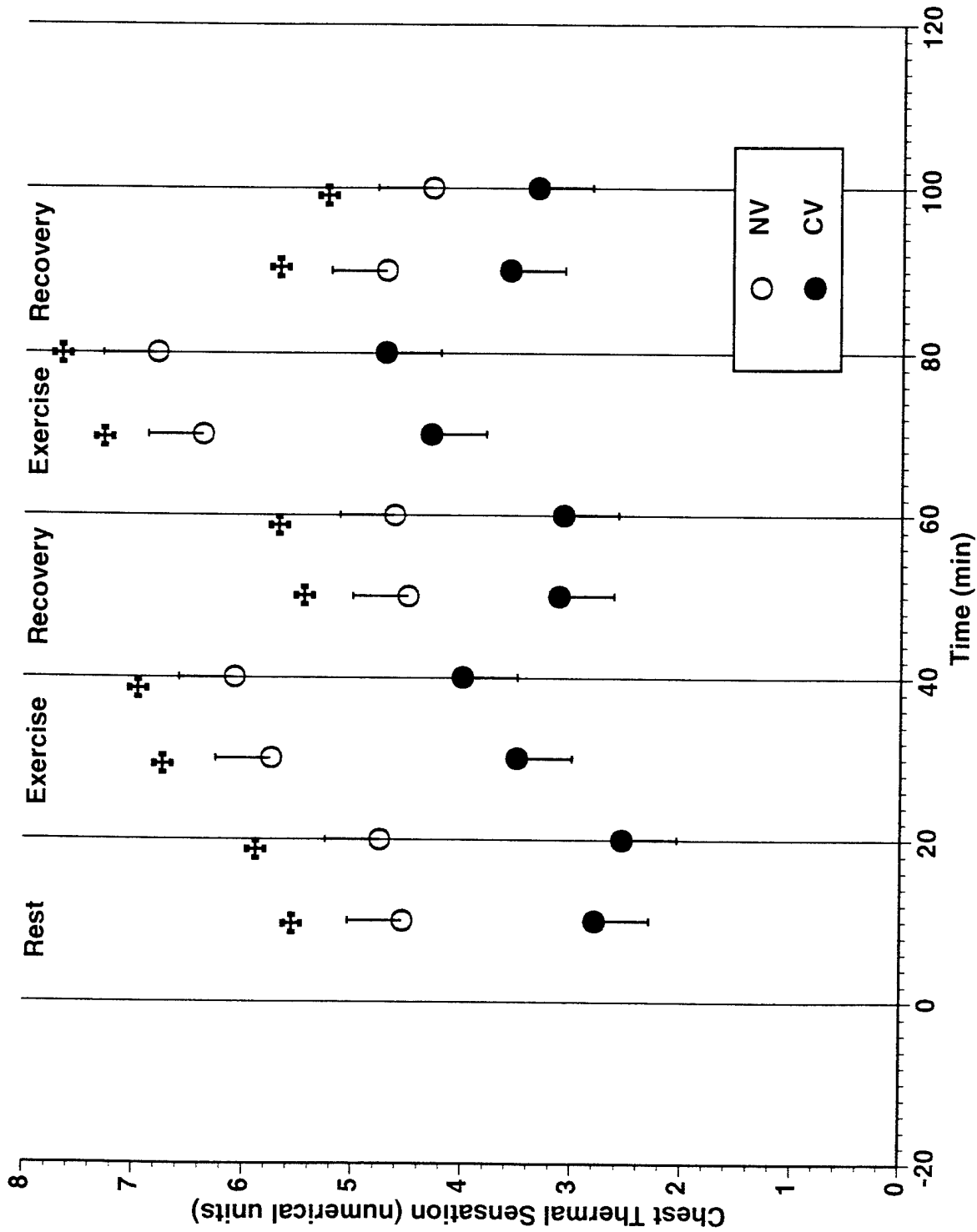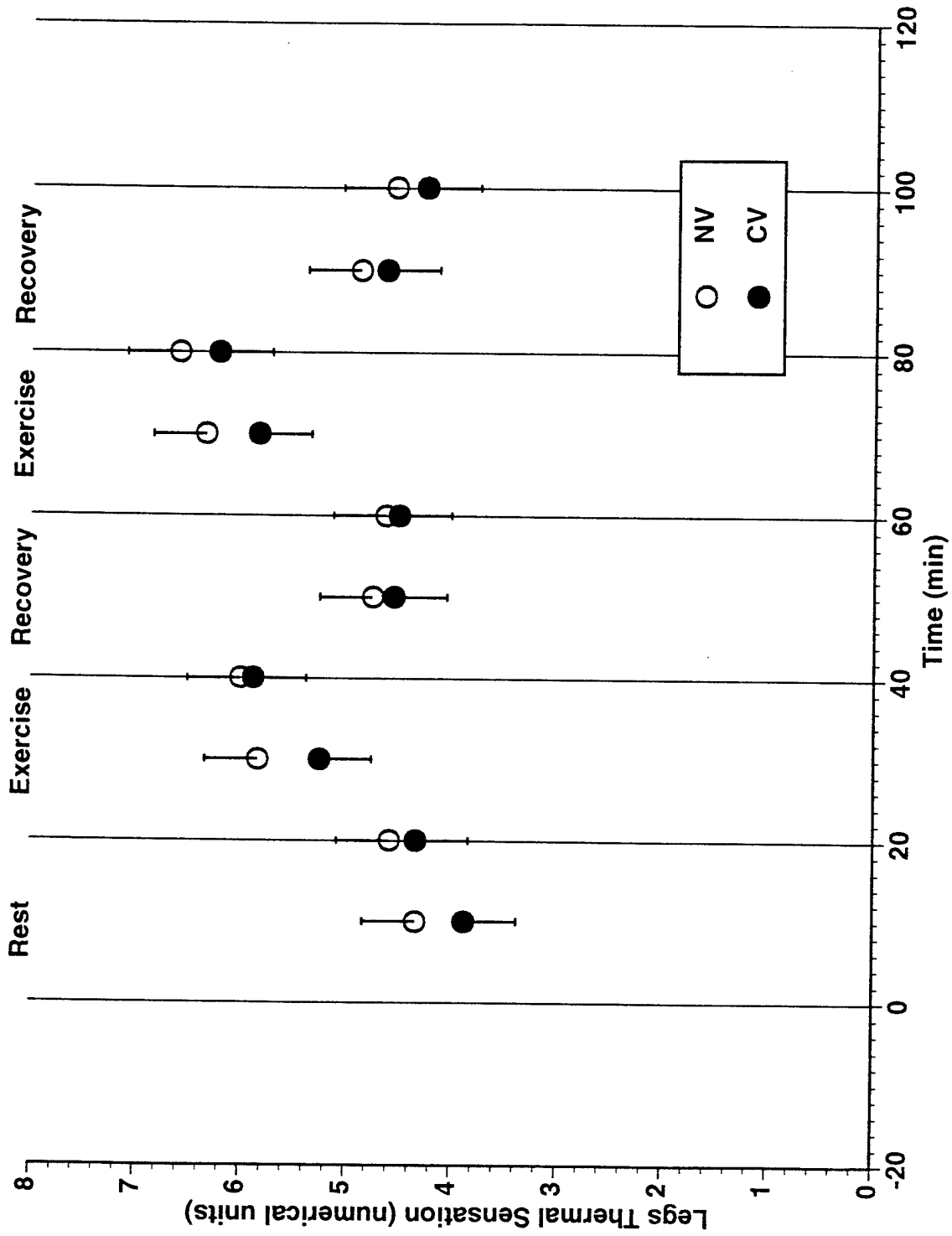
Figure 10. Average ratings of thermal sensation (TS) of the chest for CV and NV during rest and two cycles of exercise and recovery. ╪TS significantly lower for CV compared to NV.

Figure 11. Average ratings of thermal sensation (TS) of the arms for CV and NV during rest and two cycles of exercise and recovery. ✝TS significantly lower for CV compared to NV.

Figure 12. Average ratings of thermal sensation (TS) of the legs for CV and NV during rest and two cycles of exercise and recovery. Differences in TS were nonsignificant between CV and NV.

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12a. DISTRIBUTION/AVAILABILITY STATEMENT

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12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The purpose of this study was to evaluate the effectiveness of a cool vest (CV) to reduce heat strain during exercise, facilitate recovery, and minimize heat strain during subsequent return to exercise and heat exposure. Male volunteers (n=12) were monitored for heart rate (HR), and rectal (T_{re}), chest (T_{ch}), arm (T_{ar}), thigh (T_{th}), and calf (T_{ca}) temperatures during randomly ordered no vest (NV) and cool vest (CV) tests. CV was worn over cotton work clothes and under firefighting ensemble (FFE). Test protocol consisted of 20 min each of rest, exercise, recovery, exercise, and recovery. Rest and recovery occurred in 29°C/65% relative humidity (rh) air, while walking exercise (1.12 $m \cdot s^{-1}$/0% grade) occurred in 48°C/50% rh air. All NV and CV subjects completed the 100 min tests. Repeated-measures analysis of variance revealed significantly lower T_{re}, T_{ch}, T_{ar}, and T_{th} for CV compared to NV, while differences in T_{ca} and HR were nonsignificant. Compared to NV, T_{re}, T_{ch}, T_{ar}, and T_{th} for CV decreased faster ($p < .05$) during recovery and rose less ($p < .05$) during subsequent exercise. Our findings indicate that CV minimizes heat strain during exercise in hot/humid air, hastens recovery from heat strain in warm/humid air, and attenuates heat strain during subsequent exercise in hot/humid air.

14. SUBJECT TERMS
Heat strain, cool vests, exercise and recovery

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